Development of small-scale irrigation using limited groundwater resources

Third Interim Report

DEVELOPMENT OF SMALL-SCALE IRRIGATION USING LIMITED GROUNDWATER RESOURCES

THIRD INTERIM REPORT

C.J. Lovell, C.H. Batchelor, A.J. Semple,
Institute of Hydrology, Wallingford, Oxon OX10 8BB, UK

M. Murata, E. Mazhangara & M. Brown
Lowveld Research Station, P.O. Box 97, Chiredzi, Zimbabwe

ODA 92/4

July 1992

Cover Photograph:- A harvest and market day at the first off station collector well garden at Tamwa/Sihambe/Dhobani Kraals in Chivi Communal Area, Southern Zimbabwe

Executive Summary

WIDER OBJECTIVES OF THE PROJECT

In semi-arid areas, low and unreliable rainfall combined with periodic drought years have resulted in farmers adopting agricultural practices that involve cultivating large areas and herding cattle and goats. Unfortunately, overgrazing and soil erosion on a massive scale and over vast areas of the semi-arid world have reduced the ability of the land to support this traditional farming system. In addition, increasing population pressure and the possibility of climatic change are making an already hazardous strategy more prone to failure. There is therefore an urgent need to develop sustainable farming systems for semi-arid areas that minimise the risk of land degradation.

The research described in this report has the potential to improve the sustainability of agriculture over large areas of the semi-arid world by reducing farmers reliance on extensive farming systems. The overall aim of the project is to promote the use of irrigated communal or allotment-type gardens that can be operated in conjunction with traditional rainfed cropping. In years of good rainfall these gardens complement rainfed crop production, reduce the need to crop marginal land and improve nutrition and health by providing a continuous supply of vegetables throughout the dry season. In years of drought, such as being experienced currently in Southern Africa, there is no rainfed cropping. Under these circumstances irrigated gardening provides rural communities with a vital "safety net" by providing the only means of food production.

SPECIFIC OBJECTIVES OF THE PROJECT

In October 1988 the Institute of Hydrology (IH) began an ODA-funded collaborative research project with the Zimbabwean Lowveld Research Station (LVRS) and the British Geological Survey (BGS). The specific objectives of this project are to study the feasibility of using shallow aquifers as a source of water for irrigating communal or allotment-type gardens and to compare and assess simple low-cost irrigation methods that can be used to improve water use efficiency on this type of irrigated garden. This interim report describes the experimental work and on-farm trials that have been carried out by the project during the period October 1990 to March 1992.

COLLECTOR WELLS

Recent progress of the groundwater component of the project is described in a separate report (Chilton and Talbot, 1992). Research carried out to date has demonstrated the feasibility of using shallow basement aquifers as a source of water for irrigation schemes or irrigated gardens of approximately one hectare in area. In particular, the project has shown the potential of using collector wells as a means of abstracting sufficient water from basement aquifers to meet domestic and stock water requirements and still provide sufficient water to meet the requirements of an irrigated garden. A collector well is a shallow, hand-dug well of large diameter with horizontal boreholes drilled radially from its base to a distance of approximately 30 metres.

Worldwide, thirty percent of the arid and semi-arid areas of developing countries is underlain by basement rocks. A characteristic of this geology is a superficial weathered layer that contains a groundwater reservoir that is perched on the hard rock below. Boreholes or traditional hand dug wells tend to be ineffective in exploiting this resource. Experience with collector wells constructed in basement areas in Zimbabwe and elsewhere would suggest that collector wells can give safe yields in excess of 1 l/s.

RESULTS OF EXPERIMENTAL STUDIES

A number of replicated trials and experiments were carried out at the Lowveld Research Station during the 1990/91 rainy season and the 1991 dry season. Research during this period concentrated on comparing the water use effectiveness of different irrigation practices and on assessing the potential problems of irrigating with saline groundwater. To achieve these aims the components of the soil water balance were quantified and followed on the treatments of the different trials and experiments. The main findings were:

a) Comparisons between subsurface irrigation and conventional flood irrigation have continued to show that subsurface irrigation results in crops that grow more vigorously and have higher yields than crops grown under conventional flood irrigation. However, yield increases, as yet, have not translated into higher water use effectiveness because cumulative water use has been relatively higher on the subsurface irrigation treatments;

b) Comparison between mulched and unmulched irrigated treatments has continued to show the benefits of using simple mulches in terms of saving water during the period from planting to canopy closure. Although a higher incidence of pest damage was recorded on some mulched treatments, there was an indication that this might be reduced by mulching with leaves from the Neem tree (*Azadiratchta indica*) as these have insecticidal properties;

c) The importance of crop establishment in determining water use effectiveness was noted in several experiments. Observation trials have shown the potential of simple mulches, particularly of manure, in improving crop establishment;

d) The very high yields achieved on the replicated 1991 dry season tomato trial, and the results of an ongoing irrigation scheduling observation trial have given an indication of the yield advantage that can be accrued from improved irrigation scheduling;

e) The data from the lysimeter studies continue to be used for quantifying soil evaporation losses and validating soil evaporation models. During a complete season, it was shown that soil evaporation under irrigated maize accounted for 54% of total water use and plant transpiration for only 46%. It was shown also that the capacitance probe could be used successfully for measuring soil evaporation;

f) The trials comparing irrigation with saline and good quality irrigation water have shown that subsurface irrigation with saline water is feasible. However, this trial will need to be continued over a number of seasons so that the build up of salts in the soil profile can be monitored. It should be noted that between half and three quarters of all boreholes constructed in the drier parts of Zimbabwe are saline to some degree.

RESULTS OF ON-FARM TRIALS

The drought that has affected Zimbabwe during 1991/92 is the worst on record and the people of many areas are suffering due to the lack of rain for farming. Indeed within the project area there has been no rainfed cropping, and existing gardens also monitored by the project have failed due to a lack of water. This is the background to the implementation of the first collector well and garden project at Tamwa/Sihambe/Dhobani Kraals in Ward 22 of Chivi Communal Area.

Cropping on the garden commenced in August 1991 with 46 families paying a $10 membership fee to join the scheme. The first cropping season during the 1991 dry season was slightly disappointing as a result of a combination of factors, the most important being a lack of experience, poor social cohesion and a failed attempt to operate the garden collectively. It should be noted that, as far as possible, decision making was left to the scheme participants. From the outset, it was stressed that the scheme belongs to the participants and that it was up to the participants to decide on the crops to be grown and the organisation of the irrigation schedules. Project staff have only provided advice when asked.

In contrast to the first cropping season, the ongoing second cropping season has been a resounding success; the scheme participants are quickly learning from past mistakes. At present the collector well is providing at least a part of the drinking water requirement of over 1200 people and a continuous supply of vegetables for both home consumption and for sale. The scheme also benefits those people who resell vegetables purchased at the garden and those who barter other goods and staple foods for vegetables. The scheme is providing hope for many people who would have few alternatives in the present drought.

Organisationally, the management of the garden has improved with each family having individual, rather than collective, responsibility for their plots. It is clear that the women are the driving force behind the success of the scheme as they continue to carry out most of the day to day tasks. They are also well represented on the garden committee and clearly make a significant contribution to decisions relating to the operation of the garden.

Initial economic analysis of the scheme indicates that the scheme yields an internal rate of return (IRR) of 33%, and a net present value (NPV) of Z$55,577 (£1=Z$8.5) at a discount rate of 12% on constant projected cash flows of Z$9,836 over a ten year period. A sensitivity analysis with a reduction in the projected returns of vegetables from the scheme of 25%, would still indicate a rate of return of 21%. These figures are based on data collected in the field and, while necessary assumptions are made regarding the future trend of cash flows, it is clear that the scheme is economically viable.

Whilst assessing the overall performance of the collector well garden, project staff have set up small plots within the garden perimeter to demonstrate the potential benefits of subsurface irrigation, the use of mulches and improved irrigation scheduling. To date there has been much interest in subsurface irrigation and an encouraging adoption of mulching using dry leaves. During the drought, monitoring of water levels and management of the collector well have been important. The scheme members have reduced cultivation in an attempt to preserve the life of the well until the next rainy season. Irrigation of the garden places a heavy demand on the well, typically using five times as much water as is taken for domestic use. There is evidence that the scheme members hope to improve water use efficiency so that the maximum area of land can be irrigated and the maximum crop yield achieved.

FUTURE WORK

The success of the first collector well garden has stimulated enormous interest in collector well gardens and improved irrigation techniques for use on small gardens. This is indicated by the agreement of ODA to fund the construction and monitoring of a further six collector well gardens as a precursor to an expansion of the project to a much wider scale. Plan International (an NGO) has also offered to fund the construction of an additional six collector well gardens as part of their long term development programme in Zimbabwe.

Research to improve the efficiency of water use in garden irrigation will be a high priority. Experience from the first scheme at Tamwa/Sihambe/Dhobani Kraals highlights the high demand for water of an irrigated garden. More efficient use of water in irrigation practices will be fundamental to the future success of collector well gardens. Further research into appropriate irrigation schedules and the establishment of the main vegetable crops grown will be required.

The present cropping patterns adopted at Tamwa/Sihambe/Dhobani Kraals are more appropriate to a large irrigation scheme, with crops planted in regimental blocks. A more informal cropping pattern may offer the potential to improve water use efficiency, pest control and ensure production of a continuous supply of vegetables for home consumption and sale. Experiments to demonstrate the benefits of these ideas to visitors from other collector well schemes will be set up at the Lowveld Research Station.

Contents

1. Introduction

Agricultural practices in semi-arid areas have been developed in response to an unpredictable climate. In the dry regions of Africa, farmers often compensate for unreliable rainfall by cultivating large areas and by herding cattle and goats. This is a reasonable low-risk strategy where population densities are low. However, with increasing population densities, this practice is becoming more hazardous. In many regions of Africa overgrazing and soil erosion on a massive scale are now reducing the ability of the land to support agricultural production.

In areas where sufficient water resources are available, large-scale irrigation projects are feasible. However, in semi-arid areas of Africa, these schemes are usually expensive and they do not integrate well with existing rainfed farming systems. Large irrigation projects can also cause a range of socioeconomic, health related and environmental problems. By contrast informal small-scale (or garden) irrigation is relatively inexpensive and integrates well with traditional farming systems. When used in conjunction with improved rainfed farming practices, small-scale irrigation has the potential to improve the sustainability of crop production by providing a continuous supply of vegetables throughout dry seasons and years of drought and by reducing reliance on stock and extensive rainfed farming systems.

Since 1988, the Institute of Hydrology has been collaborating with the British Geological Survey and the Lowveld Research Station on a project to assess the feasibility of using shallow aquifers as a source of water for irrigation schemes or irrigated gardens of up to one hectare in area. In particular, the project is assessing the potential of using collector wells as a means of abstracting sufficient water from shallow basement aquifers to meet domestic and stock water requirements and still provide enough water to meet the requirements of an irrigated garden. A collector well is a shallow, hand-dug well of large diameter with horizontal boreholes drilled radially from the bottom of the well to a distance of approximately 30 metres. Experience with collector wells constructed in basement areas in Zimbabwe and elsewhere would suggest that collector wells can give safe yields in excess of domestic and stock water requirements. This excess yield is typically sufficient for irrigated gardens of approximately one hectare in size, which can provide vegetables for a hundred households if each household has a 100 square metre plot, or allotment, within the garden. A second objective of the project is to compare and quantify the benefits of different methods of improving the water use effectiveness of the irrigation methods practised on irrigated gardens. As water is the principal constraint in determining the size of a garden that can be cultivated, there are obvious benefits to be gained from using water as efficiently as possible.

Previous results of the irrigation component of the project can be found in two interim reports (Batchelor *et al.*, 1990; Lovell *et al.*, 1990). This third interim report differs from earlier interim reports in that it contains socio-economic and technical information on the installation and operation of the first collector well garden to be constructed outside a research station. Two previous collector well gardens have been used for research purposes at the Maha Illuppallama Research

Station in Sri Lanka and the Lowveld Research Station.

Funding for the project has been provided via three projects (T05054B1, T05054F1 and T05054H1) that are supported by the Engineering Division of the British Overseas Development Administration.

2. Experimental Studies at Lowveld Research Station

2.1 EXPERIMENTAL SITE

2.1.1 Climate

The experimental site is located at the Lowveld Research Station in south-east Zimbabwe (21°S, 31°E, elevation 429 m). The climate of this area is semi-arid with annual rainfall between 250 and 750 mm (standard deviation approximately 40%). Most rainfall occurs as high intensity thunderstorms during the period November to April. Maximum temperatures in excess of 30°C occur throughout the year and temperatures exceeding 40°C are not unusual during summer months. Rainfall and meteorological data are collected at the experimental site by an automatic weather station (Didcot Instruments Ltd., UK).

2.1.2 Soil

The soil type at the experimental site is a dark reddish-brown sandy clay loam derived from basic gneiss and classified as a clayey, mixed hyperthermic Udic Rhodustalf (USDA, 1988). Hydraulic conductivity functions and moisture characteristic curves measured for this soil at different depths are presented in Figures 2.1.2 and 2.1.3. Further information on the hydraulic properties of this soil can be found in earlier interim reports (Batchelor *et al.*, 1990; Lovell *et al.*, 1990). Soil salinity data are presented in Section 2.5 of this report.

2.1.3 Water quality

Water used in the irrigation experiments that was pumped from the research station collector well is of "high" salinity hazard (USDA, 1954), typically having an electrical conductivity of 1 mS/cm. Water from Lake Kyle that was used in Expt 91/2 was largely free from salts and of "low" salinity hazard (USDA, 1954) with an electrical conductivity typically of about 0.2 mS/cm. Chemical analyses of the Kyle and collector well water are given in Section 2.5 along with the sodium absorption ratio, residual sodium carbonate and electrical conductivity, pH, chloride, hardness and iron concentration measured on a number of dates during the 1991 dry season.

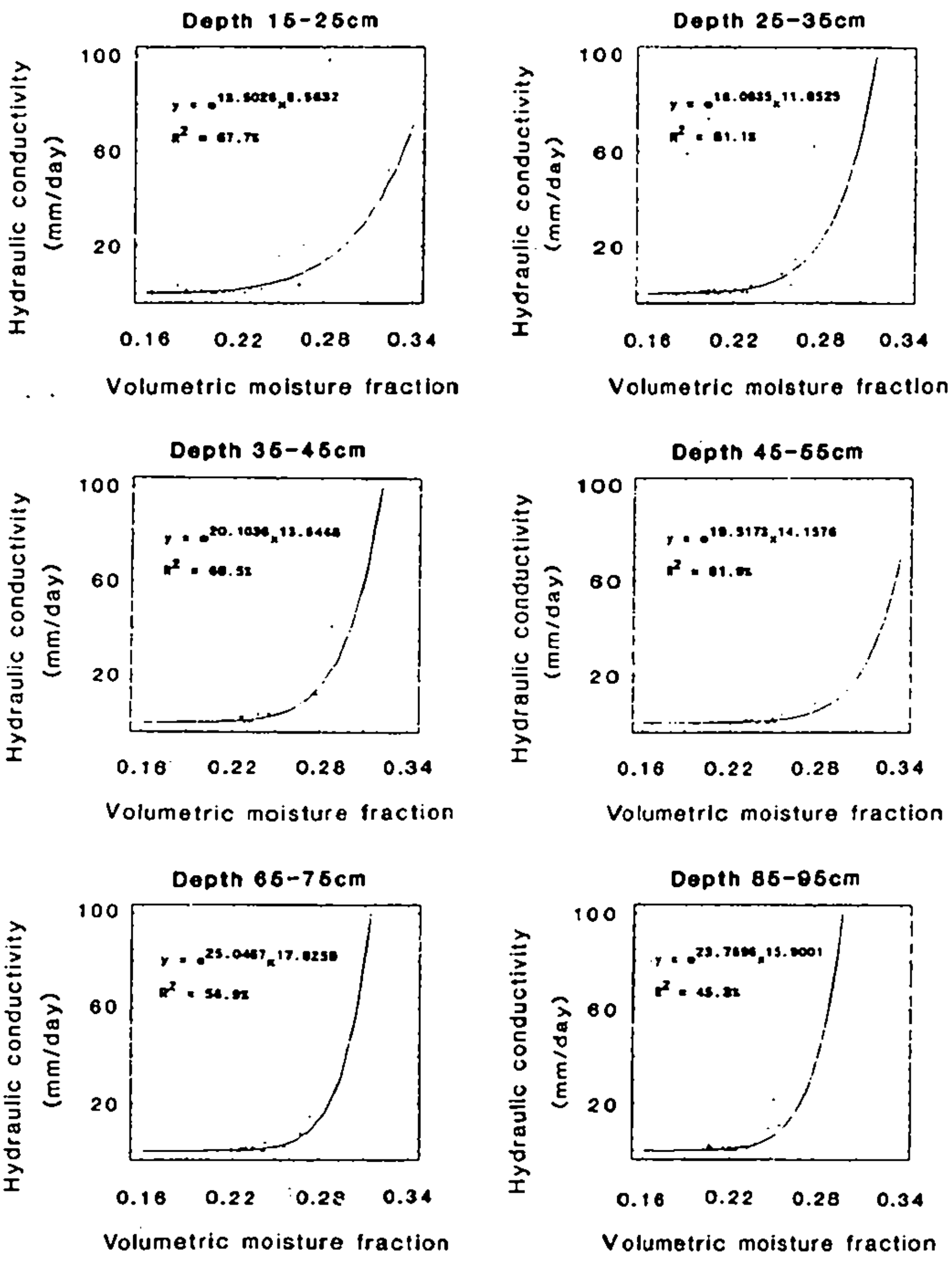


Figure 2.1.2 Hydraulic conductivity functions of experimental site soil at different depths

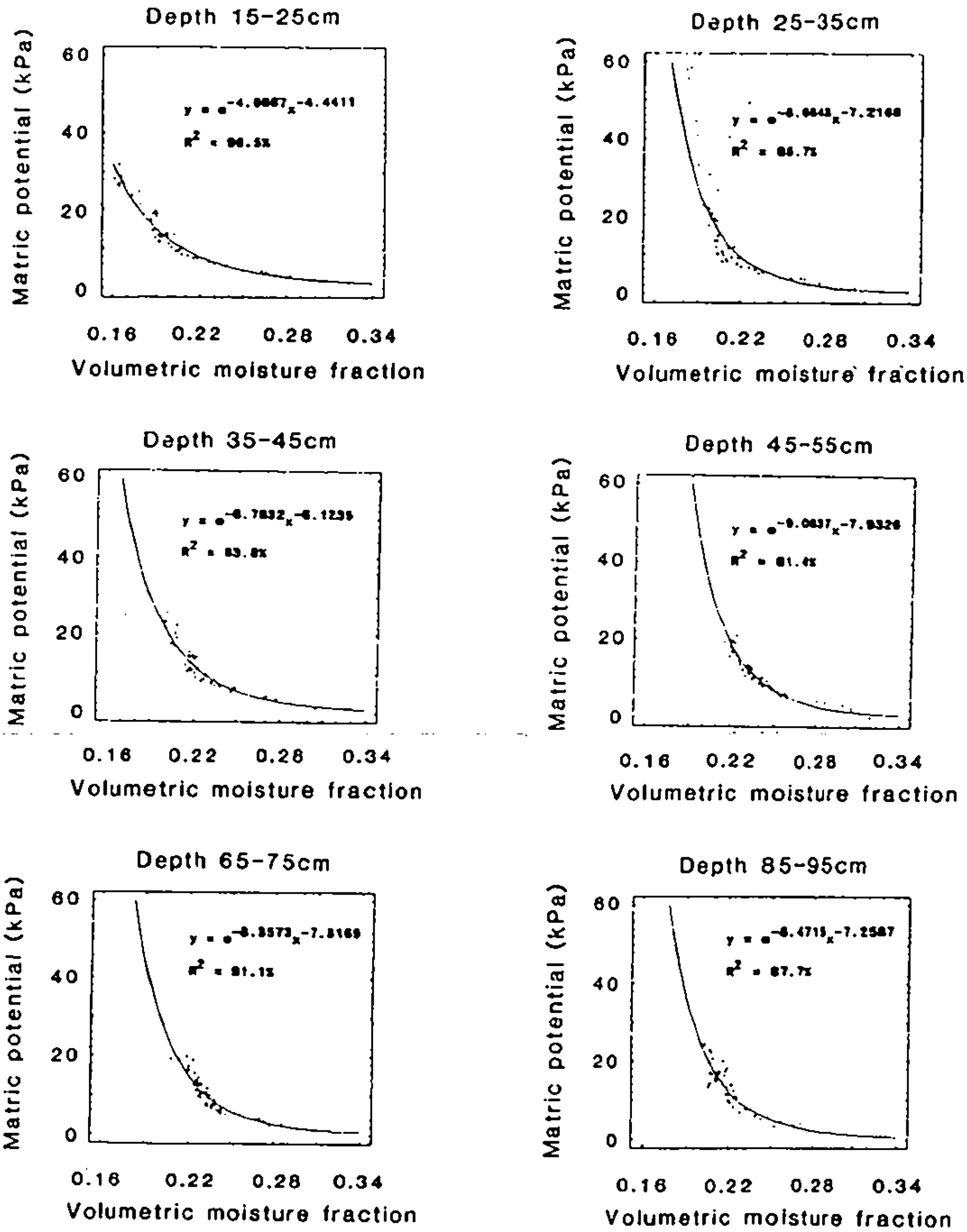


Figure 2.1.3 Moisture characteristic curves of experimental site soil at different depths

2.2 EXPT 90/3: MAIZE WATER USE EFFICIENCY TRIAL

2.2.1 Introduction

Flood irrigation (or basin irrigation) is widely used in gardens throughout semi-arid areas of the developing world, but this traditional method is not efficient in water use. Some water applied at the soil surface is lost as evaporation. As demand on limited water supplies intensifies in semi-arid areas, there is increasing need for more efficient methods of irrigation suitable for small-scale use.

One method that shows promise is irrigation using subsurface clay pipes. To reduce evaporation, water is applied beneath the soil surface via shallow, horizontal pipes laid between plant rows. The water passes directly into the root zone via joints between the clay pipe sections. A second method also more efficient than direct flood irrigation is flood irrigation beneath a surface mulch. In a replicated bean trial conducted in Zimbabwe during the dry season, 60% less water was needed prior to plant canopy closure on mulched treatments than on traditional flood irrigation treatments (Lovell *et al.*, 1990).

Maize and other vegetables are commonly grown during the rainy season in Zimbabwe, irrigation being used to supplement rainfall during dry periods. A replicated maize trial was conducted to quantify the saving in water possible during the rainy season by use of subsurface clay pipes and flood irrigation beneath mulch as opposed to traditional flood irrigation. To best achieve this aim, irrigation requirements for each irrigation method were determined individually by monitoring soil moisture depletion beneath each. In this way, a direct measure of effective rainfall was also obtained. A secondary objective was to improve crop establishment above deep (20 cm) subsurface clay pipes, a problem encountered in the aforementioned bean trial.

2.2.2 Materials and methods

Experimental design

The experiment was a maize trial (*Zea mays* cv R201) of four treatments with four replicates. The sixteen plots were arranged in a randomised block design.

Each plot comprised of four beds, each 3 m long by 1 m wide and surrounded by a low earth bund. On the mulched flood irrigation treatment rice straw at a rate of 12 tonnes/ha was placed within two furrows spaced at 0.3 m (Fig. 2.2.1). On the pipe treatments, subsurface clay pipes were placed along the centre line of beds. Twelve pipes were used per bed, simply laid end to end in a level trench then backfilled with soil. The pipes were made locally using a simple mould and fired in a shallow bark-filled pit. Further details of pipe manufacture are given by Lovell *et al.* (1990). The pipes were of length 0.24 m, inside diameter 0.075 m and outside diameter 0.115 m. They were placed with either 0.1 m or 0.2 m of soil above them (Fig. 2.2.1).

Rainfed maize, receiving no irrigation, was grown in eight beds beside the main trial for comparison. Four beds had rice straw mulch within two furrows (as described above), the remaining four were open and flat.

Instrumentation

One plot of each treatment was instrumented with a two-dimensional tensiometer array and three neutron probe access tubes. Each tensiometer array consisted of 12 mercury manometer tensiometers installed at three depths (0.1 m, 0.4 m and 0.7 m) and four positions across the 1 m wide bed (0.125 m and 0.375 m either side of the centre line). The three access tubes were installed to a depth of 1 m at spacings of 0.125 m, 0.375 m and 0.625 m one side of the centre line, the outer access tube thus being outside the bed.

Irrigation

Measurements of soil water content made in situ using a neutron probe were used to monitor soil moisture depletion under each irrigation method and thus to determine individual irrigation requirements for each. The aim of this approach was to obtain similar high yields under each method by maintaining a favourable moisture status, but to apply less water to maintain this status to those methods more efficient in their water use.

Rainfall soon after planting brought all treatments to a moisture content approaching "field capacity". At this time, soil moisture content (mm) to a depth of 0.9 m was measured at both access tube positions within each bed, and the average value per bed recorded as the starting condition for that treatment. Thereafter, average soil moisture content to 0.9 m was monitored in the same way and, when necessary, the soil moisture deficit calculated individually for each treatment was applied as irrigation. Irrigation to the subsurface clay pipes was applied four times per week (Monday, Tuesday, Thursday and Friday) and to flood beneath mulch twice per week (Monday and Thursday) when necessary. Irrigation by direct flood was applied once per week (Monday) to allow a reasonable soil moisture deficit to accrue and to follow more closely the traditional practice. Both the neutron probe and the tensiometers were read prior to each possible irrigation and again 24 hours later, and after each rainfall event.

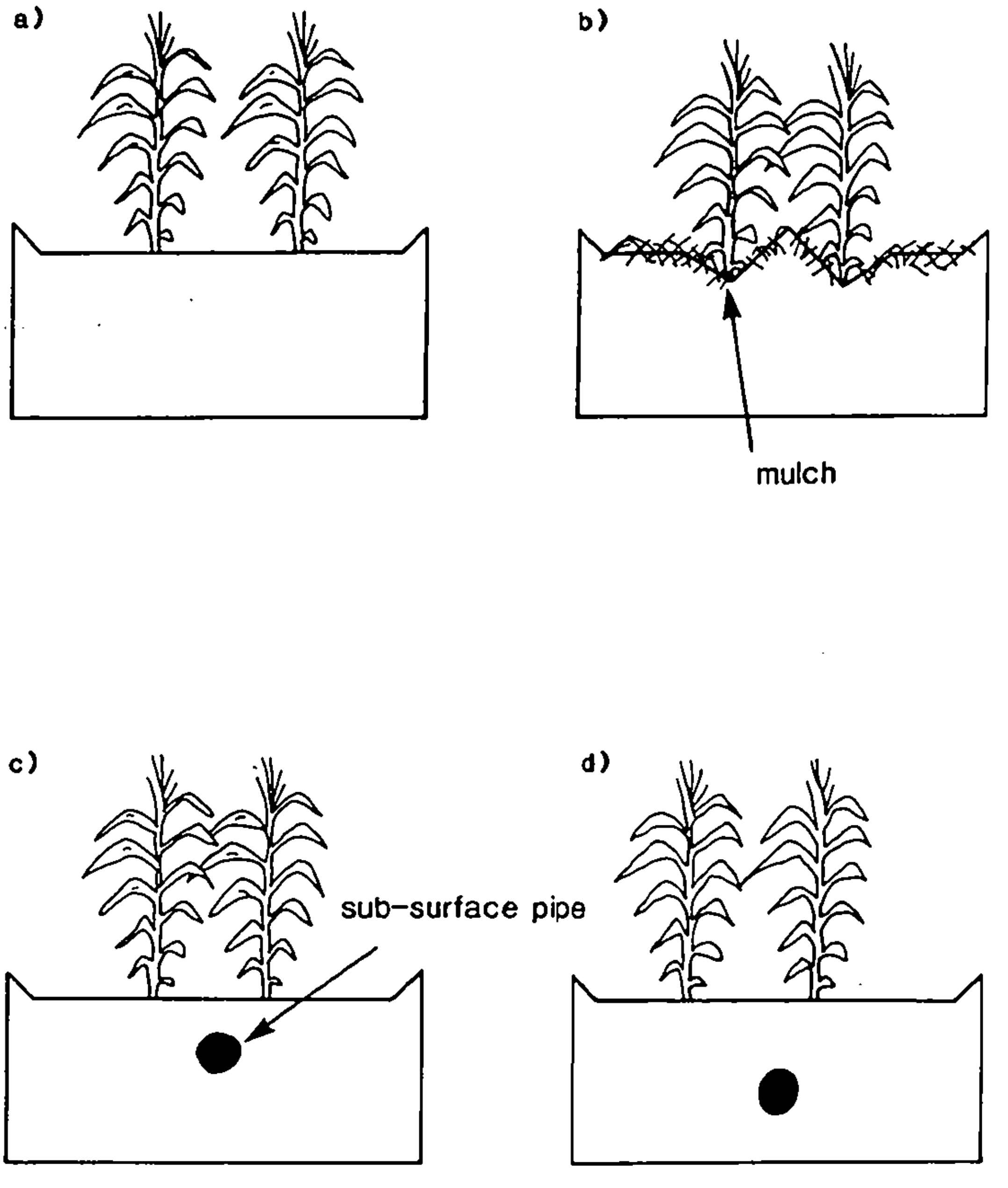


Figure 2.2.1 Schematic diagram of (a) flood irrigation (b) flood irrigation beneath mulch (c) subsurface pipes at 0.1 m depth (d) subsurface pipes at 0.2 m depth

Agronomy

Short season maize variety R201 was sown on 29 November 1990. During the 8 days prior to sowing 28.6 mm of rain fell. The maize was sown, two seeds per hole, in two rows per bed. Row spacing and within row spacing were 0.3 m and 0.3 m respectively, giving a plant population of 30,800 plants/ha. To ensure germination and crop establishment, particularly above the deeper subsurface clay pipes, 6.6 mm (1 litre) of water was applied per station with the seed and dry soil replaced above. The mulch was also placed in position at this time. 400 kg/ha of fertiliser in the form of Compound D (8N 14P 7K) was incorporated by hoe at planting. The plants were thinned at 12 days. 50 kg/ha N in the form of ammonium nitrate was applied as a top dressing at 35 days, to the surface of treatments irrigated by flood but in solution via the subsurface pipes. Carbaryl foliar spray was applied at 13 days and 19 days to combat millipedes and crickets which were eating the young plants and to combat *Spodoptera* (Army worms). Endosulfan was applied as a spray at 29 days and as granules at 42 days to combat maize stalk borer (*Busseola fusca*) and as a spray at 62 days to combat *Heliothis* cob borers. On day 67, monkeys stole one cob from one replicate of each subsurface pipe treatment. The maize was harvested green on 22 February 1991.

Yield (kg/ha) was determined for each treatment by summing the fresh weight of cobs produced per bed; paths between beds were included in areal calculations. The number of mature plants, dry matter production, number of cobs and average dry cob weight per treatment were also recorded at harvest.

2.2.3 Results and discussion

Weather during the crop season

The mean monthly meteorological data measured during the crop season is presented in Table 2.2.1. Above average temperatures were observed throughout the season. Early season rainfall was low, November being 30 mm below average. Late season rainfall was above average, but a serious dry spell occurred between January and February.

Table 2.2.1 Mean monthly meteorological data

Month	TMAX	TMIN	TDRY am	TWET am	TDRY pm	TWET pm	WIND	SUN	RAIN	PAN	Et
	°C	°C	°C	°C	°C	°C	km/d	hrs	mm	mm	mm
Nov	32.3	18.4	24.6	19.5	31.2	20.5	146	8.6	34.0	8.4	6.0
Dec	33.4	20.6	25.8	21.7	32.1	22.5	155	8.8	115.0	7.3	6.2
Jan	33.4	22.1	26.3	22.6	31.2	23.5	125	9.7	100.2	7.6	6.3
Feb	32.4	22.6	25.5	22.8	31.4	23.3	120	8.1	101.9	6.2	5.9

Et = Potential evaporation (Penman 1963)

Rainfall and irrigation

Figure 2.2.2 shows the pattern of rainfall received and irrigation applied to each treatment throughout the crop season. The different irrigation schedules adopted for each treatment are also illustrated.

Early rains precluded the need for irrigation on all treatments until day 18. Thereafter, rainfall of 40 mm immediately fell. Rainfall between days 19 and 45 was insufficient to prevent plant stress and supplementary irrigation was needed on all treatments. Rainfall of 42 mm was received on day 50, but this was followed by 31 days of drought during which full irrigation was needed on all treatments. The storm of 70 mm which finally came on day 81 was too late to benefit the crop which by this time had started to senesce.

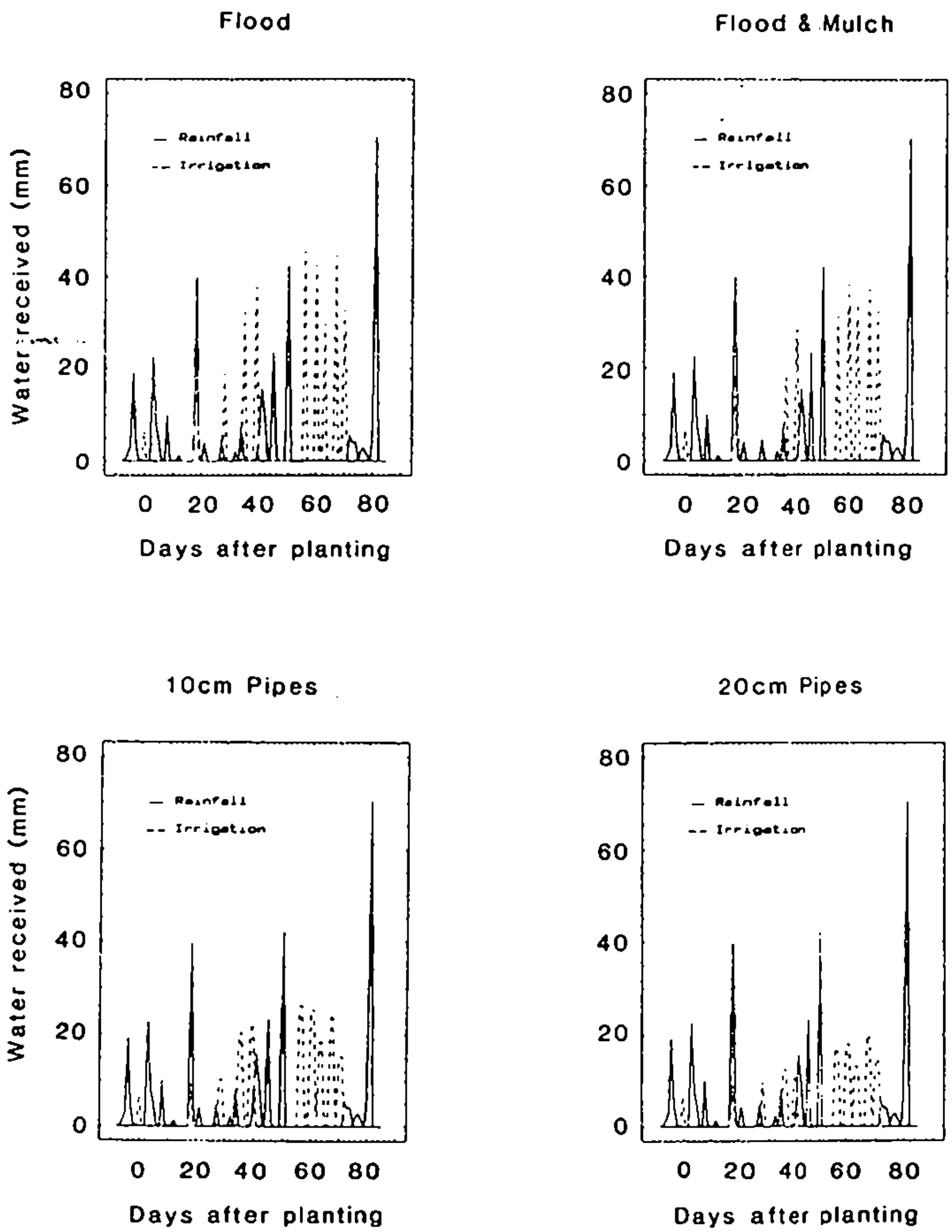


Figure 2.2.2 Pattern of rainfall received and irrigation applied to each treatment during the crop season

The two-dimensional arrays of mercury manometer tensiometers were installed vertically across the crop rows to provide a comparison of soil moisture distribution under each irrigation method. The numerous distributions of soil moisture potential recorded throughout the crop season were processed to give diagrams of soil moisture status using a method developed by Bell *et al.* (1990). The percentage of each soil profile maintained wetter than certain threshold values of matric potential is shown plotted against time (Fig. 2.2.3). The threshold values correspond to critical values on the soil moisture release curve (Lovell *et al.*, 1990); moisture in the range 0 to -7.5 kPa is readily "available" to the crop, there is a decreasing amount of moisture "available" in the range -7.5 to -15 kPa, and virtually no moisture "available" when the soil is drier than -40 kPa.

Figure 2.2.3 shows the fluctuating pattern of soil moisture status that corresponds to intermittent rainfall and supplementary irrigation. The rainfall events of days 3;8;18;41;45 and 50 were clearly important in defining the similar overall patterns of wetting and drying under each treatment, and two rainless periods between days 20 and 40 and days 50 and 80 are apparent. The need for supplementary irrigation is also very clear, soil profiles under each treatment very quickly drying to potentials of less than -40 kPa after both rainfall and irrigation as the crop approached physiological maturity.

Looking in more detail at Fig. 2.2.3, different responses to rainfall can be observed for each treatment. A higher percentage of soil profile was maintained moist under subsurface pipe irrigation than under flood irrigation during the early rains of days 1 to 18. Perhaps due in part to reduced evaporation, this probably reflects the faster germination and crop establishment observed under each method of flood irrigation. Irrigation and rainfall on day 18 brought all treatments to a moisture content approaching "field capacity". Patterns of wetting and drying were then similar until day 35, when all profiles had dried to a potential of less than -40 kPa. It is important to note that less supplementary irrigation was applied to mulch and to 20 cm deep pipes during this period to maintain this status. With the rains of days 41 to 50, more moisture became "available" to plants under pipe irrigation than under flood irrigation, but by day 54 all treatments had again returned to a dry condition. Average potential evaporation at this time was 6.9 mm/day. From day 54 to cessation of irrigation at day 70, moisture was consistently more "available" beneath mulch. Irrigation to the 20 cm deep pipes was perhaps low during this period, but crop yields attained do not reflect this. Late rains between days 70 and 78 increased "available" moisture more under flood irrigation than under pipe irrigation, but daily water use at this time was similar under all treatments (see Fig. 2.2.4 later).

Crop development and yield

Differences measured in soil moisture distribution and status beneath each irrigation method did affect crop development, but more important were the pests and strong winds that occurred during this hot rainy season.

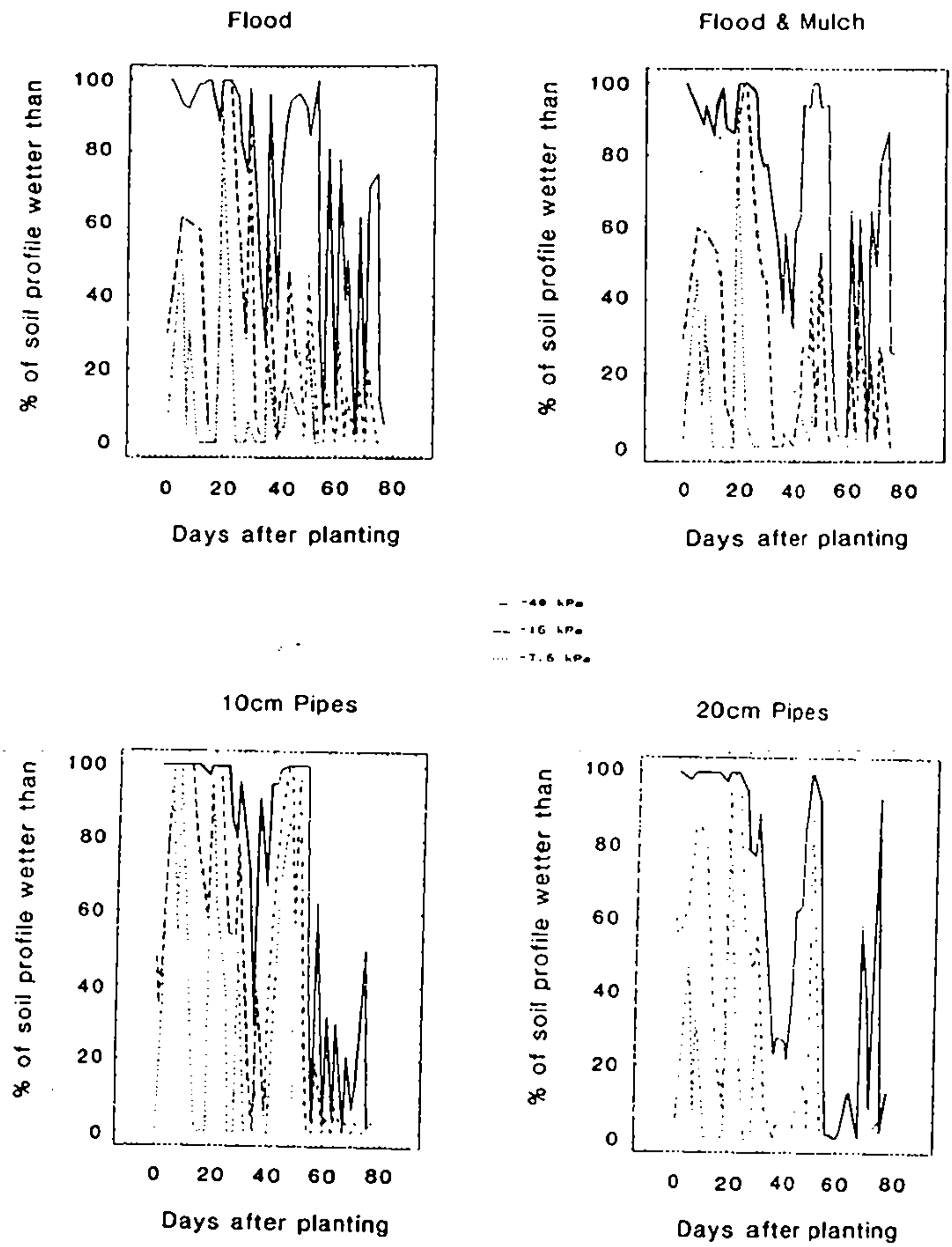


Figure 2.2.3 The percentage of each soil profile maintained wetter than certain threshold values of matric potential

Germination was rapid in moist soil maintained beneath the mulch, but 14% of the young plants were eaten by millipedes and crickets that sheltered under the straw.

Germination (95%) and crop establishment were good for each of the remaining treatments, including the 20 cm deep subsurface clay pipes. At day 19, mulch was cleared from around the base of each maize plant because the plants were prematurely developing adventitious prop roots and were unstable and some plants were blown over in the storm of day 18. Clearing this area had the added advantage that pesticides to combat the millipedes and crickets could be applied directly to the base of the plants. Plant development was then uniform on all treatments and 50% tasselling was observed at day 46. At this time, both rainfed treatments were wilting. Silking was observed first at day 50 on the 20 cm deep subsurface pipes, but on day 55 winds of up to 4.3 m/s broke 3% of plants on this treatment and 2% of plants grown by traditional flood irrigation. By day 74, many cobs were ready for harvest and irrigation ceased on all treatments. Much of the rainfed crop had by this time died.

Table 2.2.2 shows that significantly fewer plants reached maturity on flood irrigation beneath mulch because of the pests that thrived under the straw during this summer season. Consequently, the yield for this treatment was reduced. The highest yield was achieved by 10 cm deep subsurface pipes, being significantly higher than both 20 cm deep subsurface pipes and flood irrigation beneath mulch. It was average cob weight produced per treatment that contributed to these differences in final yield, there being no significant difference in the number of cobs produced by these treatments. Seed fill was poor and yields were significantly lower on both rainfed treatments, but the benefits of conserving rainfall by use of mulch are clear.

Table 2.2.2 Average crop yields

Method	Plants (per plot)	Dry Matter (kg/ha)	Cobs (per plot)	Cob.Wt (kg)	Yield (kg/ha)	Adj. Yield (full stand) (kg/ha)
Flood	74.0	4620	72.50	0.2860	7972	8620
Mulch	66.3	5142	64.75	0.2858	7088	8583
10 cm pipe	74.0	4672	73.25	0.3071	8645	9352
20 cm pipe	72.0	4265	73.25	0.2664	7504	8349
Rainfed open	71.0	3182	20.00	0.1610	1238	1395
Rainfed mulch	49.0	4676	29.00	0.2021	2254	3680
LSD (p=0.05)	5.2	623	4.65	0.0341	753	1024

LSD = least significant difference

Individual irrigation requirements were determined in order to maintain a favourable moisture status beneath each treatment, to achieve similar crop yields by each treatment and to apply less water to those treatments more efficient in their water use.

Had pests and high winds not reduced the plant stands of certain treatments, similar yields may have been achieved. Table 2.2.2 shows no significant difference between treatment yields adjusted to represent the desired full stand of 80 plants per plot.

Water use effectiveness

Figure 2.2.4 shows the pattern of water use by each irrigation method throughout the crop season, water use comprising of crop water use plus evaporation plus drainage, and being calculated bi-weekly as the sum of rainfall plus irrigation plus net loss of moisture from the soil profile.

Water use was lowest using 20 cm deep subsurface pipes and flood irrigation beneath mulch. A considerable saving in water was made by these methods and occurred primarily during the period of supplementary irrigation between days 18 and 46. During the early rains of days 1 to 18, irrigation was not necessary and similar use of rainfall was made by all treatments. After day 46 and up to day 70, as the plants approached physiological maturity and the canopy closed, water use was similar on all treatments except 10 cm deep subsurface pipes. Water use by this method was higher than that of traditional flood irrigation, repeating the result measured for sugar beans grown during winter (Lovell *et al.*, 1990), but again the highest yield was also achieved by this method.

Table 2.2.3 shows values of water use effectiveness (Bos, 1985) calculated for each irrigation method. The effectiveness of 20 cm deep subsurface pipes is shown to be excellent compared to that of traditional flood irrigation. The effectiveness of flood irrigation beneath mulch, reduced by the poor plant stand, is still equal to that of the traditional method, and using values of yield adjusted to represent the desired full stand it becomes significantly better and comparable to that of 20 cm deep subsurface pipes. The effectiveness of 10 cm deep subsurface pipes is equal to that of traditional flood irrigation, but higher yields are obtained if 7% extra water is available. Finally, if water is available, the benefits of supplementary irrigation in a season such as this are clearly illustrated in Table 2.2.3. Rainfed water use effectiveness is doubled by use of supplementary irrigation, even when considering the best dryland treatment possible.

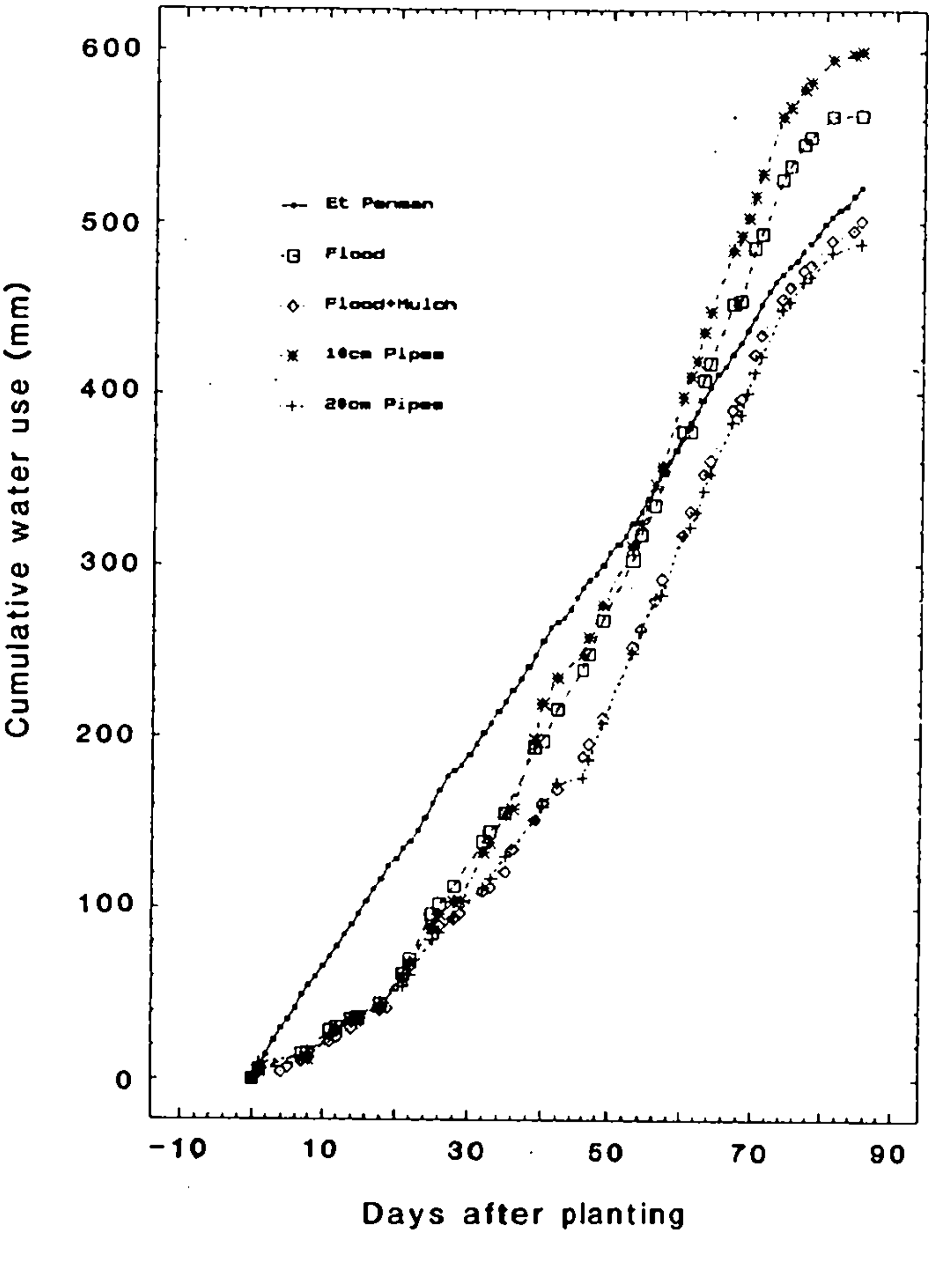


Figure 2.2.4 The pattern of water use by irrigation method throughout the crop season

Table 2.2.3 Water use effectiveness

Method	Water use (mm)	Water use (% of flood)	Water use effectiveness (kg/m^3)	Adj. Water use effectiveness (full stand)(kg/^{3})
Flood	562	100	1.42	1.53
Mulch	500	89	1.42	1.72
10 cm pipe	600	107	1.44	1.56
20 cm pipe	488	87	1.54	1.71
Rainfed open	331	59	0.37	0.42
Rainfed mulch	331	59	0.68	1.11

Water use effectiveness (Bos 1985) = crop produced (kg)/water use (m^3)

2.2.4 Conclusions

Water can be saved during the rainy season by use of alternative methods of irrigation in preference to traditional flood irrigation. Water savings of 13% and 11% were made here by use of 20 cm deep subsurface clay pipes and flood irrigation beneath mulch respectively. These savings occurred primarily during a low rainfall period between days 19 and 46, a period prior to plant canopy closure when supplementary irrigation first became necessary. Had rainfall not occurred earlier and irrigation had been necessary from the start, even greater savings in water might have been expected.

Crop establishment above 20 cm deep subsurface clay pipes was successfully achieved by applying irrigation water directly with the maize seed and covering with dry soil. With good crop establishment, the method shows itself to be highly efficient in water use. Pest problems experienced beneath mulch during this rainy season were not experienced during the past dry winter season (Lovell *et al.*, 1990). To avoid these problems, it is recommended that a pesticide be applied before placing the mulch on the beds, and that a gap be left between young plants and the mulch. If pest problems are overcome, adjusted yield figures for a full stand (Table 2.2.2) suggest that flood irrigation beneath mulch will be as efficient as 20 cm deep subsurface pipes, with the added advantage of significantly higher dry matter production. In the Communal areas of Zimbabwe, where maize stover is used as animal feed, this is important. The lower dry matter production above 20 cm deep subsurface pipes may also make these plants more susceptible to wind damage.

Water was not saved by use of 10 cm deep subsurface clay pipes. The method used 7% more water than traditional flood irrigation but again gave the highest yield, repeating the result measured for sugar beans grown during winter (Lovell *et al.*, 1990). If water use can be reduced (perhaps by placing mulch along the line of the pipes) without diminishing the higher yields, then the method would appear to have great potential.

2.3 EXPT 90/4: LYSIMETER EVAPORATION STUDIES

2.3.1 Introduction

An understanding of the magnitude of the different components of the soil water balance is fundamental to the improvement of water use efficiency in semi-arid crop production. In particular, it is desirable to partition total water use to water used beneficially by the crop as transpiration and to water lost from the soil either as soil evaporation or as drainage.

In semi-arid areas, soil evaporation can be an important component of the water balance, but direct measurement beneath a growing crop has proved to be difficult. Micro-lysimeters have been used with some success. However, Martin *et al.* (1985) found that rates of soil evaporation measured using micro-lysimeters were too high beneath a growing crop because plant extraction of moisture was excluded. Allen (1990) found the technique to be reliable during rain-free periods but found that rates measured after rain were too low due to disparities between recorded rainfall and actual water uptake by the micro-lysimeters.

In experiment 90/4, micro-lysimeters and a large weighing lysimeter were used to measure soil evaporation under maize, irrigated by supplementary flood irrigation during the 1990/91 hot-rainy season. Under these conditions, which are typical of small gardens in Zimbabwe, high rates of soil evaporation may be expected. The objectives of the work were : (1) to assess the potential of micro-lysimetry in a rain-fed/irrigated experiment, (2) to partition total water use to soil evaporation, plant transpiration and drainage for the life of the crop, and (3) to measure patterns of soil evaporation and plant transpiration after wetting.

2.3.2 Methods and materials

Experimental design

Short season maize (*Zea Mays* cv R201) was sown on 29 November 1990 in a square plot of side 10 m. The plot was divided into 21 beds, each 3 m long by 1 m wide, surrounded by a low earth bund, and with a pathway of 0.5 m between beds. These planting arrangements are typical of small gardens in Zimbabwe. The maize was sown in two rows per bed. Row spacing and within row spacing were 0.3 m and 0.3 m respectively, giving a plant population of 30,800 plants/ha. All evaporation measurements were made on the central bed. Total evaporation, from plant and soil, and drainage were measured hourly using a large weighing lysimeter, and by monitoring soil moisture depletion using a neutron probe. Soil evaporation, initially from bare soil and thereafter from beneath the growing crop, was measured using six micro-lysimeters. Plant transpiration was determined by difference.

Weighing lysimeter construction and use

Figure 2.3.1 shows construction of the weighing lysimeter. An open 200 litre steel drum, of internal diameter 57 cm and wall thickness 2.5 mm, was cut into two parts. The lower portion, of length 20 cm, was adapted to deliver drainage water via a 40 mm PVC pipe and flexible hose. A strong tray was welded to the base, and the interior filled with gravel. The upper sleeve, of length 80 cm, was filled with an undisturbed soil monolith. This was obtained by alternately pushing the sleeve into the soil and digging away surrounding soil until the surface of the soil was 1 cm below the upper end of the sleeve. The sleeve containing soil was then carefully lifted from the ground and rejoined to the lower portion using rivets and bitumen putty as a sealant. The undisturbed soil monolith had been in the lysimeter for 10 months prior to the experiment.

The lysimeter was placed on three load cells (Sensotec model 41/571-06, full scale capacity 1000 lbs, full scale deflection 0.003") positioned on the floor of a circular brick housing (of depth 1.2 m, internal diameter 63 cm, and wall thickness 7 cm) constructed at the centre of the central bed (Fig. 2.3.1). The flexible hose for drainage, and cables from each load cell, were passed through PVC conduit at the base of the housing to a tipping bucket flow meter (Environmental Instruments Ltd ARG100, 0.2 mm/tip) and datalogger (Campbell Scientific CR10) respectively, each located in a covered pit five metres away. The datalogger was programmed to record drainage (mm) and load cell output (mV) at hourly intervals, and both datalogger and load cells were powered by two separate 12v car batteries also stored in the pit. Load cell output (mV) was later transformed to mass (kg) using calibration factors provided by the manufacturer. The lysimeter weighed to an accuracy of 4 g, equivalent to 0.01 mm of water, and total evaporation of four maize plants within the lysimeter was calculated directly from weight loss.

Micro-lysimeter construction and use

Six micro-lysimeters were made using 20 cm lengths of aluminium pipe, of internal diameter 98 mm and wall thickness 2 mm. Six micro-lysimeter holders were made using 20 cm lengths of rigid PVC pipe, of internal diameter 105 mm and wall thickness 2.5 mm. These were installed in the central bed, in two rows 0.6 m either side of the weighing lysimeter and at spacings of 0.2 m, 0.5 m and 0.8 m across the bed (Fig. 2.3.1). The positions were chosen to ensure measurement of a representative average of the soil evaporation rate, which has been shown to vary between row and inter-row (Martin *et al.*, 1985). The crop rows ran north to south.

A procedure described by Allen (1990) was used to fill each micro-lysimeter with an undisturbed soil monolith. The aluminium pipe was inserted into the soil by alternately pushing it down a few centimetres and digging away the surrounding soil, until the surface of the soil monolith was less than 5 mm below the upper end of the pipe. After trimming away excess soil flush with the bottom of the pipe, the base was sealed by attaching a strong plastic sheet with insulating tape. The micro-lysimeter was then weighed to an accuracy of 1 g, equivalent to 0.13 mm of water, and inserted into the holder. The use of a holder allowed rapid removal and replacement

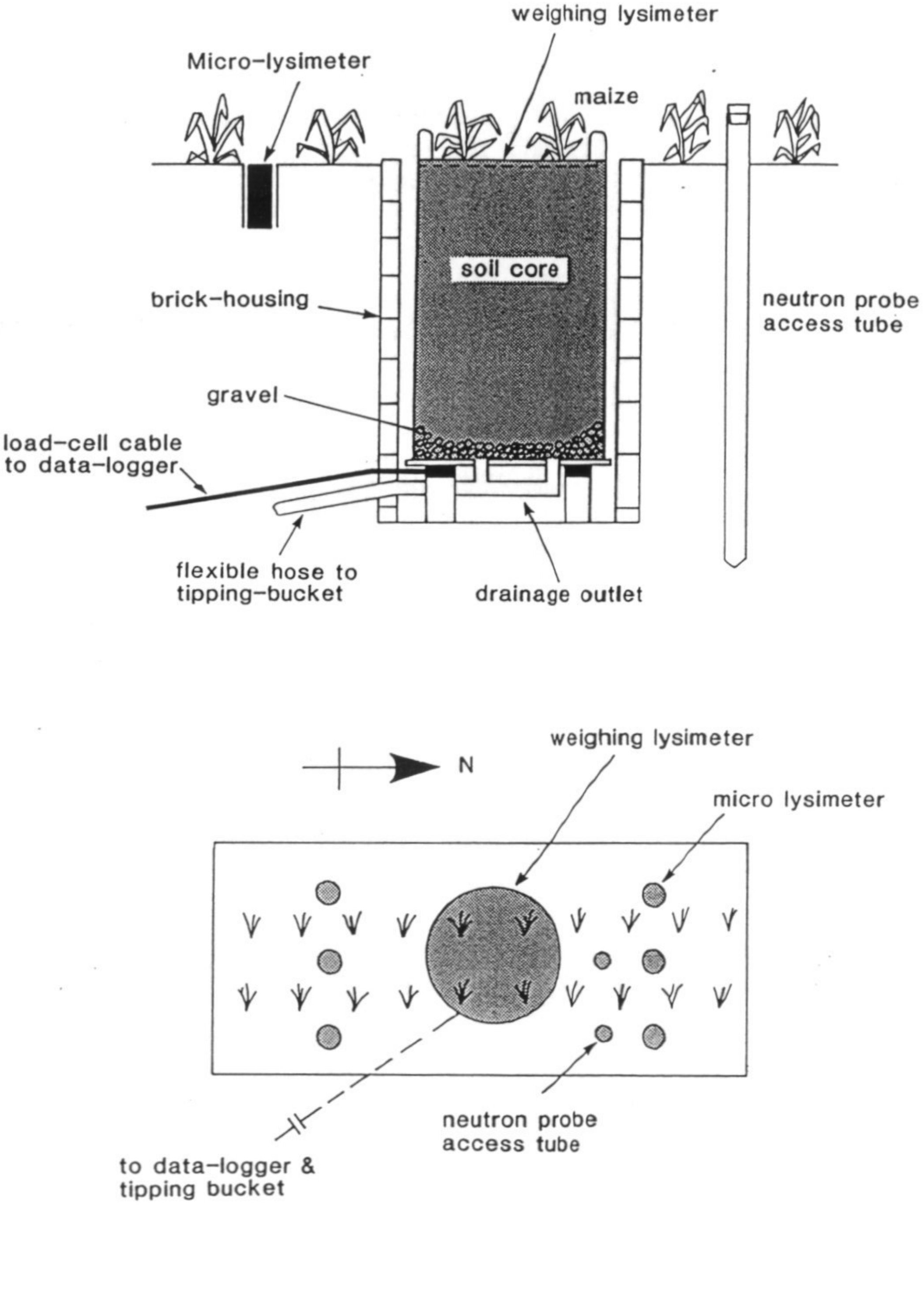


Figure 2.3.1 The construction of the weighing lysimeter

of the micro-lysimeter, with minimum disturbance to the surrounding plants. The micro-lysimeters were refilled with soil taken from outer guard beds, in undisturbed areas corresponding to the position of the micro-lysimeter in the central bed. They were weighed at 0600hrs, 0900hrs, 1200hrs and 1500hrs local time on most working days.

The inherent assumptions of micro-lysimetry have been examined by Boast and Robertson (1982) and Walker (1983). Accurate measurement of soil evaporation using a micro-lysimeter is achieved only when the soil within the micro-lysimeter has a moisture content profile similar to that of the surrounding soil. Once cut, the profile within a micro-lysimeter begins to diverge from that of the surrounding soil as vertical fluxes of water and plant extraction are excluded. To reduce such errors in this experiment, each soil core was used for a maximum of 96 hours before being replaced. Previous work (Boast and Robertson, 1982) suggests that 20 cm deep micro-lysimeters should remain representative for this period.

To eliminate errors resulting from water uptake following rainfall, each micro-lysimeter was either refilled or re-weighed early on the day after rainfall or irrigation, and results extrapolated for the short periods without data. In this way, soil evaporation was calculated from weight loss alone, independent of measured rainfall or irrigation.

Soil moisture depletion measured using a neutron probe

Two neutron probe access tubes were installed in the central bed, to a depth of 1.1 m at spacings of 0.125 m and 0.375 m one side of the centre line and 0.4 m from the large weighing lysimeter (Fig. 2.3.1). Soil moisture content (mm) was measured at intervals of 0.1 m to a depth of 1 m. Measurements were made at least four times per week, before and after irrigation and after major rainfall events. Total water use, comprising of total evaporation plus drainage during each interval between measurements, was calculated as the sum of irrigation plus rainfall plus net loss of moisture from the soil profile to a depth of 0.9 m. Runoff was not observed during the experiment.

Irrigation

Measurements of soil moisture depletion made in situ using the neutron probe were also used to determine irrigation required by the maize. Rainfall soon after planting brought the soil profile to a moisture content approaching "field capacity". At this time, moisture content (mm) to a depth of 0.9 m was measured at both access tube positions and the average value recorded as the starting condition. Thereafter, calculated soil moisture deficit was applied as irrigation once per week when necessary, allowing a reasonable deficit to develop in line with local practice. The water was applied as flood irrigation after 1600hrs on the day of irrigation, care being taken to apply the exact amount of water to the large weighing lysimeter.

Agronomy

400 kg/ha of fertiliser in the form of Compound D (8N 14P 7K) was incorporated by hoe at planting. 50 kg/ha N in the form of ammonium nitrate was applied as a top dressing at 35 days. Carbaryl foliar spray was applied at 13 days and 19 days to combat crickets which were eating the young plants and to combat *Spodoptera* (Army worms). Endosulfan was applied as a spray at 29 days and as granules at 42 days to combat maize stalk borer (*Busseola fusca*) and as a spray at 62 days to combat *Heliothis* cob borers. The maize was harvested dry on 13 March 1991, and a yield of 7088 kg/ha was recorded.

2.3.3 Results and discussion

Weather during the crop season

Rainfall and meteorological data were collected at the research station meteorological station and by an automatic weather station (Didcot Inst. Ltd, UK) installed at the site. Table 2.3.1 shows the mean monthly meteorological data measured during the crop season. Above average temperatures were observed throughout the season. Early season rainfall was low, November being 30 mm below average. Late season rainfall was above average, but a serious dry spell occurred between January and February and supplementary irrigation was needed.

Table 2.3.1 Mean monthly meteorological data

Month	TMAX am °C	TMIN am °C	TDRY am °C	TWET am °C	TDRY am °C	TWET pm °C	WIND km/d	SUN hrs	RAIN mm	PAN mm	Et mm
Nov	32.3	18.4	24.6	19.5	31.2	20.5	146	8.6	34.0	8.4	6.0
Dec	33.4	20.6	25.8	21.7	32.1	22.5	155	8.8	115.0	7.3	6.2
Jan	33.4	22.1	26.3	22.6	31.2	23.5	125	9.7	100.2	7.6	6.3
Feb	32.4	22.6	25.5	22.8	31.4	23.3	120	8.1	101.9	6.2	5.9
Mar	28.9	20.3	23.1	21.3	29.2	22.8	113	6.8	78.7	4.5	4.4

Pan = Average evaporation of two Class A open pans
Et = Potential evaporation (Penman 1963)

Seasonal patterns of plant transpiration and soil evaporation

Figure 2.3.2 compares total evaporation from plant and soil measured during the season by the weighing lysimeter and by the neutron probe, and soil evaporation measured by the micro-lysimeters. Drainage below 90 cm was not measured during this experiment. Potential evaporation, calculated hourly using the Penman equation (Penman,1963) and automatic weather station data, is provided as a measure of evaporative demand of the atmosphere. The seasonal pattern of rainfall and

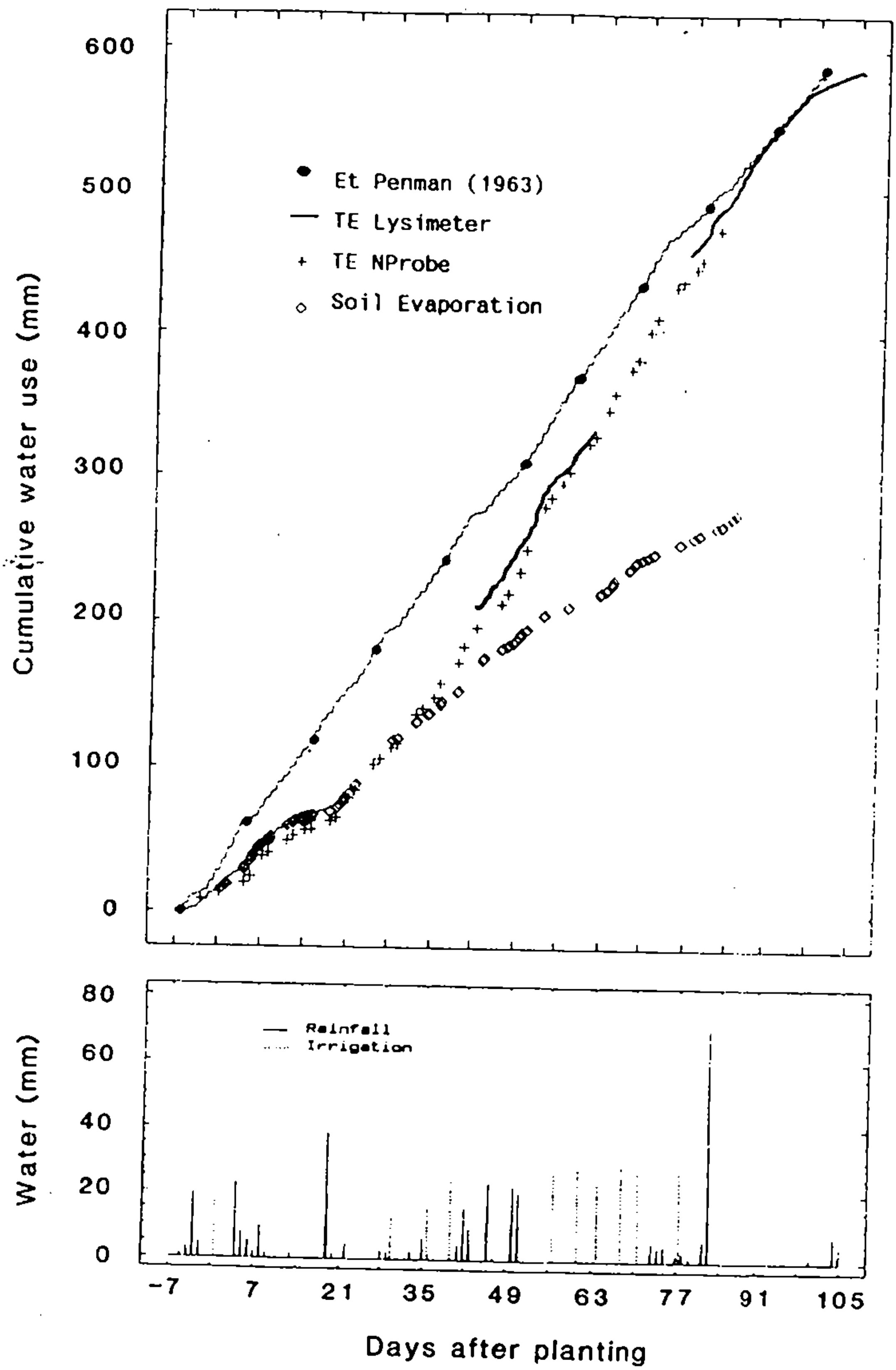


Figure 2.3.2 Comparison of potential evaporation (Penman, 1963) with total evaporation measured using a weighing lysimeter and neutron probe and soil evaporation measured using micro-lysimeters

supplementary irrigation is also illustrated.

Agreement between the weighing lysimeter and the neutron probe is shown to be very good, giving confidence in values of total evaporation measured by either instrument. Unfortunately, a full season of data was not achieved using the weighing lysimeter, due to rodent damage to a load cell cable, but sufficient data points (1,775 hours) were successfully recorded to allow comparison to be made. The first important result shown in Figure 2.3.2 is that plant transpiration was only 46% of total water use during the crop season. Soil evaporation accounted for 54%, and was the dominant process until about day 42. This result suggests that much scope remains to improve water use efficiency by reducing soil evaporation.

136 observations of soil evaporation were made using the micro-lysimeters, which were refilled 16 times and reweighed 12 times during the season to avoid disparities between water uptake and recorded rainfall or irrigation (Allen,1990). As continuous measurement by this method was not possible, linear extrapolation was used to estimate soil evaporation during the short periods without data, as follows :

$$E_n = TE_n \cdot E_{n-1}/TE_{n-1}$$

where E_n = soil evaporation during a period without data,
TE_n = total evaporation measured during that period,
E_{n-1} = soil evaporation measured during the previous period, and
TE_{n-1} = total evaporation measured during the previous period.

Figure 2.3.3 shows that the method of micro-lysimetry used here was successful. During the initial period of bare soil prior to plant emergence (days 0 to 14) the soil surface was wet by irrigation once and by rainfall six times. The micro-lysimeters were refilled after the irrigation (day 0) and after the larger rainfall event (day 3) and were reweighed after the five minor rainfall events. Agreement between soil evaporation determined in this way and also measured by the larger weighing lysimeter is shown to be very good. Divergence after about day 14 corresponds to the onset of plant transpiration.

The second important result shown in Figure 2.3.3 is that, of the rainfall and irrigation received on bare soil after sowing and prior to plant emergence, 79% was lost as soil evaporation. This loss has important implications for crop establishment which, in semi-arid areas, can often be poor as a consequence of this rapid drying.

Daily patterns of soil evaporation from bare soil early in the season

Evaporation from a soil profile initially at "field capacity" has been described as a two-stage process (Ritchie, 1972; Hillel, 1980; Gardner, 1983). A first, "constant rate" phase, when evaporation is limited by evaporative demand of the atmosphere, is followed by a second, "falling rate" phase, when evaporation is limited by hydraulic properties of the soil. Evaporation is shown to depend initially on supply of radiant energy to the soil surface, and thence on moisture content of the surface soil layers via hydraulic conductivity and diffusivity.

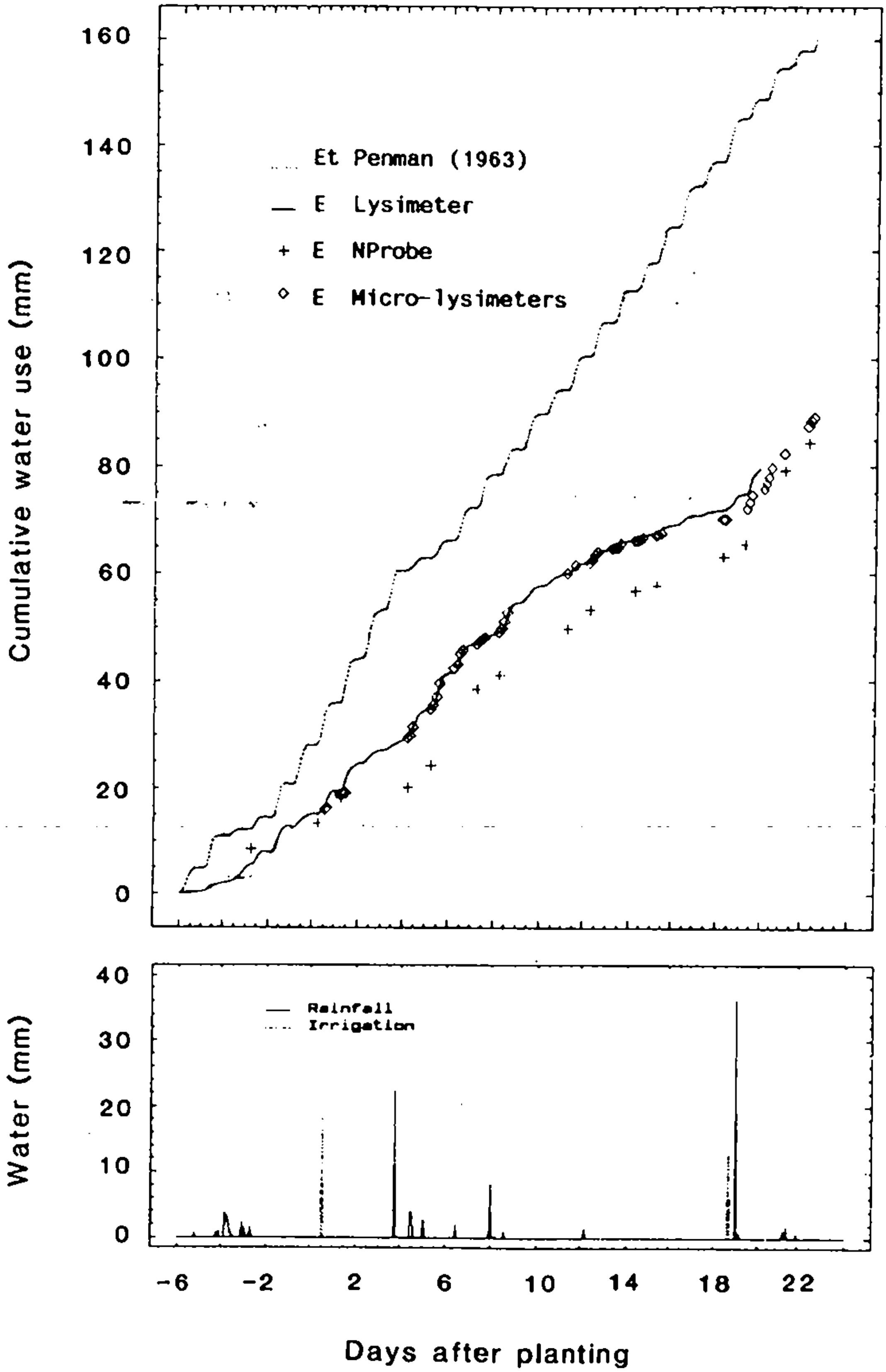


Figure 2.3.3 The relation between rainfall and irrigation events and subsequent periods of high water loss

Figure 2.3.3 illustrates well correspondences between rainfall and irrigation events and subsequent periods of high water loss. Evaporation rates of up to 7.2 mm/day were measured on those days immediately after wetting, but declined to less than 1.4 mm/day as the soil surface dried and resistance to diffusion of water vapour increased. This pattern is shown to depend very strongly on time after wetting, via moisture content of the surface soil, and less on evaporative demand. Considering the sequence shown, dry surface soil (days 2 and 3) kept evaporation low despite high evaporative demand. After rain, wet surface soil (days 4 and 5) allowed high evaporation, although evaporative demand was lower during this overcast period. Evaporation (day 6) was maintained by a shower of rain that re-wet the soil surface, but fell (day 7) as the soil surface began to dry. The sequence was repeated after rain at the start of day 8, evaporation falling from 5.6 mm/day to 2.1 mm/day by day 11 despite high evaporative demand throughout this dry period.

Measures of evaporation after each wetting event during the initial period of bare soil were used to determine a first estimate for the relationship between actual and potential evaporation (Fig. 2.3.4(a)). Values for 'day 0' represent part-days immediately after wetting, subsequent values are for complete days after wetting. The result emphasises the strong dependence on time, but scatter in data for 'day 0' reflects dependence on evaporative demand. The four values of E/Et > 2 correspond to periods of low evaporative demand immediately after the rainfall events of different size on days 18, 4, 3, and 5 after planting. In contrast, the two values of E/Et < 1.1 correspond to periods of high evaporative demand following the rainfall events of days 8 and -4, after planting (Fig. 2.3.3). This result suggests that "first-phase" evaporation did occur immediately after all wetting events, independent of event size or antecedent moisture, but was of short duration. Each value of E/Et determined for 'day 1', the first complete day after wetting, showed a significant fall in measured evaporation despite increasing evaporative demand, conditions indicative of "second-phase" evaporation having begun.

Potential evaporation, Et (Penman, 1963), is a measure of evaporative demand that reflects the supply of radiant energy to the soil surface and the effects of ventilation, turbulence and dryness of the air above this surface. However, the equation is not exact, neglecting soil heat flux and advection, and values determined here for bare soil appear to be low, giving rise to the values of E/Et > 1 (Fig. 2.3.4(a)). Batchelor (1984) has shown that values of Et (Penman, 1963) can be up to 23% lower than values of Et estimated using the FAO 'Modified' Penman equation (Doorenbos and Pruitt, 1977), due to different empirical relationships used to estimate the wind function and a factor included to account for differences in day and night-time conditions. Values of E/Et shown in Figure 2.3.4a were reduced by use of the 'Modified' equation calibrated for the present conditions, but still attained values up to 2.

A better measure of potential evaporation after wetting appears to be that measured from open water (Eo). Average values of daily evaporation given by two Class A pans were used to determine ratios of E/Eo for each full day after wetting (Fig. 2.3.4(b)). Hourly data for part-days immediately after wetting were not available. Although the result shows some scatter, probably due to inaccuracies in measuring open-pan evaporation after rain, ratios of E/Eo approach unity immediately

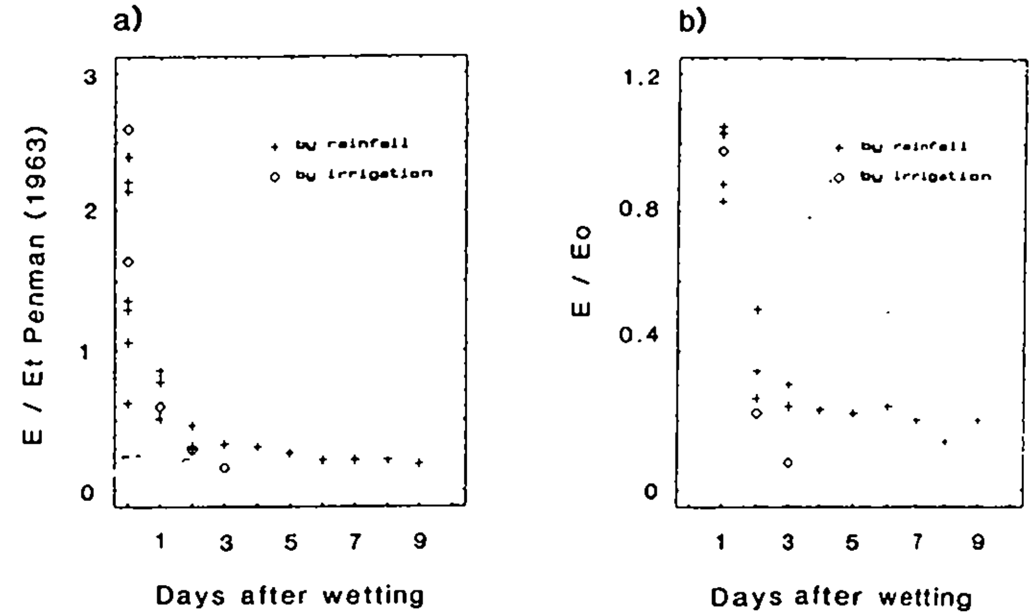


Figure 2.3.4 ***Measured soil evaporation E as a fraction of (a) potential evaporation Et (Penman, 1963) and (b) open-pan evaporation Eo, on consecutive days after wetting early in the season***

after wetting and again indicate the strong dependence on time.

Diurnal patterns of soil evaporation after wetting

Different patterns of soil evaporation from bare soil were measured after different wetting events. Figure 2.3.5 provides an example. On day 0, 15.4 mm of irrigation was applied at 1300 hrs to a dry soil profile (104 mm soil water content to a depth of 0.9 m). Despite constant evaporative demand, measured evaporation exceeded potential evaporation for only 10 hours. Thereafter, evaporation was limited by increasing resistance to vapour diffusion in the still relatively dry soil profile. In contrast, rainfall of only 5.4 mm at 0300 hrs on day 5 fell onto a wetter soil profile (136 mm soil water content to a depth of 0.9 m). Measured evaporation this time exceeded potential evaporation for 33 hours until very high rates of evaporation finally dried the soil sufficiently to limit vapour diffusion. This result indicates that patterns of soil evaporation will depend on antecedent moisture within the soil profile.

Fluctuations in the rate of soil evaporation measured by the third day after each wetting event are not to be expected. The falling and rising rates of evaporation suggest that resistance to vapour diffusion increases as the soil is dried by evaporation but may decrease for short periods, perhaps as the soil is "re-wet" by moisture from beneath. Similar patterns were also observed by the third day after other wetting events.

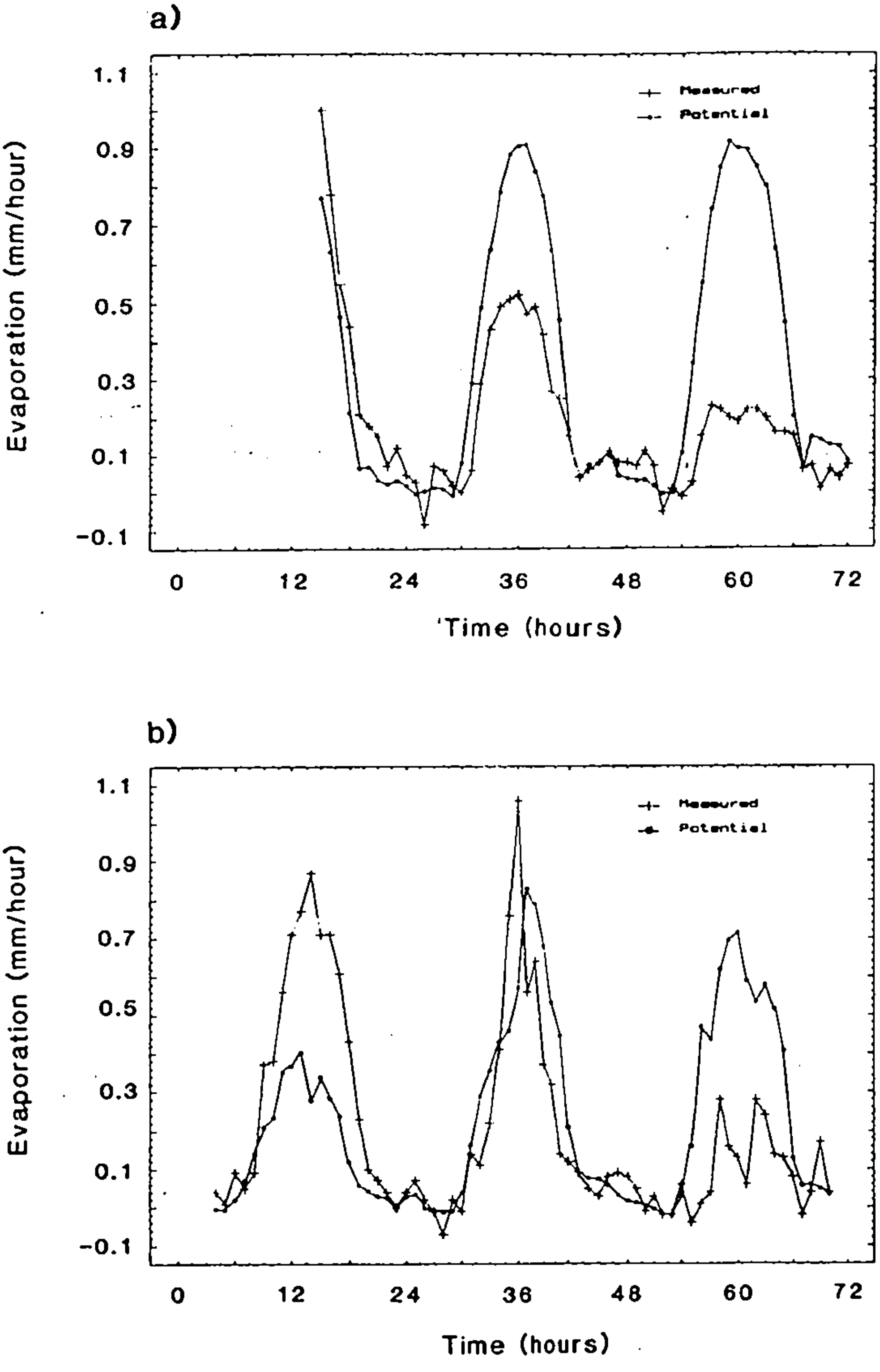


Figure 2.3.5 Different patterns of soil evaporation from bare soil after different wetting events

Plant transpiration and soil evaporation later in the season

Figures 2.3.6(a) and (b) provide examples of plant transpiration and soil evaporation measured later in the season. During a 6 day period after rainfall mid-way through the season (day 50), plant transpiration is shown to account for 62% of total water use and soil evaporation beneath the plants for 38%. During this period of relatively constant atmospheric demand, total evaporation and soil evaporation are shown to both increase soon after wetting but to decline each day thereafter. During a 5 day period after irrigation on day 77, plant transpiration is shown to account for 67% of total water use and soil evaporation still for 33%. Low atmospheric demand on day 78 limited total evaporation, which increased only on day 79. Soil evaporation is shown to be relatively constant beneath the mature plant canopy (LAI = 3.86).

Negative total evaporation shown during the early hours of day 51 indicates formation of dew on plants in the large weighing lysimeter. During the season, a total of 16.6 mm of dew were recorded, rising from an average of 0.06 mm/day early in the season to 0.24 mm/day late in the season. Typically, this formed at 2000 hrs, 0200 hrs and between 0400 and 0800 hrs, but had been lost as evaporation by 1000 hrs.

Soil evaporation measured from bare soil and predicted by the simple model of Monteith (1991)

Equations describing water, vapour, and heat transfer have been used in models that simulate evaporation from soil (e.g. Van Bavel and Hillel, 1976) but relevant soil parameters are often lacking and models become complex when they are extended to take account of processes in the atmosphere as well as the soil.

Using a relatively simple two-layer model, Monteith (1991) has recently shown that evaporation from drying soil can be predicted using the Penman-Monteith equation given in Monteith (1981) if the resistance r_s to the upward diffusion of water vapour within the soil profile is assumed to increase in proportion to the amount of water lost by evaporation since the last complete wetting.

A general form of the Penman-Monteith equation for evaporation from a surface of specified resistance r_s is :

$$L.E = \frac{D.R_n + P.C_p.\ (VPD)\ /\ r_a}{D + y.\ (1 + r_s/r_a)} \qquad (1)$$

where L = latent heat of evaporation,
E = evaporation rate expressed in mass per unit area and time,
D = increase of saturation vapour pressure with temperature,
R_n = net radiation,
$P.C_p$ = volumetric specific heat of air,
VPD = vapour pressure deficit of the air,
r_s = surface resistance,
r_a = aerodynamic resistance to vapour diffusion, and
y = psychrometric constant

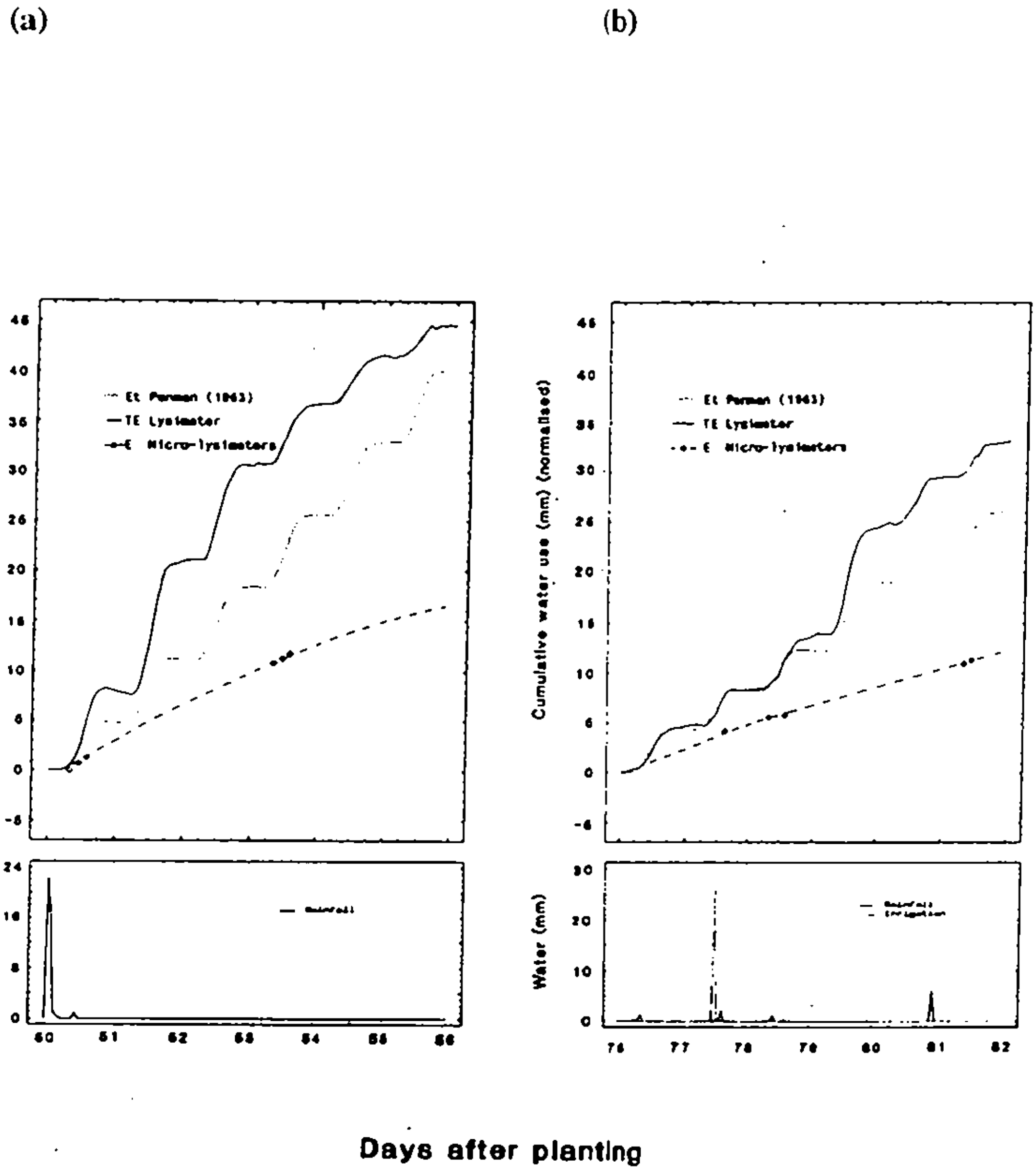


Figure 2.3.6 Examples of potential evaporation (Et), total evaporation (TE) and soil evaporation (E) measured at different times later in the season

Assuming resistance r_s to increase in proportion to the amount of water lost by evaporation (E_s) since the last complete wetting,

$$r_s = m \int E_s \, dt \tag{2}$$

where m is a constant which is a function of the soil diffusivity. Substituting for r_s in equation (1) and rearranging terms (Monteith, 1981) gives :

$$E_s = \left[2t/A + 1/E_{so}^2\right]^{-0.5} \tag{3}$$

where

$$A = r_a(D + y).E_{so}/ym \tag{4}$$

and E_{so} is the initial maximum rate of soil evaporation when $r_s = 0$.
Integrating equation (3) gives the cumulative evaporation as :

$$\int E_s \, dt = \left[2At + A^2/E_{so}^2\right]^{0.5} - A/E_{so} \tag{5}$$

An initial maximum rate of evaporation (E_{so}) determined by weather thus gives way to a rate proportional to the square root of time as well as to E_{so}. To predict cumulative evaporation using this model, only values of E_{so} and soil constant (A) are thus required.

Figure 2.3.7 shows cumulative daily evaporation 'predicted' using equation (5) and measured after four wetting events that occurred during the initial period of bare soil during experiment 90/4. Values of E_{so} were taken as equal to values of open-pan evaporation measured on the particular days of wetting, in light of the good agreement shown previously in Figure 2.3.4(b). Values for the soil constant (A), defining the relation between soil resistance and accumulated water loss, were determined independently for each event by non-linear regression using measured values of cumulative evaporation in equation (5).

The good agreement shown between values of cumulative evaporation measured and 'predicted' in this way indicates that the form of equation (5) describes well the form of evaporation that occurred after wetting, particularly at longer time periods during "second-phase" evaporation. However, the different values of soil constant (A) determined for each event reflect the different antecedent soil moisture profiles that prevailed, and pose a problem if the model is to be used predictively. The model assumes that evaporation commences after 'complete' wetting. Complete wetting did not occur at any time during experiment 90/4, and in this part of Zimbabwe is less common than incomplete wetting. The event of day 5, although of only 5.4 mm, came closest to attaining 'field capacity' due to previous rains on days 3 and 4. The value of constant (A) determined for this event is shown to be very different to values determined for other events when the soil profile was drier.

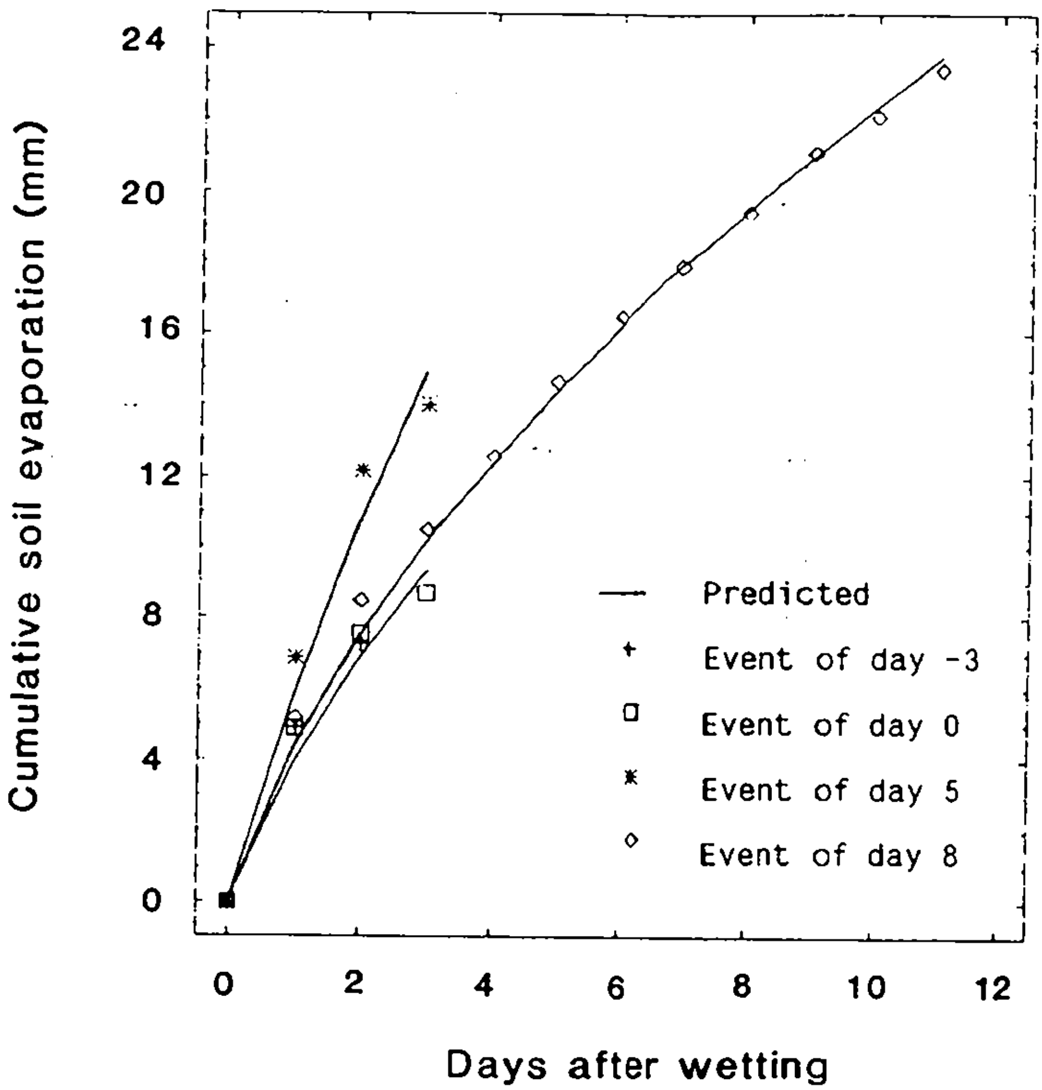


Figure 2.3.7 Cumulative daily evaporation measured and 'predicted' using the simple model of Monteith (1991). The points are measurements and the four curves were fitted by non-linear regression using equation (5). For the four wetting events initial evaporation rates E_{ro} of 5.9, 5.0, 6.7 and 5.9 mm/day were used. Values of soil constant (A) determined were different, being 38.1, 38.4, 148.4 and 40.5 mm²/day respectively.

A second assumption made in deriving this model is that evaporation commences at an initial maximum rate determined by weather. Discrepancies shown in Figure 2.3.7 between measured and 'predicted' values of evaporation at short time periods are due to the changes in evaporative demand that occur in practice. In irrigated agriculture, evaporative demand may remain reasonably constant prior to and after wetting, but in rainfed agriculture this is less likely. Typically, in this part of Zimbabwe, the evaporative demand of the second day after rain exceeds that of the first day. By assuming evaporation to commence at an initial rate determined by the weather of the first day, the model is shown to underpredict evaporation during these early stages.

The problems outlined above are not serious when a soil profile is brought to "field capacity" by a large, discrete event and total evaporation is then calculated over a period of a week or longer. Under such conditions, good agreement between measured and predicted evaporation is reported for contrasting soil types (Monteith, 1991). If a soil profile is not brought to "field capacity", or is wet by consecutive smaller events with consequent short periods of drying, the simple model may be improved if daily values of E_{so} were considered, and if a term relating cumulative evaporation to remaining soil moisture content could be included to allow estimation of the appropriate value of constant (A) at the beginning of each successive drying sequence.

Finally, rearranging terms in the Penman-Monteith equation (equation 1) gives:

$$r_s = \frac{r_a . D . R_n}{L.E.y} + \frac{P.C_p . VPD}{L.E.y} - \frac{r_a \, . \, D}{y} - r_a \tag{6}$$

r_s is assumed to increase linearly with cumulative soil evaporation in the simple model of Monteith (1991). Figure 2.3.8 shows the relationship determined here between values of r_s calculated hourly using equation (6) and cumulative soil evaporation measured hourly after each wetting event described in Figure 2.3.7. The results suggest that, rather than linear, the relationship between r_s and cumulative soil evaporation is better described as exponential. Only values of r_s calculated hourly between 0800 and 1800 hours on each day after wetting are shown; values of r_s calculated outside these hours were negative when energy for evaporation was not available. Absolute values of r_s calculated using equation (6) were sensitive to the value of aerodynamic resistance (r_a) assumed, and to possible extra energy for evaporation that may be available due to advection. The values of r_s shown in Figure 2.3.8 were determined assuming a value of 160 s/m for aerodynamic resistance r_a of soil (Sharma, 1985) and zero advection.

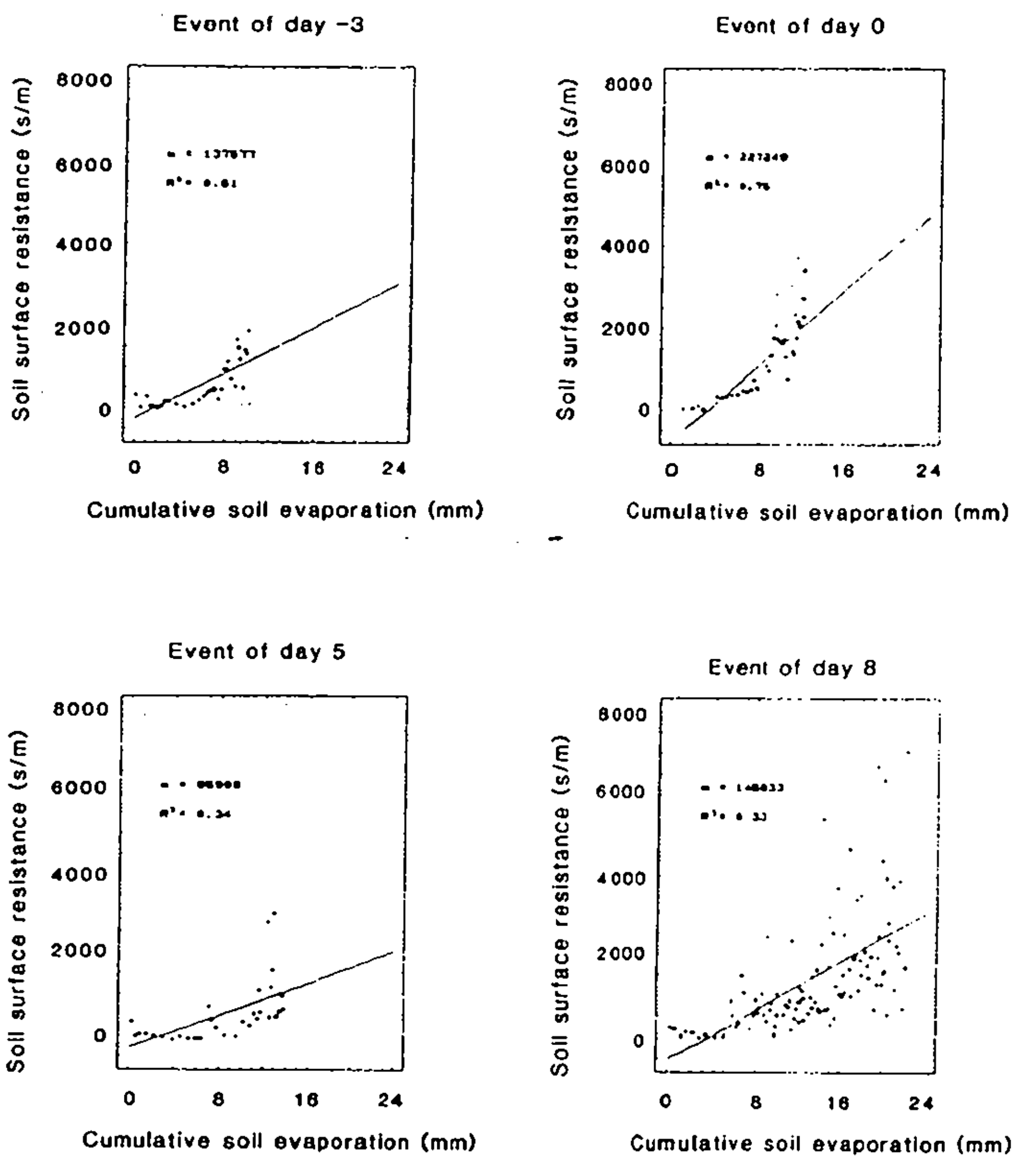


Figure 2.3.8 The relationship between r_s calculated hourly using equation (6) and cumulative soil evaporation measured hourly after four wetting events. The linear relationship assumed by Monteith (1991) is shown, but the results are better described by an exponential term $r_s = e^{m \int E_s dt} + c$. For the four events: $m=0.4146$, $c=3.0414$ ($R^2=0.65$); $m=0.3525$, $c=3.6361$ ($R^2=0.88$); $m=0.2762$, $c=3.1626$ ($R^2=0.57$); and $m=0.1479$, $c=4.8093$ ($R^2=0.55$) respectively.

2.3.4 CONCLUSIONS

The method of micro-lysimetry used here in a rainfed/irrigated experiment was successful. Agreement between soil evaporation from bare soil determined in this way and that measured by the larger weighing lysimeter is shown to be very good. Discontinuous measurement of soil evaporation, and exclusion of vertical fluxes of water and plant extraction, are inherent limitations of micro-lysimetry that may be overcome in the future by use of improved field probes for soil water content measurement of the soil surface layer (i.e. the IH capacitance probe or time domain reflectometry).

Crops cultivated in small irrigated fields and gardens are prone to enhanced soil evaporation losses as a result of advection. During this experiment, plant transpiration accounted for only 46% of total water use. Soil evaporation accounted for 54%, and was the dominant process until about day 42. Of the rainfall and irrigation received on bare soil prior to plant emergence, 79% was lost as soil evaporation. Transpiration began to contribute significantly to water use at about day 14, but even when the plants had reached maturity (corresponding to a leaf area index of 3.86 at about day 80) transpiration was still only 67% of daily water use and soil evaporation still 33%.

It should be noted that not all water that evaporates from soil beneath a crop is entirely wasted because humidification of air within the canopy reduces demand for water imposed on leaves, allowing stomata to open more widely with the consequence of a faster photosynthetic rate (Monteith, 1991). However, the results of this experiment do suggest that scope remains to improve water use efficiency by reducing soil evaporation. Indeed, significant savings in water are being made in this project using the simple, low-cost methods of irrigation designed to do this.

In Zimbabwe and other semi-arid areas, the challenge must now be to evolve cropping systems that do not require any more water in total, but which make more efficient use of the limited water available. Further use of the available measurement techniques is needed, on different soil types and under different cropping systems, to collect the data required to further develop simulation models of plant growth and soil evaporation, and to assess different management practices designed to achieve higher water use efficiency.

2.4 EXPT 91/1: TOMATO WATER USE EFFICIENCY TRIAL

2.4.1 Introduction

Soil evaporation can be reduced, and efficiency of irrigation improved, if water is applied beneath the soil surface using subsurface clay pipes, or if water is applied beneath a surface mulch that acts as a barrier to evaporation. In previous Experiment 90/1, considerable savings in water were achieved while growing sugar beans by use of these two simple techniques. Prior to plant canopy closure, irrigation beneath mulch used only 43% of water used by the traditional method, and over the entire season the highest crop yield and largest seeds were achieved using subsurface clay pipes placed at 10 cm depth.

In light of these results, Experiment 91/1 was designed with four main objectives :

(a) To confirm improvements in water use efficiency possible by use of these two simple techniques for a crop that, unlike sugar beans, does not entirely cover the ground surface. Tomatoes are commonly grown in small gardens in Zimbabwe, and the indeterminate variety Bermuda was chosen.

(b) To compare water use efficiencies of plants grown both on flat beds and in furrows; both methods of land preparation are employed at present in gardens in Zimbabwe.

(c) To compare improvements in water use efficiency achieved using two types of mulch, dried native grasses (*Eragrostis sp.* and *Heteropogon sp.*) and leaves of the Neem tree (*Azadirachta indica*). Dried native grasses are freely available in most parts of Zimbabwe. Leaves of the Neem tree have insecticidal properties; if leaves can be used as both a water saving mulch and as an environmentally safe form of pest control it would be a valuable contribution, as much garden irrigation in Zimbabwe is practised using water from shallow aquifers particularly susceptible to pollution by chemicals from above.

(d) To compare incidence rates of pests and diseases on those tomato plants grown without mulch, with grass mulch, and with Neem mulch.

2.4.2 Materials and methods

Experimental design

The experiment was a tomato trial (*Lycopersicon esculentum* cv Bermuda) of eight treatments with four replicates. The thirty-two plots were arranged in a randomised block design. Each plot comprised of two beds, each 3 m long by 1 m wide and surrounded by a low earth bund. Beds were either flat or furrowed, the furrows being 0.3 m apart with a central ridge of height about 0.2 m. The eight treatments were:

Irrigation method	Type of mulch	Mulch application rate
Flood (flat bed)	unmulched	
Flood (furrow	unmulched	
Flood (flat bed)	grass mulch	10 tonnes/ha (dry weight)
Flood (furrow)	grass mulch	10 tonnes/ha (dry weight)
Flood (flat bed)	neem mulch	8 tonnes/ha (fresh weight)
Flood (furrow)	neem mulch	8 tonnes/ha (fresh weight)
Pipes (10 cm deep)	grass mulch	10 tonnes/ha (dry weight)
Pipes (20 cm deep)	unmulched	

Subsurface clay pipes were placed along the centre line of beds. Twelve pipes were used per bed, simply laid end to end in a level trench then backfilled with soil. The pipes were made at the research station, using a simple mould and fired in a shallow bark-filled pit. Further details of pipe manufacture are given in the Second Interim Report (Lovell *et al.*, 1990). The pipes were of length 0.24 m, inside diameter 0.075 m and outside diameter 0.115 m. They were placed with either 0.1 m or 0.2 m of soil above them.

Instrumentation

One bed of each treatment was instrumented with two neutron probe access tubes, installed to a depth of 1 m at spacings of 0.125 m and 0.375 m to one side of the centre line.

Measurements of soil water content made in situ using the neutron probe were used to monitor soil moisture depletion and thus to determine irrigation requirements individually for each treatment. The aim of this approach was to apply water on demand and, thereby, to obtain similar high yields under each treatment by maintaining a favourable moisture status beneath each. In theory less should have been required to maintain this status on those treatments more efficient in their water use.

Irrigation at transplanting brought all treatments to a moisture content approaching "field capacity". At this time, soil moisture content to a depth of 0.9 m was measured at both access tube positions under each treatment, and the average value recorded as the starting condition for that treatment. Thereafter average soil moisture content to 0.9 m was monitored weekly, and calculated soil moisture deficit applied to each as irrigation.

Agronomy

The tomato seed was sown in a nursery on 25 March 1991. During 35 days the seedlings received 114 mm of water before being transplanted to the experimental site on 30 April. Twenty seedlings (leaf area= 16.9 cm^2, LAI=0.01) were placed in two rows per bed. Row spacing and within row spacing were 0.5 m and 0.3 m respectively, giving a plant population of 30,770 plants/ha. Irrigation of 13.3 mm (2l/plant) was applied in two small furrows along the rows of all treatments and covered with dry soil. Rainfall of 2.5 mm also fell on this day.

80 kg/ha single super phosphate (P_2O_5), 50 kg/ha ammonium nitrate in granular form (AN), and 40 kg/ha potassium sulphate (K_2SO_4) were applied to the surface of those treatments irrigated by flood and in solution via the subsurface pipes. 50 kg/ha AN and 40 kg/ha K_2SO_4 were applied as a top dressing in the same way at days 14, 27, 41, 55 and 70.

Aldrin foliar spray was applied at day 6 to combat crickets which were eating the young plants. The problem was most severe under grass mulch. Damaged plants were replaced, 5% of plants on beds with grass mulch, 2:8% and 2.3% of plants on beds with Neem mulch and no mulch respectively. Plants on all treatments were well established by day 20 and pinching-out of sideshoots began. By day 49, some plants affected by a mosaic virus were removed and burnt (4% of plants with grass mulch and Neem mulch, 3% of plants with no mulch, and 1.5% of plants grown using subsurface pipes). Copper oxychloride and chlorothalonil (Bravo) foliar sprays were applied at regular intervals to control leaf and fruit diseases, endosulphan (Thiodan) applied to control *Heliothis* and leafeaters, dimethoate applied at day 37 to control whitefly, and dicofol (Kelthane) applied at day 63 to control red-spider mite. At day 74, birds began to eat the fruit and thereafter scaring was necessary. Fungal disease *(Botrytis cinerea)* was observed at day 90. Counting of diseased fruit confirmed that the problem was most severe on those plants with grass mulch (47 diseased fruit) compared to 27 diseased fruit with Neem mulch and 9 diseased fruit with no mulch. Control of this disease using iprodione was not considered practical in light of the high cost of this chemical.

The first harvest of fruit was at day 84, the fifteenth and final harvest at day 153. Total yield was determined for each treatment by summing the fresh weight of tomatoes produced per bed; pathways 0.5 m wide between beds were included in areal calculations. Dry matter production, number of tomatoes, and average weight of tomato were also recorded.

2.4.3 Results

Weather during the crop season

The mean monthly meteorological data measured during the crop season is presented in Table 2.4.1. Maximum and minimum temperatures were generally above average for the area, as were the hours of sunshine recorded during the season. Rainfall in May was above average, but rainfall later in the season was below average.

Table 2.4.1 Mean monthly meteorological data

Month	TMAX °C	TMIN °C	TDRY °C am	TWET °C am	TDRY °C pm	TWET °C pm	WIND km/d	SUN hrs	RAIN mm	PAN mm	Et mm
May	27.4	12.4	17.3	14.9	26.5	17.1	41	8.2	23.5	3.2	3.1
June	25.3	10.1	14.6	12.5	24.4	16.1	49	7.9	3.3	2.9	2.6
July	25.8	9.0	14.1	11.4	24.9	15.3	52	9.0	0.0	3.5	3.0
Aug	27.9	11.1	13.3	13.1	17.4	16.7	73	9.2	1.2	4.6	3.9
Sept	31.4	16.5	21.0	17.1	30.4	19.7	95	8.5	0.0	6.0	5.2

Pan = Average evaporation of two Class A open pans
Et = Potential evaporation (Penman 1963)

Water use, crop yield, and water use effectiveness (WUE)

Figure 2.4.1 shows the pattern of water use measured for each treatment during the season. Water use was calculated bi-weekly as the sum of irrigation plus rainfall plus net loss of moisture measured from the soil profile. Potential evaporation (Penman, 1963) is also shown as a measure of evaporative demand.

In previous experiment 90/1, considerable savings in water were achieved while growing sugar beans by use of a surface mulch. During the first 30 days, prior to plant canopy closure, soil evaporation was reduced and irrigation beneath mulch used only 43% of water used by traditional flood irrigation. Figure 2.4.1 shows that this direct saving in water was not repeated when growing tomatoes. Initial water use was similar on all treatments, except for subsurface pipes placed at 20 cm depth. On this treatment growth rate (and hence water use) was never equal to that of other treatments and by day 69 plants and fruits of this treatment were pale, suggesting either a nutrient deficiency or problem of rooting at depth where water was being applied. Plants on all other treatments were healthy however, and by day 49 (with leaf area= 1725 cm^2, LAI= 1.15) shading of the soil surface reduced soil evaporation reducing the beneficial effects of surface mulch to some degree. Deviations in water use later in the season reflect different rates of plant growth. Those plants grown on flat beds with a grass mulch used most water because they were the largest plants with highest dry matter production.

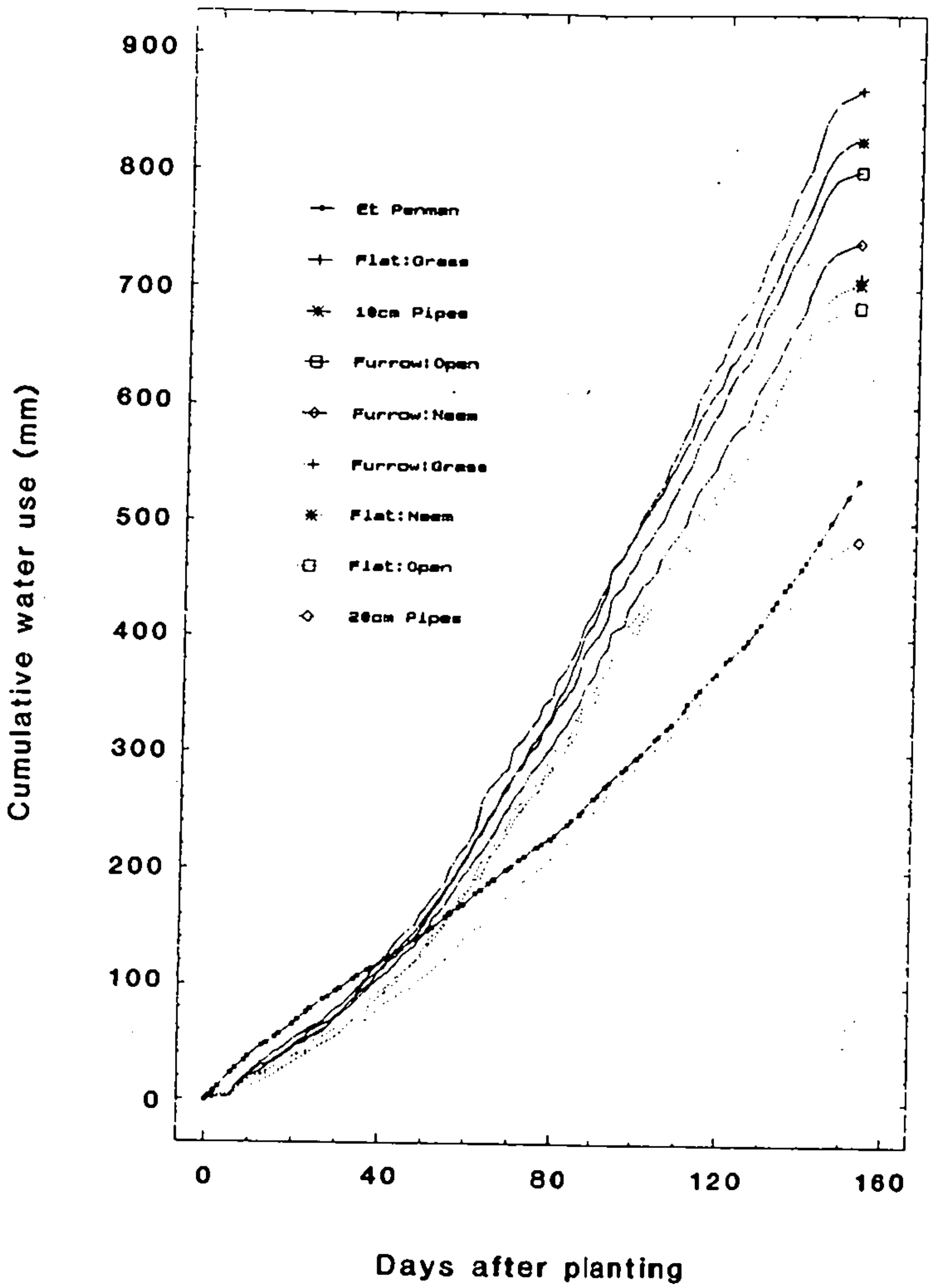


Figure 2.4.1 The pattern of water use measured for each treatment during the season

Table 2.4.2 Water use, average crop yields, and water use effectiveness (WUE)

Irrigation method	Surface cover	Water use (mm)	Stover (T/ha)	No. Tomatoes per ha	Av. Weight of tomato (g)	Yield (T/ha)	WUE (kg/m³/ha)
Flood flat	Grass	872.9	4.6797	952.876	127.01	121.02	13.86
Pipes 10 cm	Grass	829.0	3.2077	899.304	126.12	113.40	13.69
Flood furrow	Open	802.9	3.9694	947.872	109.21	103.93	12.94
Flood furrow	Neem	740.7	2.8897	929.305	115.87	107.69	14.54
Flood furrow	Grass	706.7	3.4701	890.494	108.75	96.72	13.69
Flood flat	Neem	706.6	3.4776	919.066	113.05	103.04	14.58
Flood flat	Open	686.3	3.1922	844.303	111.12	93.54	13.63
Pipes 20 cm	Open	486.3	2.1624	632.870	95.48	60.20	12.38
LSD (p=0.05)			0.8206	8.708	12.94	12.48	NS

LSD = least significant difference
WUE (Bos, 1985) = crop yield produced (kg)/total water used (m^3)

Although direct savings in water were not achieved, highest water use efficiencies (kg of tomatoes per mm of water applied) were obtained using the two Neem mulches followed by the two grass mulches, demonstrating again the value of this simple management practice for improving water use efficiency in garden irrigation. The highest crop yields (121 tonnes/ha and 113 tonnes/ha), achieved using grass mulch and shallow subsurface pipes, are amongst the highest yields ever recorded at the Lowveld Research Station.

Table 2.4.3 shows that landforming had no significant effect on dry matter production, yield or water use effectiveness. The presence or absence of mulch did not significantly affect yield or water use effectiveness, but did significantly affect dry matter production, grass mulch being superior to Neem mulch in this respect.

The first harvest of fruit was made at day 84, the fifteenth and final harvest at day 153. Figure 2.4.2 indicates that patterns of fruit production were very similar on all treatments, except for subsurface pipes placed at 20 cm depth. Plants on this treatment failed to produce the flush of fruit at about day 120 experienced on all other treatments, and in fact began to senesce at about this time.

Table 2.4.3 The effect of growing tomatoes on flat beds and in furrows with three surface management practices on stover production, yield, and water use effectiveness (WUE)

	Stover (t/ha)	Yield (T/ha)	WUE (kg/m^3/ha)
Flat Bed	3.783	105.9	14.0
Furrow	3.443	102.8	13.7
LSD (p=0.005)	NS	NS	NS
No mulch	3.581	98.7	13.3
Grass mulch	4.075	109.9	13.8
Neem mulch	3.184	105.4	14.6
LSD (p=0.005)	0.673 (p=0.005)	NS	NS

The incidence of pests and diseases on those treatments with no mulch, grass mulch and Neem mulch

Tomatoes are commonly grown in the Lowveld, but are particularly susceptible to attack by pests and diseases of both the fruit and the leaves. Leaves of the Neem tree (*Azadirachta indica*) are reputed to discourage insect pests and may be used as a mulch to control soil pests (Barrow, 1987). Weekly scouting was used during experiment 91/1 to measure the incidence of pests and diseases on those treatments with no mulch, grass mulch and Neem mulch.

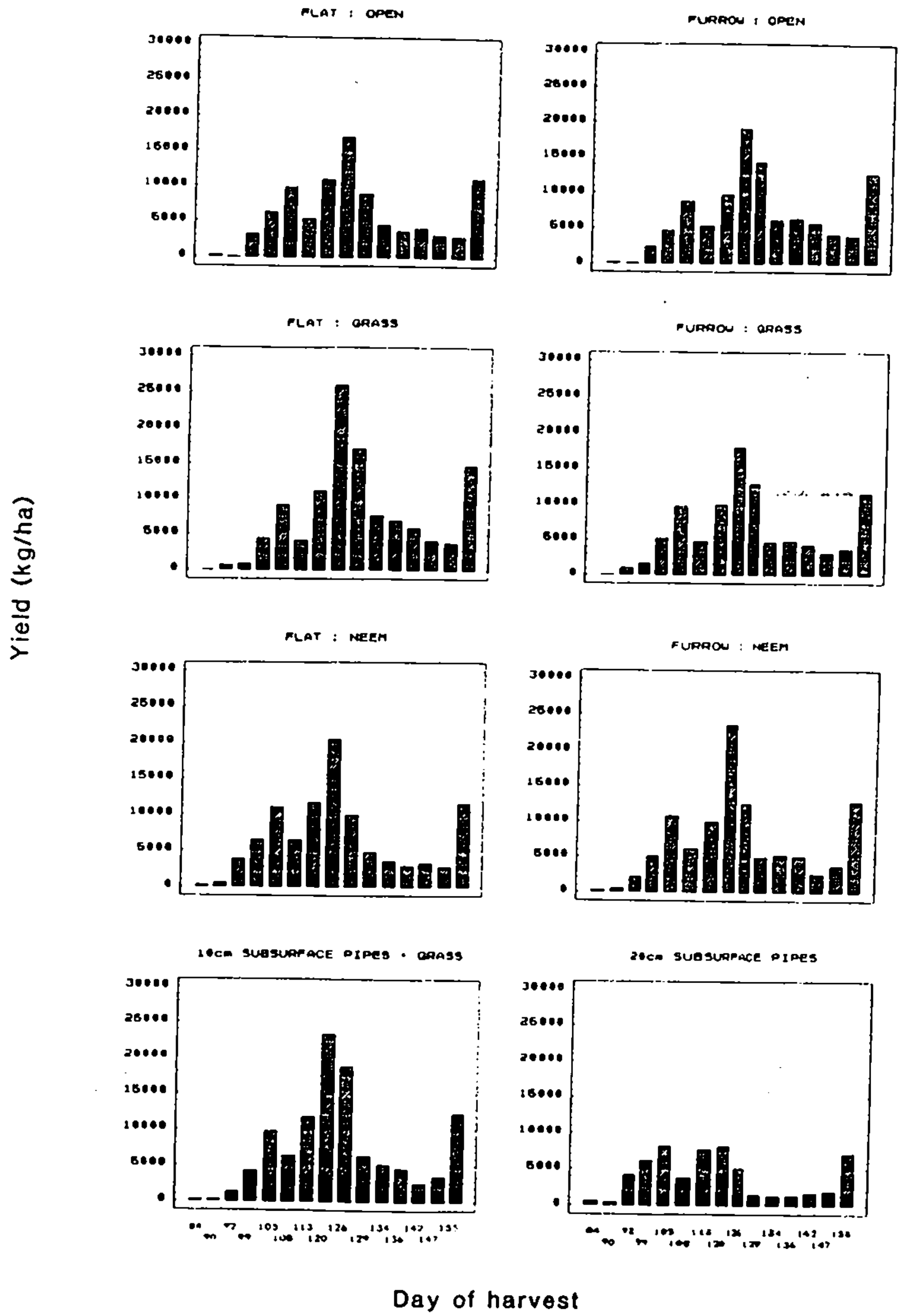


Figure 2.4.2 The temporal pattern of tomato production for each treatment of Expt 91/1

Table 2.4.4 The incidence of leaf disease, fruit disease and whitefly on treatments and replicates of Experiment 91/1

Treatment		Leaf Disease (score)	Fruit Disease (score)	Whitefly (score)
Flood furrow	Neem	28.75	11.50	70.75
Flood flat	Neem	33.25	12.00	65.75
Flood furrow	Grass	37.00	14.25	68.25
Flood flat	Grass	36.00	14.25	68.00
Pipes 10 cm	Grass	40.00	15.41	76.00
Flood furrow	Open	28.25	11.25	70.25
Flood flat	Open	28.75	11.00	74.75
Pipes 20 cm	Open	35.25	13.58	74.75
LSD (p=0.005)		8.34	NS	NS
Neem		31.00	11.75	64.88
Grass mulch		36.50	14.25	69.63
No mulch		28.50	10.13	67.50
LSD (p=0.005)		7.86	NS	NS
Furrow		31.33	12.33	75.08
Flat		32.67	11.75	72.92
LSD (p=0.005)		NS	NS	NS

Replicate	Leaf Disease (score)
1	30.17
2	36.00
3	25.17
4	36.67
LSD(p=0.005)	6.52

Table 2.4.4 shows no significant difference in the incidence of whitefly between either treatments or replicates, whitefly moving freely around the experimental plot to affect all areas equally. However, a highly significant difference was measured in the incidence of leaf disease between replicates, showing that some areas within the experimental plot were affected more than others; leaf disease was significantly lower on plants of replicate three, which produced the strongest plants with highest dry matter production. Leaf disease was significantly higher on those plants with grass mulch, suggesting that either the grass mulch was carrying the disease or that wind borne spore germinated freely in the moist environment preserved beneath it. Differences in the incidence of leaf disease between plants with Neem mulch and with no mulch were not significant. There were no significant differences in the incidence of fruit disease between either treatments or replicates, suggesting that fruit occurring higher on the plant are less susceptible to disease caused by a moist environment. Finally, there was no significant effect of landform on the incidence of either pests or diseases.

2.4.4 Discussion and conclusions

High yields and improved water use efficiency achieved using surface mulches of both Neem and grass confirm the value of this simple management practice for garden irrigation. No significant differences were measured between flat beds or furrows, although furrows may be preferable during the wet season to prevent loss of water as runoff.

The water use efficiency of subsurface pipes placed at 10 cm depth was also very high, fifth behind the Neem and grass mulches mentioned, and would perhaps have been even higher had water not been applied strictly on demand. Plants on this treatment flourished. Consequently, to satisfy measured demand, more water was applied to this treatment than was applied to the traditional flat open bed.

The amount of irrigation to be applied can be determined either by measurement of soil water or rate of evaporation calculated using meteorological data and empirical crop factors (Doorenbos and Pruitt, 1977). The former approach was adopted because it allowed irrigation requirements to be calculated individually for treatments designed to differ in water use efficiency. Furthermore, uncertainties exist in the choice of appropriate crop factor when irrigation methods and management practices other than open flood are used.

A uniform application of water calculated to satisfy plants grown by open flood is shown to be incorrect for plants that are grown by other methods. The difference appears to depend on crop type. A uniform application, based on open flood, applied to the bean seedlings and mulch of experiment 90/1, would have been excessive because considerable water normally lost as soil evaporation was conserved by the mulch. A uniform application, if applied to the tomato plants and mulch of this experiment, would have been insufficient, particularly later in the season, because those plants grown with mulch flourished earlier in the season with the improved water use efficiency, and subsequently required more water than the smaller plants growing on open flood.

Consequently, it is suggested that, to obtain a true comparison of water use efficiency of different irrigation methods and management practices, it is necessary to first establish a correct irrigation schedule for the efficient method(s) of irrigation and particular crop (achieved by monitoring soil moisture depletion and applying water on demand), followed by a second experiment in which this schedule is applied to all treatments to be compared. In this way (in theory), plants grown using the efficient method of irrigation for which the schedule is designed will flourish, while plants grown using less efficient methods will experience shortage of water.

Water use efficiency was improved by the use of both neem leaves and native grasses as a mulch. The incidence of leaf disease was significantly higher on those plants grown with a grass mulch, but the benefits to yield and water use efficiency suggest that either mulch can still be recommended for garden irrigation.

2.5 EXPT 91/2 : BEAN WATER QUALITY TRIAL

2.5.1 Introduction

One factor that may hinder the widespread use of collector wells for irrigated gardens is the prevalence of saline groundwater in semi-arid areas. Localised saline groundwater occurs as a result of the low rainfall and high evaporation, which lead to relatively slow downward movement of water through the unsaturated zone. On basement rocks, salts resulting from weathering and mineralisation are often leached into confined aquifers. The exact location of these saline aquifers, or of good quality groundwater, is difficult to predict without exploratory drilling, but typically between half and three-quarters of all boreholes constructed in the drier parts of Zimbabwe are saline to some degree (Min. of Energy and Water Resources Development - Masvingo, pers.comm.). Appendix 2 of the Second Interim Report (Lovell *et al.*, 1990) confirms the variable nature of water quality in the Lowveld.

Saline groundwater can be used for irrigation given correct management. The key to this correct management is provision of a net movement of soil water and salts away from the crop root zone. ODA-funded research carried out by IH and LVRS in Zimbabwe has shown that subsurface irrigation using clay pipes can reduce upward diffusion of water and loss as soil evaporation, and has the potential to increase water use efficiency in garden irrigation.

A replicated trial was conducted to establish whether subsurface irrigation using clay-pipes can be used effectively with saline irrigation water, and whether the method maintains a higher irrigation efficiency than traditional flood irrigation when the water source is of low quality. The experiment was envisaged as a first part of a longer-term study of salt accumulation in small-scale irrigation.

2.5.2 Materials and methods

Experimental design

The experiment was a bean trial (*Phaseolus vulgaris* cv Natal Sugar) of four treatments with four replicates. The four treatments were :

Poor quality water : Flood (flat bed) grass mulch
Poor quality water : Subsurface pipes (10 cm depth) grass mulch
Good quality water : Flood (flat bed) grass mulch
Good quality water : Subsurface pipes (10 cm depth) grass mulch

The sixteen plots were arranged in a latin square design. Each plot comprised of four beds, each 3 m long by 1 m wide and surrounded by a low earth bund. Grass mulch was applied to all beds at a rate of 10 tonnes/ha in light of savings in water achieved by this method in previous experiments.

Subsurface clay pipes were placed along the centre line of beds. Twelve pipes were used per bed, simply laid end to end in a level trench then backfilled with soil. The pipes were made at the research station using a simple mould and fired in a shallow bark filled pit. Further details of pipe manufacture are given by Lovell *et al.* (1990). The pipes were of length 0.24 m, internal diameter 0.075 m and external diameter 0.115 m. They were placed with 0.1 m of soil above them.

The poor quality water used for the experiment was taken from the radially drilled shallow collector well constructed at the LVRS (Chilton *et al.*, 1990). This water is of 'high' salinity hazard (USDA, 1954), having an electrical conductivity typically of about 1 mS/cm. The good quality water used for the experiment was treated water taken from Lake Kyle and was largely free of salts. This water is of 'low' salinity hazard (USDA, 1954), having an electrical conductivity typically of about 0.2 mS/cm. Table 2.5.1 illustrates the chemical contrast between these two water sources. Table 2.5.2 indicates values of sodium-adsorption-ratio (SAR) and residual sodium carbonate (RSC) calculated for each, and Table 2.5.3 presents details of water quality measured during the period of experiment 91/2.

The interrelation of the two criteria electrical conductivity (EC) and sodium-adsorption-ratio (SAR) were evaluated as the first step in the interpretation of the irrigation water analysis.

Table 2.5.1 Chemical analyses of water taken from the LVRS collector well and of treated water taken from Lake Kyle (6/6/90) (taken from Chilton et al., 1990)

	EC (mS/cm)	Na	K	Ca	Mg	Alk. (HCO_3)	SO_4	Cl	NO_3-N	Si	Sr	Fe
C. Well	0.990	86	1.0	68.7	66.4	604	41.3	60.5	0.5	27.6	0.38	0.02
Kyle	0.078	6.6	2.3	5.5	2.7	41	3.0	4.5	0.08	6.7	0.04	0.37

* All figures in mg/l unless stated

Table 2.5.2 Values of sodium-adsorption ratio (SAR) and residual sodium carbonate (RSC) calculated for water taken from the LVRS collector well and of treated water taken from Lake Kyle

	SAR	RSC (meq/l)
C. Well	3.69	0.934
Kyle	1.20	0.172

* Calculated using equations presented by USDA (1954)

Table 2.5.3 Water qualities measured for the LVRS collector well and treated water taken from Lake Kyle during the period of experiment 91/2

Date	EC (mS/cm)		pH		Chloride (mg/l cl)		Hardness (mg/l $CaCo_3$)		Iron (mg/l)	
	C. Well	Kyle	C. Well	Kyle	C. Well	Kyle	C. Well	Kyle	C. Well	Kyle
30/5/91	1.060	0.204	8.0	8.0	120	20	420	60	0.1	0.1
21/6/91	1.050	0.149	8.0	8.0	100	20	460	60	0.1	0.1
05/7/91	1.040	0.140	8.0	8.0	80	20	420	60	0.1	0.1
19/7/91	0.896	0.193	8.0	8.0	80	20	340	60	0.1	0.1
01.8/91	1.030	0.180	7.0	8.0	80	20	420	60	0.1	0.1
15/8/91	1.040	0.193	7.0	8.0	80	20	420	60	0.1	0.1
29/8/91	1.020	0.209	8.0	8.0	80	20	420	60	0.1	0.1
12/9/91	1.010	0.180	8.0	8.0	80	20	420	60	0.1	0.1

* EC measured using an ELE conductivity meter (model 4070) pH, Cl, $CaCo_3$ and Fe estimated using an ELE Palintest Water kit

Using the procedure proposed by the US Salinity Laboratory (USDA, 1954), water from the LVRS collector well may be classified as C3-S1. This high salinity water (C3) "should not be used on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected". However, this water is low in sodium (S1) and "can be used for irrigation on almost all soils with little danger of the development of a sodium problem". The second source of water used in experiment 91/2, treated water taken from Lake Kyle, may be classified as C1-S1 and is low in both salinity and in sodium. It "can be used for irrigation with most crops on most soils with little danger that a salinity or a sodium problem will develop".

Instrumentation

One plot of each treatment was instrumented with a two-dimensional tensiometer array and two neutron probe access tubes. Each tensiometer array consisted of 12 mercury manometer tensiometers installed at three depths (0.1 m, 0.4 m and 0.7 m) and four positions across the 1 m wide bed (0.125 m and 0.375 m either side of the centre line). The two access tubes were installed to a depth of 1 m at spacings of 0.125 m and 0.375 m to one side of the centre line.

Irrigation

All treatments received the same amount of irrigation independent of water quality, based on crop water requirements calculated by multiplying potential evaporation (Penman, 1963) of the previous week by an appropriate crop factor taken from Doorenbos and Pruitt (1977). Irrigation to all treatments was applied once per week (Thursday) to allow a reasonable soil moisture deficit to accrue and to follow the traditional practice. Both neutron probe and tensiometers were read prior to each irrigation and again 24 hours later. Soil moisture depletion under each treatment was monitored using the neutron probe to check values of crop factor used and to avoid over or under irrigation. Average values of soil moisture content (mm) to a depth of 0.9 m were determined using data from both access tube positions under each treatment.

Measurement of soil salinity profiles

Twenty-four hours after alternate irrigations, accumulated soluble salts were measured in the soil profiles beneath each treatment. Soil samples were taken at the surface (0-2 cm) and by augering at depths 2-20 cm, 20-40 cm, 40-60 cm and 60-80 cm beneath crop rows on each treatment, and on a control area approximately 4 meters from the experimental area that had not received any irrigation water.

The soil samples were allowed to air dry and passed through a 2.0 mm sieve. Electrical conductivity (mS/cm) of a suspension of 1 part (20g) of soil in 5 parts of distilled water, stirred intermittently for 1 hour, was determined at 20°C using a Kent EIL conductivity meter (Model 5007). Replication of this technique was found to give a standard deviation typically of above 6% about the average. pH of a suspension of 1 part (20g) of soil in 5 parts of calcium chloride (0.01 M $CaCl_2$), stirred intermittently for 1 hour, was determined at 20°C using a Pye Unicam pH meter (Model 292).

Agronomy

Common bean, which is a salt sensitive crop, was sown on 30 May 1991 in two rows per bed. Row spacing and within row spacing were 0.3 m and 0.05 m respectively, giving a plant population of 185,000 plants/ha. 700 kg/ha of fertiliser in the form of Compound X (20N $10P_2O_5$ $5K_2O$) was incorporated by hoe at planting, and 40 mm of water was applied to the surface of all treatments to ensure germination. Dimethoate foliar spray was applied at 28 days and 36 days to combat aphids, chlorothalonil foliar spray at 28 days and at weekly intervals thereafter as a disease control, endosulphan foliar spray at weekly intervals from day 43 and fenvalerate foliar spray at day 102 to combat *Heliothis* pod borers. The beans were harvested dry on 23 September 1991.

Yield was determined for each treatment by summing the fresh weight of beans produced per bed; paths between beds were included in calculations of area. Dry matter production, number of pods per plant, number of seeds per pod and 1000 seed weight were also recorded at harvest.

2.5.3 Results and discussion

Weather during the crop season

The mean monthly meteorological data measured during the crop season is presented in Table 2.5.4. Maximum and minimum temperatures were generally above average for the area, as were the hours of sunshine recorded during the season. Rainfall in May was above average, but rainfall later in the season was below average.

Table 2.5.4 Mean monthly meteorological data

Month	TMAX °C	TMIN °C	TDRY °C am	TWET °C am	TDRY °C pm	TWET °C pm	WIND km/d	SUN hrs	RAIN mm	PAN mm	Et mm
May	27.4	12.4	17.3	14.9	26.5	17.1	41	8.2	23.5	3.2	3.1
June	25.3	10.1	14.6	12.5	24.4	16.1	49	7.9	3.3	2.9	2.6
July	25.8	9.0	14.1	11.4	24.9	15.3	52	9.0	0.0	3.5	3.0
August	27.9	11.1	13.3	13.1	17.4	16.7	73	9.2	1.2	4.6	3.9
September	31.4	16.5	21.0	17.1	30.4	19.7	95	8.5	0.0	6.0	5.2

- Pan = Average evaporation of two Class A open pans
- Et = Potential evaporation (Penman 1963)

Patterns of irrigation and water use

All treatments received the same amount of irrigation independent of water quality. Figure 2.5.1 shows the irrigation applied and the cumulative water use measured individually on each treatment. Water use, comprising of transpiration plus soil evaporation plus drainage, was calculated bi-weekly as the sum of irrigation plus rainfall (negligible in this experiment) plus net loss of moisture measured from the soil profile.

Water use was lower from subsurface clay-pipe irrigation than from traditional flood irrigation for both qualities of water. This was due in part to reduced soil evaporation from the former method, but also due in part to increased dry matter production on the flood irrigation treatments (see Table 2.5.5).

Crop water requirements were calculated by multiplying potential evaporation (Penman, 1963) of the previous week by an appropriate crop factor taken from Doorenbos and Pruitt (1977). This method was not entirely satisfactory. At about day 84, irrigation calculated in this manner became insufficient, and plants on all treatments exhibited signs of stress. This problem has been encountered before at LVRS. It reflects the sensitivity of the method to the values of crop factor chosen, and to the importance of residual moisture present in the soil profile prior to planting. Residual soil moisture in this experiment was low. Based on measures of soil moisture depletion monitored using the neutron probe, additional water was added at day 91 to compensate for the apparent under-irrigation.

Soil moisture distribution

The two-dimensional arrays of tensiometers were installed vertically across the crop rows to provide a comparison of soil moisture distribution under each treatment.

Figure 2.5.2 shows distributions of total negative potential (kPa) measured beneath each treatment 24 hours after the irrigation of 20 mm on day 35. At this time, the soil profiles beneath each treatment were at their wettest condition recorded, and it is reasonable to assume that the diagrams thus indicate approximate limits of wetting that occurred beneath each treatment during the experiment. The position of salt profiles, taken directly beneath crop rows at regular intervals during the season, are also shown.

The numerous distributions of soil moisture potential recorded for each treatment during the crop season were processed to give diagrams of soil moisture status using a method developed by Bell *et al.* (1990). The percentage of each soil profile maintained wetter than certain threshold values of matric potential is shown plotted against time in Figure 2.5.3. The threshold values correspond to critical values on the soil moisture release curve; moisture in the range 0 to -7.5 kPa is readily available to the crop, there is a decreasing amount of moisture available in the range -7.5 to -15 kPa, and virtually no moisture available when the soil is drier than -40 kPa.

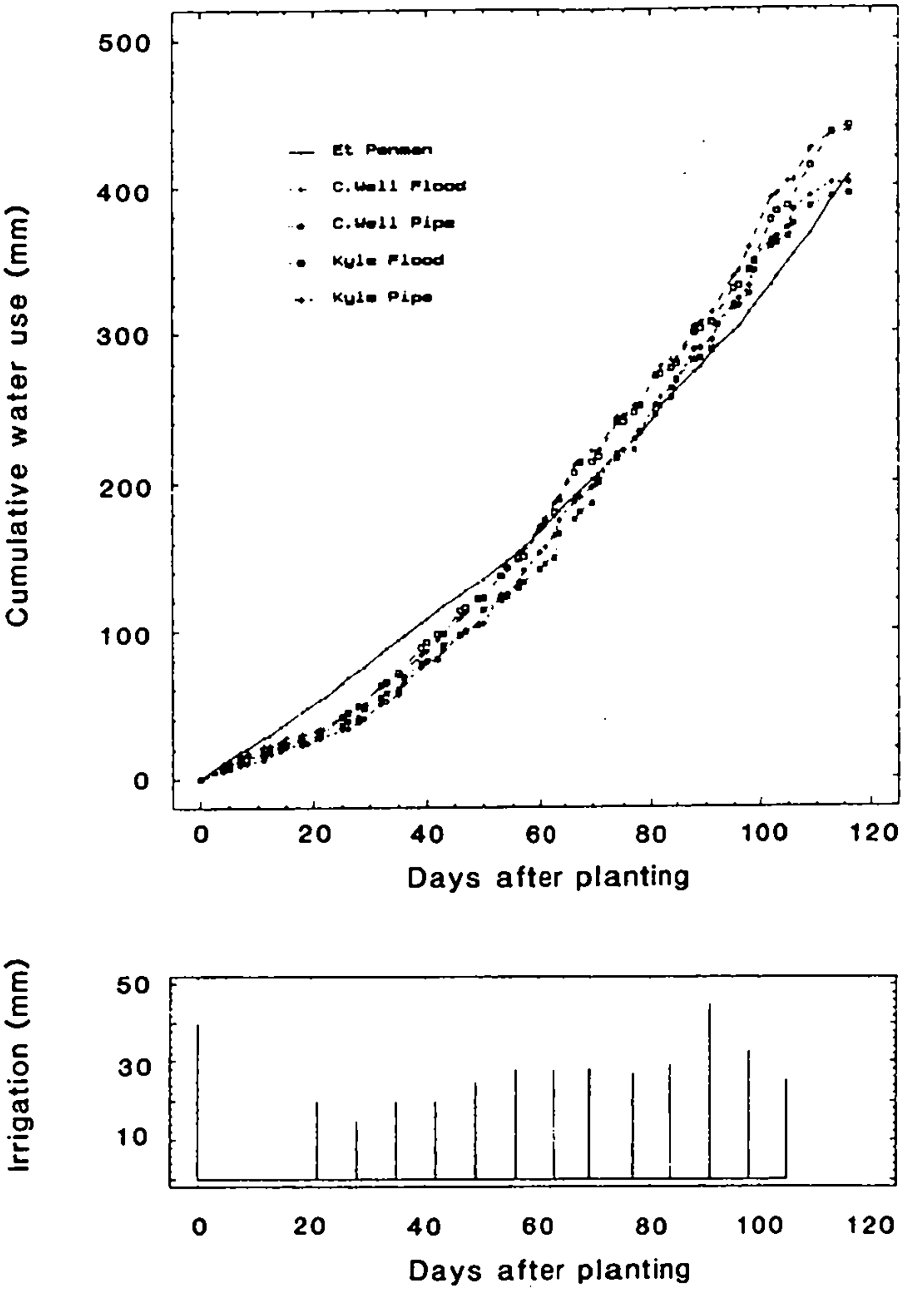


Figure 2.5.1 Irrigation applied and cumulative water use under different treatments

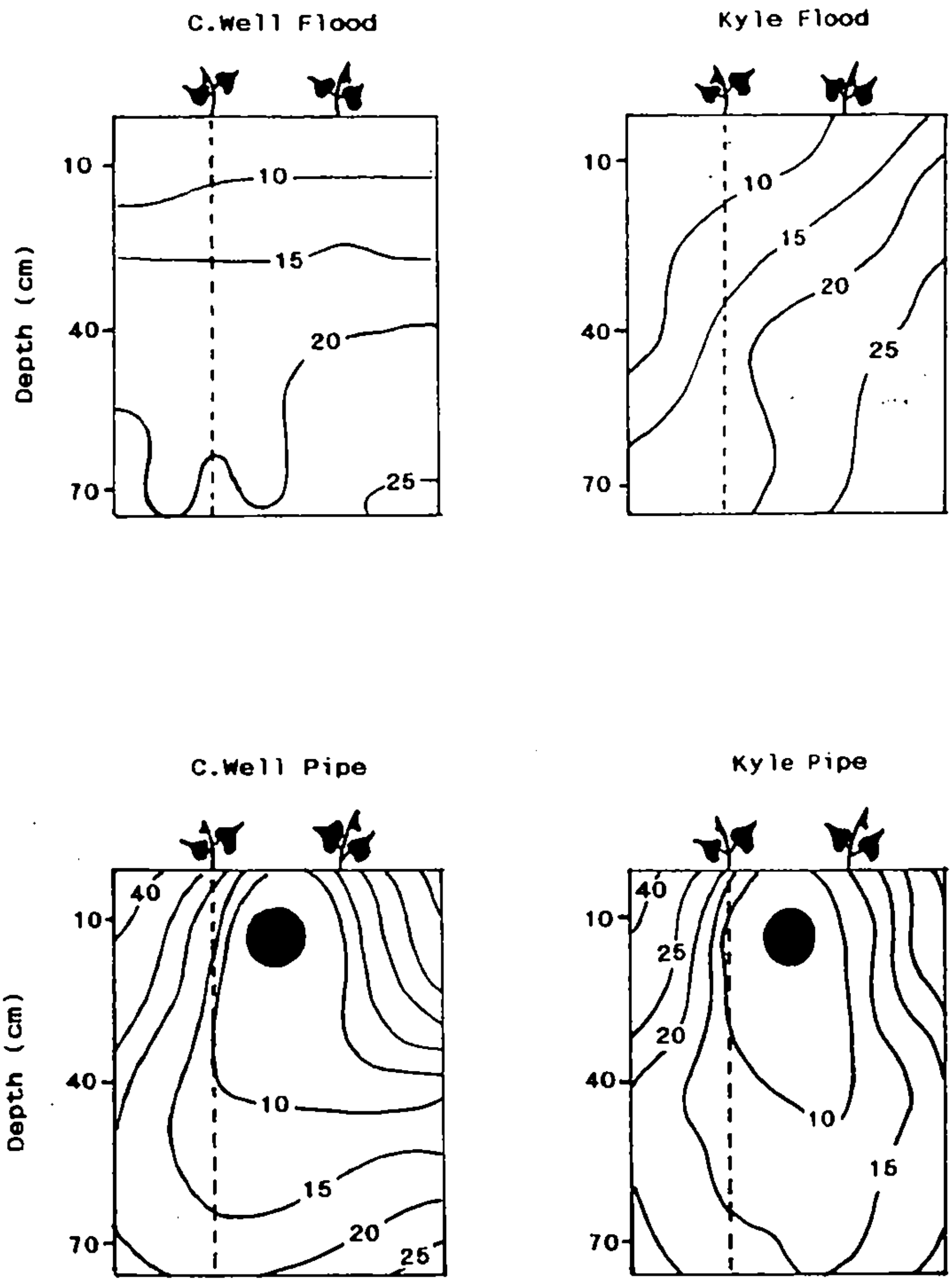


Figure 2.5.2 The distributions of total negative potential (kPa) measured beneath each treatment 24 hours after the irrigation of 20 mm on day 35

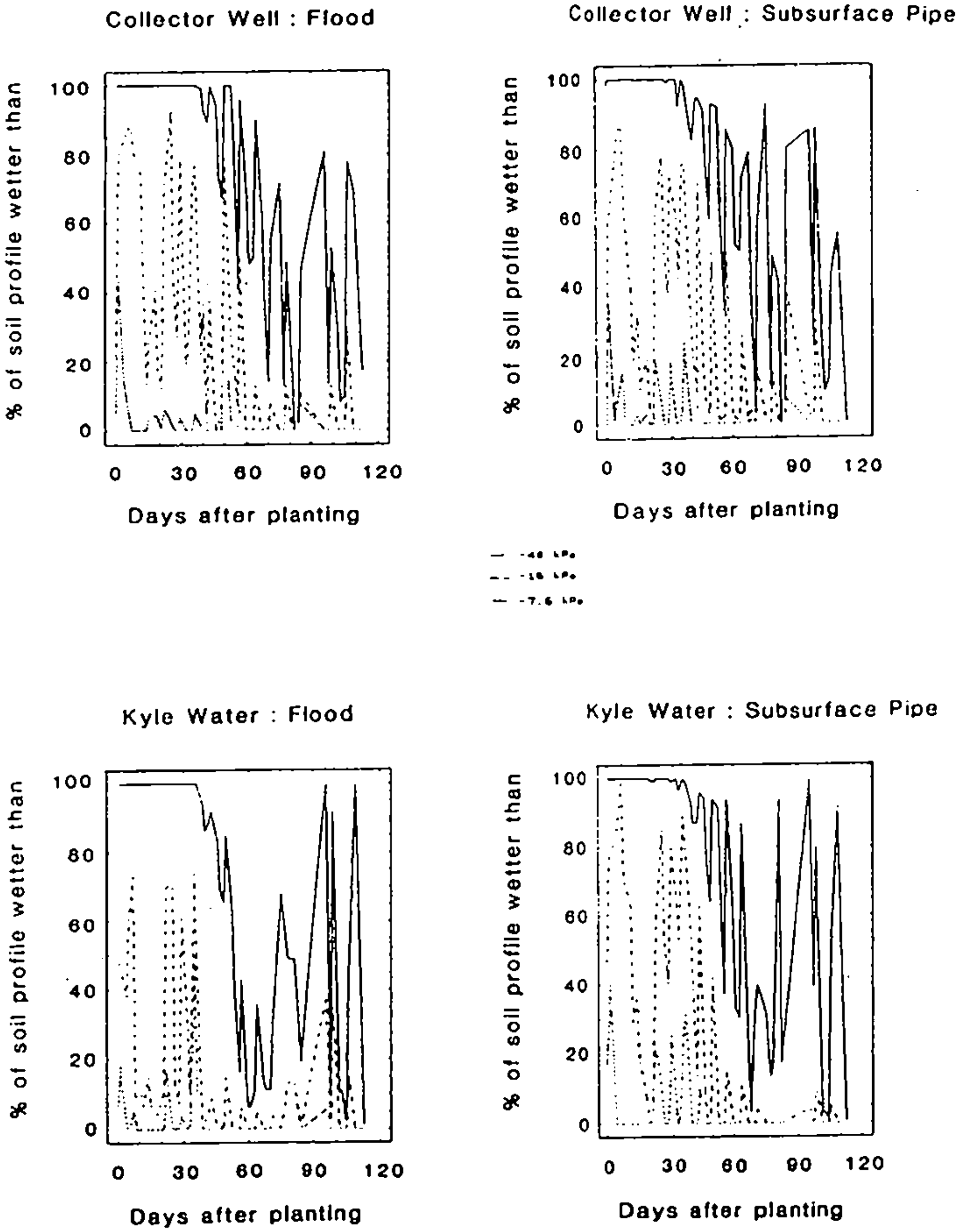


Figure 2.5.3 Fluctuating patterns of soil moisture status

The fluctuating patterns of soil moisture status shown in Figure 2.5.3 reflect regular application of irrigation. Although patterns of soil moisture status were similar under each treatment during the crop season, slightly wetter soil profiles prevailed beneath those treatments receiving saline irrigation water. This may be because plants grown on the higher salt content were able to abstract less water before suffering from water shortage (Wild, 1988), but may also reflect different rates of plant growth early in the season. If less water was abstracted due to salt content, this difference was not indicated by the final water use (Fig. 2.5.1) or high dry matter production (Table 2.5.5) of those plants grown by flood irrigation using saline water. Plants grown using saline water may in fact have suffered less during the period of under irrigation (days 70 to 80) because of the wetter soil profiles that prevailed prior to this period, but plant physiological measurements are again needed if such differences in plant growth rate and rate of photosynthesis are to be identified and their cause and relation to soil moisture status and salt content established.

Crop development, yield and water use effectiveness

At about day 36, those plants receiving saline irrigation water exhibited a slight tinge of blue compared to the deep green colour of plants receiving non-saline water, but generally no differences were visible between treatments other than that plants grown by flood irrigation appeared to be slightly larger than plants grown by subsurface pipe irrigation.

Table 2.5.5 Average crop yields, water use, and water use effectiveness (WUE)

Treatment	Stover kg/ha^2	Pods/plant	Seeds/pod	1000 Seed wt (kg)	Yield kg/ha	Water Use mm	WUE kg/m^3
C. Well Flood	1898.6	8.94	3.68	0.328	1260.0	437.4	0.288
Kyle Flood	1828.9	9.19	3.92	0.455	1300.4	440.9	0.295
C. Well Pipe	1799.9	9.06	3.70	0.361	1389.6	394.3	0.352
Kyle Pipe	1518.4	8.25	4.09	0.431	1279.2	402.1	0.318
LSD (p=0.05)	NS	NS	NS	NS	NS	-	0.051

* LSD = least significant difference
* WUE (Bos, 1985) = crop yield produced (kg) / total water used (m^3)

Table 2.5.5 confirms that stover production by flood irrigation tended to be higher than by subsurface pipe irrigation, but that the final differences were not significant. In fact, no significant effects on crop yield were measured for either water quality or irrigation method, but a significantly higher water use effectiveness was achieved by the use of subsurface pipe irrigation as opposed to traditional flood irrigation. Water use effectiveness is shown to be unaffected by water quality for flood irrigation, but to be significantly higher for subsurface pipe irrigation when saline water is used as opposed to non-saline water.

Patterns of salt accumulation

Figure 2.5.4 shows patterns of salt accumulation measured during the crop season in soil profiles taken beneath each treatment and beneath a control area that received neither irrigation nor rainfall during the experiment. For each treatment, samples were taken in a single profile directly beneath a crop row. At this position in the beds, salt accumulation at the soil surface (0-2 cm) diagonally above subsurface clay pipes is shown to be very high for both qualities of water applied, and to be significantly higher than when using either flood irrigation. Between 2-20 cm and 20-40 cm, accumulation of salt was not significant for either method of irrigation or quality of water, but at depths greater than 40 cm very large fluctuations in salt content were recorded under all treatments including the control.

Beans are a salt sensitive crop. Wild (1988) reports that crop yield will be reduced when electrical conductivity of the soil saturated extract exceeds 1 mS/cm, and halved when this value exceeds 3.6 mS/cm. The crop is intolerant of values exceeding 4 mS/cm.

Figure 2.5.4 shows that tolerable levels of salt content were far exceeded in the soil surface above subsurface clay pipes using both qualities of water, but at depths 2-40 cm salt content generally remained at or below 1 mS/cm under all treatments. In the field, salts are usually unevenly distributed in the soil, so that those roots growing in volumes of soil containing less salt than average will take up relatively more water than those roots growing in volumes containing more than average (Gardner, 1967). With this buffer, it is reasonable to assume that at the 'safe' values of salt content measured here beneath the soil surface, crop yields in this experiment were not reduced by salt content *per se*. However, to determine any longer-term threat posed by salt accumulation, it will be important to monitor the fate of those salts accumulated at the soil surface during the coming wet season and beyond.

The large fluctuations in salt content recorded at 60-80 cm and to a lesser extent at 40-60 cm are attributed to the recurring problem of spatial variability experienced in the measurement of many soil properties, and in particular, to the spatial variability of depth to weathered bedrock beneath this experimental site. Typically this depth to bedrock is about 0.8 m, but it does vary. It is suggested that those samples taken at depth exhibiting low EC corresponded to samples of true soil, whereas samples taken at depth exhibiting very much higher EC had penetrated weathered bedrock and hence included salts accumulated at this "barrier" during decades of leaching from the soil above.

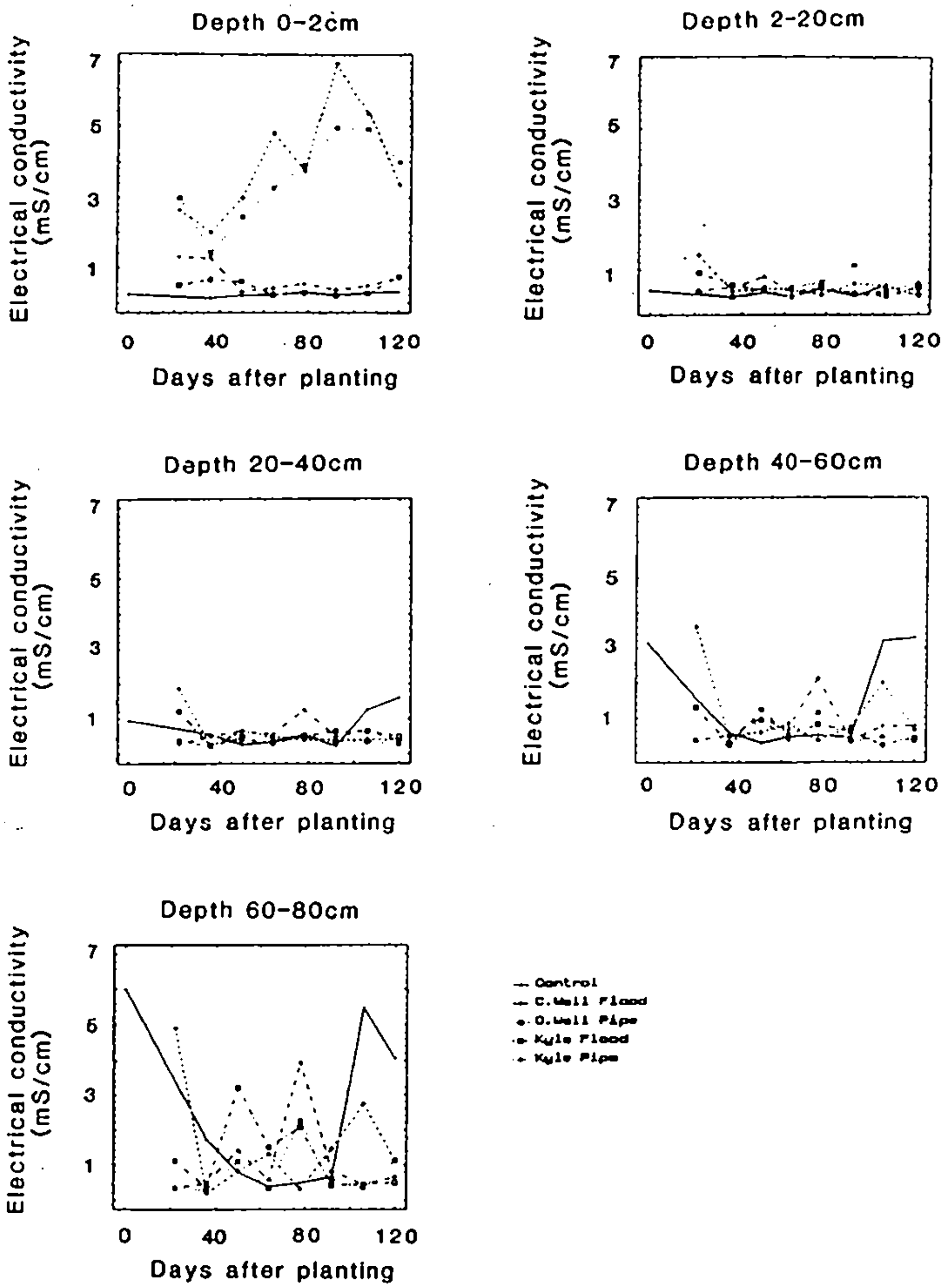


Figure 2.5.4 Patterns of salt accumulation measured during the cropping season in soil profiles taken beneath each treatment and beneath a control area that received neither irrigation nor rainfall

Salt content of the control area

Table 2.5.6 shows salt content calculated for the control area of Experiment 91/2, an area of approximately 4 m by 4 m of bare soil that received neither irrigation nor rainfall during the experiment, and which has never previously received irrigation water. Because no salts were added, the salt content beneath this area should have remained constant with time. The variability in salt content demonstrated at shallow depths confirms the problem of spatial variability, and the increasing variability with depth reflects the additional problem introduced by the presence of weathered bedrock beneath this site.

To reduce these effects of spatial variability, it is suggested that all control samples, and treatment samples where possible, be taken from single locations of more limited area (perhaps one square metre) in future experiments.

Salt balance of each treatment

Table 2.5.7 shows the mass of salt added to each treatment as irrigation water during the experiment, totals of 62.3 g/m^2 and 264.3 g/m^2 for treatments receiving Lake Kyle water and collector well water respectively. Table 2.5.8 shows salt balances calculated for each treatment at regular intervals during the experiment.

The marked fluctuations in salt content also measured beneath each treatment again makes detailed inspection of salt balance difficult. The measured fluctuations often far exceed any possible change due to the addition or build up of salts added as irrigation water, and peaks in salt content recorded after day 35 do not coincide with possible wetting fronts in the dry soil recorded at depth (Figs. 2.5.2 and 2.5.3). It is again reasonable to attribute these fluctuations primarily to spatial variability, but consideration of the average values of salt content measured during the season does also suggest that the method of sampling for salt at a single location beneath a crop row may be inadequate.

For convenience, Table 2.5.9 presents again the average values of salt content measured during the season beneath all treatments including the control, and shows that, in the upper soil profile, increases in salt content were dependent not on the salinity of water applied but instead on the method of irrigation. To a depth of 20 cm, an increase of about 100 g/m^2 was measured for both qualities of water applied as subsurface pipe irrigation compared to 23 g/m^2 applied as flood irrigation. Remembering that 264 g/m^2 of salt were applied as collector well water and 62 g/m^2 as Kyle water, to both methods of irrigation, this result suggests that redistribution of salts already present in the upper soil profile is important, additional salts may be released during the experiment, and that the method of sampling at a single location beneath a crop row is insufficient to give a complete picture of salt movement and accumulation beneath these irrigation methods.

Table 2.5.6 Salt balance measured beneath the control area during Experiment 91/2

Depth (cm)		Days after planting 0	36	50	64	78	92	106	Av. (g/m²)	s.d. (g/m²)
0-2	EC	0.045	0.024	0.036	0.040	0.060	0.044	0.056		
	Wt	10.85	8.89	10.01	10.39	12.26	10.76	11.89	10.72	1.14
2-20	EC	0.080	0.044	0.066	0.044	0.090	0.048	0.110		
	Wt	128.06	97.50	116.18	97.50	136.55	99.19	153.54		
0-20	Wt	138.92	106.38	126.19	107.88	148.81	109.95	165.42	129.1	22.8
20-40	EC	0.190	0.110	0.050	0.070	0.110	0.040	0.250		
	Wt	246.07	1270.60	113.99	132.86	170.60	104.55	302.68		
0-40	Wt	384.99	276.98	240.17	240.74	319.41	214.51	468.10	306.4	91.6
40-60	EC	0.630	0.110	0.055	0.090	0.100	0.086	0.640		
	Wt	652.31	168.31	117.11	149.69	159.0	145.97	661.62		
0-60	Wt	1037.30	445.28	357.29	390.43	478.40	360.47	1129.72	599.8	334.1
60-80	EC	1.00	0.340	0.160	0.075	0.098	0.130	1.100		
	Wt	1231.14	397.99	223.61	141.27	163.55	202.30	1134.26		
0-80	Wt	2268.43	843.27	580.90	531.69	641:95	562.77	2263.97	1099.0	803.4

* EC = electrical conductivity (mS/cm) of 20 g soil: 100 ml distilled water
Wt = mass of salt (g/m²) = (Ms/20) x (ppm/10)
where M_s = mass of soil (g) in part profile
= volume x bulk density (DRSS, 1969)
and ppm = 44.843 + (633.184 x EC) (Hagan *et al.*, 1967)

Table 2.5.7 Salt added as irrigation water during Experiment 91/2

Days after planting	Irrigation (mm)	Salt added (g/m²) C. Well	Total	Kyle	Total
0	40	28.64	28.64	6.96	6.96
21	20	14.19	42.83	2.78	9.74
28	15	10.65	53.48	2.09	11.83
35	20	14.07	67.55	2.67	14.50
42	20	14.07	81.62	2.67	17.17
49	25	15.31	96.93	4.18	21.35
56	28	17.14	114.07	4.68	26.03
63	28	19.52	133.59	4.45	30.48
70	28	19.52	153.11	4.45	34.93
77	27	18.99	172.10	4.51	39.44
84	30	20.96	193.06	4.98	44.42
91	45	31.08	224.14	7.97	52.39
98	33	22.79	246.93	5.85	58.24
105	25	17.38	264.31	4.03	62.27

* Mass of salt (g/m²) = (ppm x litres of water / 1000)
where ppm = 44.843 + (633.184 x EC) (Hagan *et al.*, 1967)
and EC is as given in Table 2.5.3.

Table 2.5.8 ***Salt balance measured beneath each treatment during Experiment 91/2***

Depth (cm)		22	36	50	64	78	92	106	120	Av. (g/m²)	s.d. (g/m²)
C. Well Flood											
0-2	EC	0.260	0.250	0.060	0.082	0.105	0.074	0.095	0.140		
	Wt	31.00	30.06	12.26	14.32	16.48	13.57	15.54	19.76	19.1	7.37
2-20	EC	0.080	0.100	0.160	0.070	0.090	0.070	0.070	0.060		
	Wt	128.1	145.0	196.0	119.6	136.6	119.6	119.6	111.1		
0-20	Wt	159.1	175.1	208.3	133.9	153.1	133.2	135.1	130.8	153.6	27.2
20-40	EC	0.054	0.100	0.135	0.110	0.250	0.100	0.135	0.073		
	Wt	117.8	161.2	194.2	170.6	302.7	161.2	194.2	135.7		
0-40	Wt	276.9	336.3	402.5	304.5	455.8	294.4	329.3	266.6	333.3	65.3
40-60	EC	0.066	0.100	0.200	0.130	0.425	0.070	0.150	0.150		
	Wt	127.4	159.0	252.1	187.0	461.5	131.1	205.5	205.5		
0-60	Wt	404.3	495.3	654.6	491.5	917.3	425.5	534.8	472.1	549.4	167.0
60-80	EC	0.072	0.096	0.280	0.115	0.790	0.165	0.090	0.130		
	Wt	138.4	161.6	339.9	180.0	833.9	228.5	155.8	194.6		
0-80	Wt	542.7	656.9	994.5	671.5	1751.2	654.0	690.6	666.7	828.5	394.4

Depth (cm)		22	36	50	64	78	92	106	120	Av. (g/m²)	s.d. (g/m²)
C. Well Pipe											
0-2	EC	0.600	0.280	0.490	0.650	0.780	0.990	0.980	0.800		
	Wt	62.86	32.88	52.56	67.55	79.73	99.41	98.47	81.61	71.9	22.7
2-20	EC	0.078	0.042	0.100	0.100	0.125	0.225	0.080	0.120		
	Wt	126.4	95.8	145.0	145.0	166.3	251.2	128.1	162.0		
0-20	Wt	189.3	128.7	197.6	212.6	246.0	350.6	226.6	243.6	224.4	63.3
20-40	EC	0.075	0.043	0.098	0.095	0.105	0.070	0.069	0.051		
	Wt	137.6	107.4	159.3	156.4	165.9	132.9	131.9	114.9		
0-40	Wt	326.9	236.1	359.9	369.0	411.9	483.5	358.5	358.5	362.7	70.0
40-60	EC	0.072	0.041	0.185	0.071	0.230	0.60	0.090	0.064		
	Wt	132.9	104.1	238.1	132.0	280.0	121.8	149.7	125.5		
0-60	Wt	459.8	340.2	595.0	501.0	691.9	605.3	508.2	484.0	523.2	107.3
60-80	EC	0.06913	0.057	0.220	0.065	0.450	0.120	0.070	0.220		
	Wt	5.5	123.8	281.7	131.6	504.6	184.9	136.4	281.7		
0-80	Wt	595.3	464.0	876.7	632.6	1196.5	790.2	644.6	765.7	745.7	222.9

* EC and Wt calculated as per Table 2.5.6.

Table 2.5.8 (continued)

Depth (cm)		22	36	50	64	78	92	106	120	Av. (g/m^2)	s.d. (g/m^2)
Kyle Flood											
0-2	EC	0.100	0.130	0.120	0.044	0.057	0.036	0.050	0.145		
	Wt	16.01	18.82	17.88	10.76	11.98	10.01	11.32	20.22	14.63	4.07
2-20	EC	0.180	0.110	0.081	0.042	0.097	0.060	0.045	0.100		
	Wt	213.0	153.5	128.9	95.8	142.5	111.1	98.3	145.0		
0-20	Wt	229.0	172.3	146.8	106.6	154.5	121.1	109.6	165.2	150.6	40.2
20-40	EC	0.240	0.048	0.086	0.061	0.100	0.130	0.130	0.098		
	Wt	293.2	112.1	148.0	124.4	161.2	189.5	189.5	159.3		
0-40	Wt	522.2	284.4	294.8	231.0	315.7	310.6	299.1	324.5	322.8	85.5
40-60	EC	0.260	0.048	0.245	0.097	0.160	0.120	0.043	0.080		
	Wt	307.9	110.6	294.0	156.2	214.8	177.6	105.9	140.4		
0-60	Wt	830.1	395.0	588.8	387.2	530.5	488.2	405.0	464.9	511.2	146.7
60-80	EC	0.220	0.074	0.640	0.300	0.410	0.079	0.090	0.100		
	Wt	281.7	140.3	688.6	359.2	465.8	145.1	155.8	165.5		
0-80	Wt	1111.8	535.3	1277.4	746.4	996.3	633.3	560.8	630.4	811.5	280.0

Depth (cm)		22	36	50	64	78	92	106	120	2Av. (g/m^2)	s.d. (g/m^2)
Kyle Pipe											
0-2	EC	0.530	0.400	0.600	0.960	0.750	1.400	1.100	0.670		
	Wt	56.3	44.1	62.9	96.6	76.9	137.8	109.7	69.4	81.7	31.1
2-20	EC	0.280	0.080	0.090	0.080	0.060	0.120	0.110	0.050		
	Wt	297.9	128.1	136.6	128.1	111.1	162.0	153.5	102.6		
0-20	Wt	354.2	172.2	199.5	224.7	188.0	299.8	263.2	172.0	234.2	66.3
20-40	EC	0.370	0.048	0.130	0.100	0.078	0.080	0.080	0.075		
	Wt	415.9	112.1	189.5	161.2	140.4	142.3	142.3	137.6		
0-40	Wt	770.1	284.3	389.0	385.9	328.4	442.1	405.5	309.6	414.4	153.3
40-60	EC	0.720	0.090	0.115	0.170	0.068	0.145	0.400	0.130		
	Wt	736.1	149.7	173.0	224.2	129.2	200.9	438.2	186.9		
0-60	Wt	1506.2	434.0	562.0	610.1	457.6	643.0	843.7	496.5	694.1	352.6
60-80	EC	0.980	0.037	0.165	0.260	0.062	0.290	0.545	0.230		
	Wt	1018.0	104.5	228.5	320.5	128.7	349.6	596.6	291.4		
0-80	Wt	2524.2	538.5	790.5	930.6	586.3	992.6	1440.3	787.9	1073.9	649.7

* EC and Wt calculated as per Table 2.5.6.

Table 2.5.9 ***Average values of salt content (g/m^2) measured beneath each treatment during the season compared with the control area***

	Control	C. Well Flood	C. Well Pipe	Kyle Flood	Kyle Pipe
0-2 cm	10.7	19.1 (+8.4)	71.9 (+61.2)	14.6 (+3.9)	81.7 (+71.0)
0-20 cm	129.1	153.6 (+24.5)	224.4 (+95.3)	150.6 (+21.5)	234.2 (+105.1)
0-40 cm	306.4	333.3 (+26.9)	362.7 (+56.3)	322.8 (+16.4)	414.4 (+108.0)
0-60 cm	599.8	549.4 (-50.4)	523.2 (-76.6)	511.2 (-88.6)	694.1 (+94.3)
0-80 cm	1099.0	828.5 (-270.5)	745.7 (-344.3)	811.5 (-287.5)	1073.9 (-25.1)

* Values in brackets indicate change in salt content (g/m^2) compared to control

2.5.4 Conclusions

Although problems of spatial variability and inadequacies in experimental technique have been highlighted, several important conclusions may still be drawn from this first study of water quality in small-scale irrigation, and recommendations put forward for future experiments.

Subsurface clay-pipe irrigation, a method previously found to be efficient in experiments conducted using poor quality water, maintained a significantly higher irrigation efficiency than traditional flood irrigation when used in comparison with a good quality water. Hence, at this stage, it appears that the method can be used effectively with poor quality, saline water. Salts were concentrated in the surface layer, allowing the crop to grow normally. No significant effects of water quality on crop yield were measured, but long term studies of the effect of salt accumulation on crop yield and the fate of accumulated salts during rainy seasons are now needed.

Very high levels of salt accumulation occurred in the soil surface (0-2 cm) above the clay pipes independent of water quality applied. Upward movement of salts and loss of water as soil evaporation thus continued to some degree despite placing the irrigation pipes at 10 cm depth beneath a grass mulch. The quantity of salts accumulated, similar for both qualities of water, was such that re-distribution and perhaps release of salts already present in the soil profile must have contributed at least in part. That salt was redistributed and left at the soil surface above the clay pipes may be beneficial to crop production if, in the long term, salt content in the root zone (2-40 cm) is maintained at safe levels. Salt content in the root zone was maintained at safe levels under all treatments during this first experiment. However, rainfall will tend to wash salts into the root zone.

Salts are usually unevenly distributed in the soil. Problems of spatial variability experienced here in the measurement of salt content, combined with variability in depth to bedrock, precluded detailed comparisons of salt balance beneath each treatment. Measured changes in salt content during the season often exceeded possible changes due to the addition of salts as irrigation water. Particularly large fluctuations in salt content were measured at depths corresponding to the onset of weathered bedrock, at which level salts appear to have accumulated during decades of leaching from the soil above.

A more complete picture of salt movement and accumulation may be achieved by taking samples in a two-dimensional array beneath each treatment, as opposed to the single profiles taken to date. Sampling at regular intervals during Experiment 91/2 appeared to be of little value, due to spatial variability of measurements. Hence, in future experiments, it is suggested that two-dimensional arrays of samples be taken, beneath each treatment and beneath a control of limited area, and that these arrays be replicated three times, before and after the experiment only. A control sample of known salinity should also be analysed on each occasion that electrical conductivity is determined, as a final check on laboratory procedure and instruments.

2.6 EXPT 91/3: CAPACITANCE PROBE EVAPORATION STUDIES

2.6.1 Introduction

Soil evaporation is an important component of the soil water balance in cropping systems in semi-arid areas (Monteith, 1991; Lovell, 1991) and reduction in soil evaporation will generally result in additional water being available for meeting crop water requirements. Soil evaporation has been quantified successfully using mini-lysimeters in a number of research studies (e.g. Pelton, 1961; Allen ,1990; Wallace *et al.* 1991). The procedure for using mini-lysimeters, albeit time-consuming, is simple. However, mini-lysimeters have disadvantages that include the need to be refilled after every irrigation or every rainfall event and, in common with all lysimeters, they introduce into the soil profile a barrier to drainage, capillary rise and crop abstraction. Other disadvantages include the problem that filling of lysimeters can crack the soil surface in some soil types leading to overestimation of soil evaporation and, as filling mini-lysimeters is time-consuming, it is difficult to obtain sufficient data to obtain a measure of either systematic or random spatial variability of soil evaporation.

The aim of the experiment reported here was to evaluate a capacitance probe as an alternative, or an ancillary, to mini-lysimeters in measurements of soil evaporation. Capacitance probes measure the dielectric constant of the soil and hence its water content. The version of the capacitance probe used in this study was a prototype manufactured by the Instrument Section of the Institute of Hydrology. It has two parallel metal rods, 5 or 10 cms in length, that can be inserted rapidly and easily into the soil surface. Once the rods have been inserted into the soil a reading can be taken immediately. This reading, which is the frequency of an electric oscillator in the probe, can be related to soil water content via a calibration curve that is obtained by taking gravimetric samples. The general theory of the capacitance probe has been described by Dean *et al.* (1987) and the design of this prototype is described by Dean (in prep.).

A field study using the capacitance probe to measure near surface soil water content has been reported by Robinson and Dean (1991). It should be noted that standard methods of measuring soil water content such as the neutron probe and time domain reflectometry (TDR) are not ideal for measuring near surface soil water content. The zone of influence of neutron probes is such that neutrons are lost into the atmosphere when the probe is operated near the soil surface. In the case of TDR, the minimum length of rods is around 15 cms which means that TDR rods have to be inserted horizontally if fine resolution of soil water content of the near surface is required.

2.6.2 Materials and methods

Capacitance probe calibration

The capacitance probe was calibrated for two prong lengths: 5 cms and 10 cms. Probe measurements were made and gravimetric samples taken on an area of bare soil that had been irrigated during a two week period. Data for a range of soil water contents was obtained as the soil dried. Care was taken to ensure that gravimetric samples were taken at the exact location that each probe measurement was made. These samples were weighed and then oven dried overnight at 105 deg C. The samples were then reweighed and the water content/soil volume or moisture volume fraction calculated.

Soil evaporation experiment

Two areas (1 m x 3 m) of bare soil were flooded with approximately 50 mm of irrigation. Capacitance probe measurements were made at 5 cm and 10 cms depths on both these areas four times each day (0800, 1100, 1400 and 1700) over a period of seven days. On one area soil evaporation and drainage were taking place from the soil layers measured by the capacitance probe. On the other area a large board (1 m x 1 m) painted white was used to cover the soil during the period between probe measurements thereby preventing soil evaporation.

Located within one of these areas was a large weighing lysimeter set on load cells (Sensotec Model 41/571-06) which were logged (Campbell Scientific Model CR10) at hourly intervals throughout the seven-day experiment. The lysimeter was an undisturbed soil monolith installed within a 200l oil drum. The method used to construct the lysimeter has been described by Lovell (1991). Located within the same area as the lysimeter were two neutron probe access tubes. Neutron probe measurements were made at 10 cm intervals down these access tubes to the same schedule as the capacitance probe measurements.

Meteorological data were logged at hourly intervals by an automatic weather station (Didcot Instruments Ltd, UK) that was located adjacent to the experimental site.

2.6.3 Results and discussion

Calibration

Figure 2.6.1 presents the calibration curves obtained for the 5 cm and 10 cm prong lengths. The curves were fitted by simple regression.

Weather during experiment

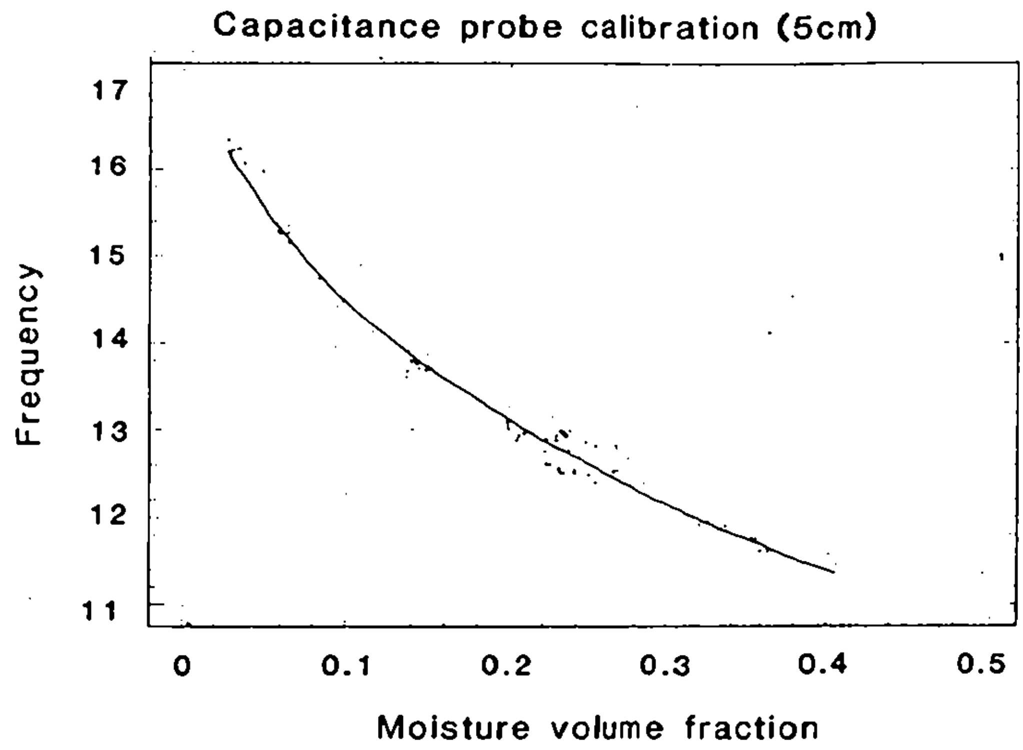
Figure 2.6.2 shows that the diurnal pattern of potential evaporation was very uniform during the period which was characterised by a complete lack of cloud cover.

Soil Evaporation

As there was no drainage from the base of the weighing lysimeter, any weight loss can be assumed to have been caused by soil evaporation. Figure 2.6.3 compares cumulative evaporation measured by the weighing lysimeter with cumulative potential evaporation calculated by the Penman (1963) equation. Soil evaporation measured by the lysimeter exceeded Penman potential evaporation during the first 80 hours after irrigation even though an albedo appropriate for bare soil was used in the Penman equation. It is possible that this difference was caused by advective energy enhancing soil evaporation on these small plots and not taken account of by the method of estimating potential evaporation. Measured soil evaporation started to fall below potential evaporation from approximately 100 hours after irrigation as the soil dried and surface resistance increased.

Figure 2.6.4. compares cumulative evaporation measured by the weighing lysimeter with cumulative water loss or reduction in water content in the near surface layer measured by the capacitance probe. As the probe data are from the uncovered plot, they include a measure of drainage and soil evaporation. It can be seen that the capacitance probe measurements to a depth of the 5 cm agree well with the lysimeter for the first 30 hours after irrigation. After 30 hours, the 5 cm capacitance probe measurements fall below the lysimeter measurements as the 5 cm layer dried completely and as progressively more water was lost to soil evaporation from deeper layers. The results suggest that there was minimal drainage from this layer. This may have been due to the fact that drainage from this layer could only commence once water had drained from deeper layers. As the wetting front of a 50 mm irrigation was some distance from the surface 5 cm, the soil in the 5 cm layer could have dried to below "field capacity" by the time that drainage could take place. This might not have been the case if the irrigation (or a rainfall event) had been less than 50 mm.

In contrast with the 5 cm layer, water loss measured by the capacitance probe to a depth of 10 cm was greater than water loss measured by the lysimeter for the first 30



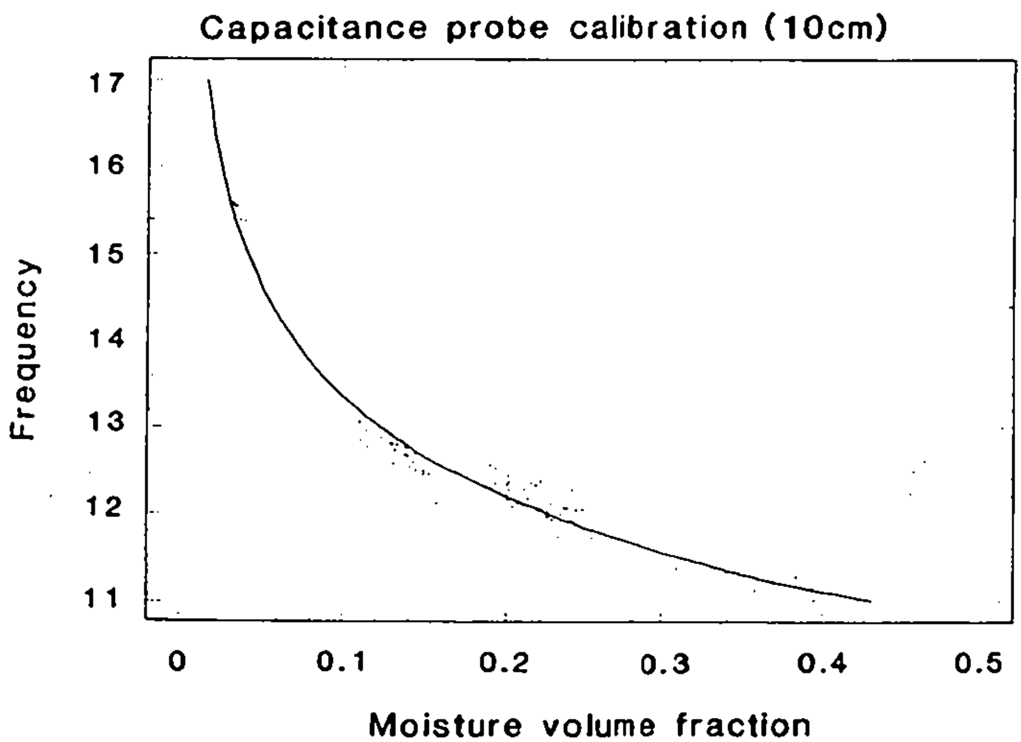


Figure 2.6.1 Calibration curves for the 5 cm and 10 cm prong lengths

hours after irrigation. As the wetting front was nearer to the 10 cm soil layer, drainage commenced soon after the irrigation took place. After 30 hours the rate of water loss measured from the 10 cm layer by the capacitance probe is similar to evaporation measured by the lysimeter. Rapid drainage would have ceased after 30 hours as the soil approached "field capacity".

Figure 2.6.5 shows the reduction in water lost from the covered plot as measured by the capacitance probe to a depth of 10 cm. As water loss by evaporation was prevented on this plot, change in soil water content is an estimate of drainage. Although drainage from this plot would have become progressively greater than drainage from open plots with time, drainage estimates from the covered and open plots were assumed to be the same during the first 30 hours after irrigation. This is the period taken by this soil to drain rapidly to "field capacity" (Batchelor *et al.*, 1990). An estimate of soil evaporation can be obtained if the drainage estimates are subtracted from the estimates of drainage plus evaporation on the open plot. Figure 2.6.6 shows that very good agreement is obtained between the weighing lysimeter and the capacitance probe when this operation is carried out. There is, however, a suggestion that capacitance probe soil evaporation estimates fall below those of the weighing lysimeter after six days as the contribution to evaporation from layers deeper than 10 cm becomes significant.

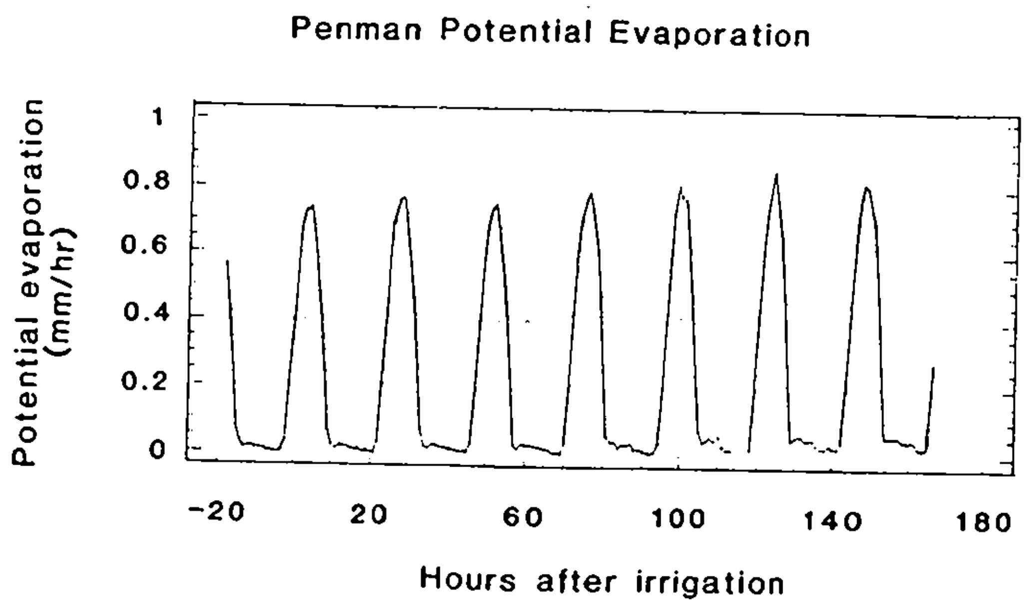


Figure 2.6.2 The diurnal pattern of potential evaporation

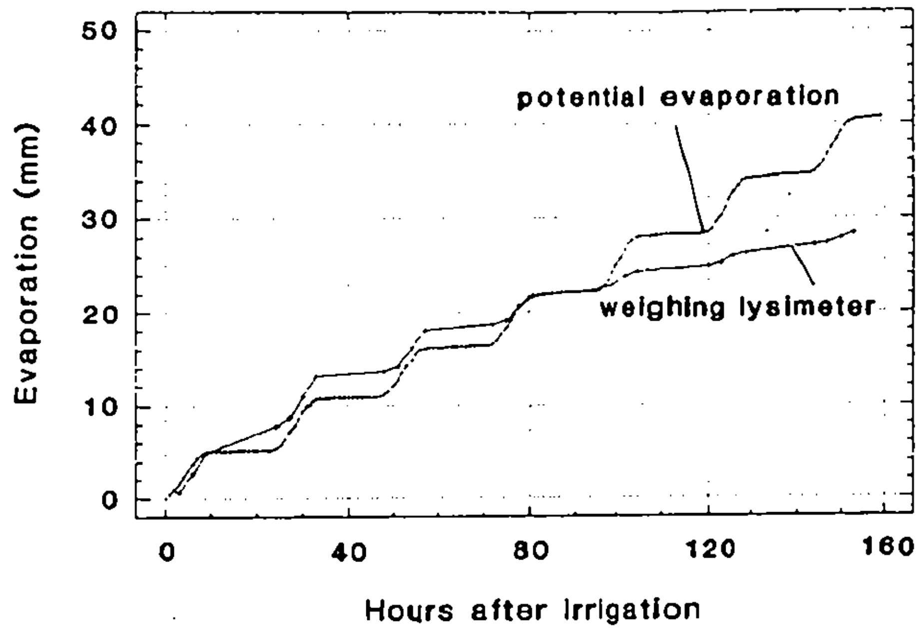


Figure 2.6.3 A comparison of cumulative evaporation measured by the weighing lysimeter with cumulative potential evaporation calculated by the Penman (1963) equation

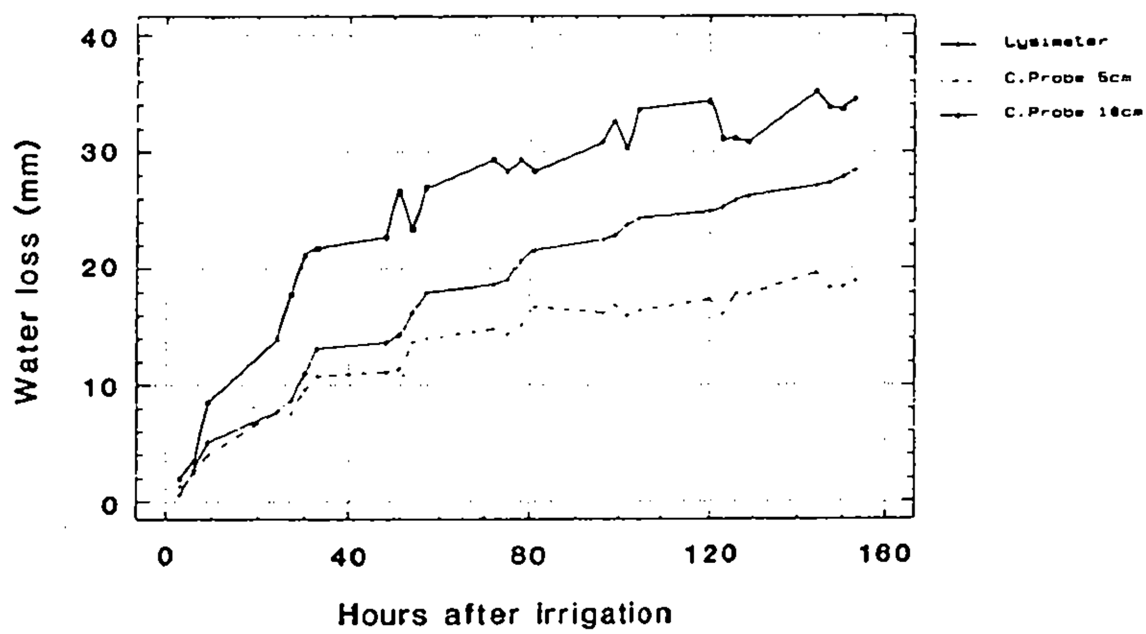


Figure 2.6.4 Cumulative evaporation measured by the weighing lysimeter compared with cumulative water loss or reduction in water content in the near surface layer measured by the capacitance probe

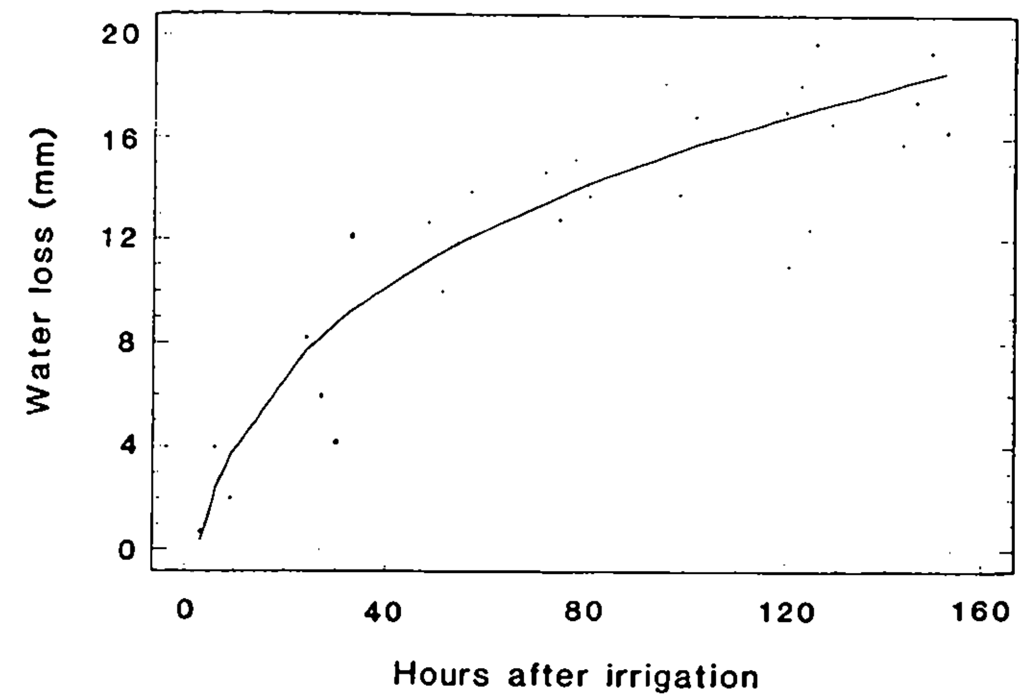


Figure 2.6.5 The reduction in water lost from the covered plot as measured by the capacitance probe to a depth of 10 cm

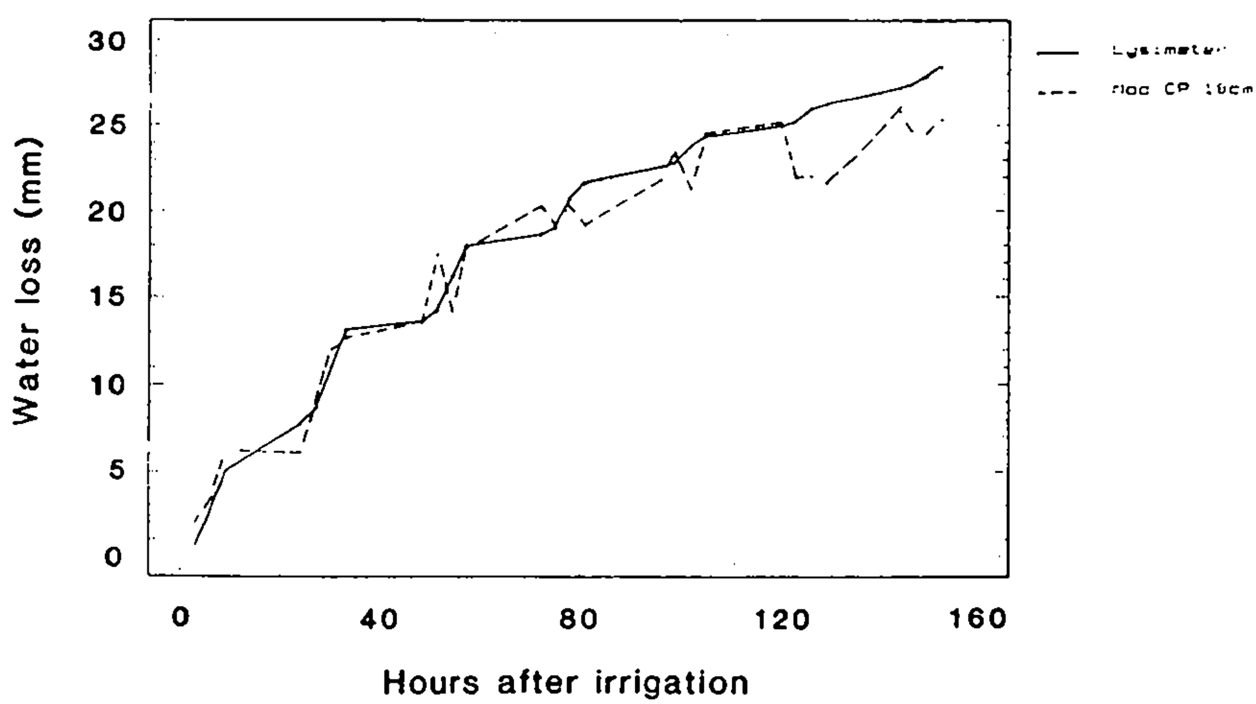


Figure 2.6.6 Agreement between the weighing lysimeter and capacitance probe

2.6.4 Conclusions

The capacitance probe measuring to a depth of 5 cm gave good estimates of soil evaporation immediately after rainfall or irrigation under conditions of minimal drainage from the 5 cm layer. This rate of soil evaporation, which is generally the maximum rate of soil evaporation during a drying cycle, can be used in initialising parameters in soil evaporation models such as the one proposed by Monteith (1981).

The capacitance probe measuring to a depth of 10 cm gave good estimates of soil evaporation after the soil had reached "field capacity" and rapid drainage had ceased. Once a correction had been made for drainage, the capacitance probe measuring to a depth of 10 cm gave a good estimate of soil evaporation during the period that drainage was taking place. For periods of longer than 7 days after rainfall or irrigation, deeper probes than 10 cm may be needed depending on soil properties and potential evaporation rate.

In conclusion the capacitance probe has much potential in studies of soil evaporation either as an adjunct to mini-lysimeters or as an alternative. The capacitance probe has advantages over time domain reflectometers because of the shorter prong length.

2.7 FUTURE EXPERIMENTAL WORK

2.7.1 Feedback from on-farm trials

The overall performance of the collector well garden at Tamwa/Sihambe/Dhobani Kraals is reported and discussed in the next section of this report. Whilst assessing the performance of this scheme, project staff have set up small plots within the garden perimeter to demonstrate the potential benefits of subsurface and pitcher irrigation, the use of mulches and improved scheduling. At the time of writing this report there had been an encouraging adoption of mulching practices and much interest in subsurface irrigation. A simple mould for making clay pipes was provided in March 1992 so that garden members can manufacture their own pipes and start using subsurface irrigation.

On each visit to the collector well garden, project staff have been bombarded with questions on all aspects of irrigation, horticulture and crop husbandry. The feedback that results from this questioning has led to a more holistic approach to the planning of the experiments at the research station. Introducing techniques to improve irrigation efficiency must be considered alongside such factors as groundwater quality, pest management, choice of crop, quality of seed, crop nutrition and cropping pattern. All these factors have a major influence on water use effectiveness because they affect water requirements, water use and yield.

The failure of the rains during the 1991/92 rainy season has led to a severe drought. There has not been any rainfed crop production during this season and many wells have dried up. The Tamwa/Sihambe/Dhobani garden is one of very few gardens still producing vegetables in Masvingo Province. The gardens at Bedzanhomba and Chamabhuku, which were being monitored by the project, have failed due to lack of water. As a result it is very unlikely that there will be cropping or on-farm trials at these gardens before November/December 1992.

2.7.2 Ongoing experiments

As stated above, the ongoing experiments have been designed following feedback from the Tamwa/Sihambe/Dhobani scheme and elsewhere. Experimentation during the 1991/92 season has included:

i) Quantifying the potential benefits in terms of water use effectiveness of using "improved" irrigation scheduling. In this replicated experiment, which is planted with maize, a traditional irrigation schedule is being compared with schedules that match water applied more closely to the maize irrigation water requirements;

ii) The plots used for the bean water quality trial (Expt 91/2) have been replanted with a maize water quality trial. The overall aim of the series of water quality trials is to compare salt accumulation in the soil profile on subsurface and flood irrigated plots. The 1991/92 season should be interesting as a result of the record low rainfall;

iii) The weighing lysimeter has been used to obtain additional data for quantifying the potential benefits of reducing soil evaporation;

iv) A crop establishment experiment is in progress to assess simple methods of improving germination and seedling establishment both on flood and subsurface irrigation.

Results from these experiments and trials will be published in the next project interim report.

3. On-farm Trials - Chivi Communal Area

3.1 CURRENT IRRIGATION PRACTICES

3.1.1 Introduction

This section describes the types of gardens, cropping patterns, crop husbandry and irrigation practices that are found in Chivi Communal Area. Information is also provided on yields and water use effectiveness achieved in existing gardens in this area.

3.1.2 Methodology of survey

The survey was conducted semi-formally using a checklist of questions (see Appendix 2) prepared by project staff[1]. Information obtained during one round of interviews was reviewed and used in deciding on additional subject areas to be covered in the next round. The interviews took place in the gardens themselves. In total, individuals representing fourteen individually-owned and two cooperatively -owned gardens were interviewed during the period February - July 1991.

3.1.3 Types of garden

Cooperative gardens

There were interesting differences between the two cooperative gardens included in the survey. In Bedzanhomba garden there were fourteen members and the whole garden was cultivated as allotments, with each member growing vegetables on his/her own part of the garden. The produce was sold separately and each member contributed a certain amount of money (agreed on by all members) to the general garden fund. The garden was run by a committee formed from members of the scheme. This committee controlled repairs to fences, pump maintenance, crops to be grown, watering and cooperative seed purchasing as well as marketing arrangements. Each member had four plots of dimensions 4 m x 2 m. Each plot being divided into ridges 2 m long with 0.4 m between ridges.

In Chamabhuku garden there were thirteen members and each household was allotted

[1]Survey conducted by Miss Monica Murata, Agronomist, Lowveld Research Station

eight beds of dimension 4 m x 1.2 m. All the beds were raised as the garden is on a slight slope and rains can sometimes wash away the beds despite there being a contour bund above the garden. The same vegetables in the same proportions were grown by each member and the produce marketed collectively. Income from such sales was divided equally among the members, with about 40% going directly to the members and 60% being retained to buy seed and fertilizer and to pay for general maintenance.

Private gardens

Most of the individually-owned gardens were operated seasonally during the March to September period. The gardens were:

i) Used primarily for growing crops for their nutritional value rather than because of their market value;

ii) Of a size that a family can cultivate;

iii) Appealing to those who produce the family's food - in most instances, women.

Any surplus from gardens was sold locally. The size of individual gardens varied from about 200 m^2 to 800 m^2, depending on family size and water availability. In polygamous families, each wife was allocated a certain number of beds depending on seniority and number of children.

Of the fourteen private gardens, three were divided into bunded beds, the average size being 4 x 1.2 m. Two of the gardens were divided into ridges only with average furrow length being 7 m. The rest of the gardens had a mixture of bunded beds and ridges. Ridges were preferred for growing tomatoes. Their length varied according to the size of garden, but was typically 5 m - 7 m. The length of the beds ranged from 3 m to 6 m and the width from 1 m to 1.2 m, but the most common dimensions were 4 m x 1.2 m. In one garden there were beds of 1 m x 0.45 m.

3.1.4 Crop production patterns

Gardening was carried out during both summer and winter, but a greater variety of vegetables could be grown in the winter period (March to September). Sweet cabbage, rape and tomatoes were the most popular vegetables in winter in both types of gardens. Onions, covo, choumoulier and okra were grown if the seeds were available. The cooperatively owned gardens also tried to grow carrots, beetroot, peas squash and peppers when the seeds were available.

The number of beds per crop was greatly influenced by seed availability and type of vegetable. Rape occupied up to 40% of the total cultivated area, the reason being that it is easy to grow, grows fast and multiple harvests are obtained. Cabbages and tomatoes each occupied 20 - 30% of the cultivated area.

In the cooperatively-owned gardens the range of crops grown depended on the size of the market for the different crops. The most popular vegetables grown were rape, cabbage, tomato and onions. There was a limited demand for carrots, beans, squash, beetroot and cauliflower.

The most popular summer crop was maize for "green mealies". Covo, tsunga, okra, pumpkin and sweet potato were also grown. Maize was normally grown in furrows occupying 50-75% of the whole garden.

The main planting arrangement encountered was rows of single crops. The most common plant spacing encountered for "leaf" vegetables, including cabbage, was 0.45 x 0.30 m. A few gardeners used closer spacings of 0.30 m x 0.15 m, their reason being that the ground between the plants was covered more quickly thereby, keeping it cooler and reducing soil evaporation. Tomatoes were normally grown in furrows at 0.30 m x 0.45 m. In the 1.2 m-wide beds, the tomatoes were planted in two rows with an in-row spacing of 0.45 m. Carrots and onions were grown in three rows per bed and with an in-row spacing ranging from 0.07 m to 0.15 m. Maize for "green mealies" was planted at 0.9 m x 0.45 m or at the wider spacing of 0.9 m x 0.9 m when it was intercropped with pumpkin. These arrangements were based on Agritex recommendations.

3.1.5 Fertilizer and manure

Fertilizer use in the gardens visited was very low. Some gardeners could not afford it or it was not available in the rural stores. Some gardeners did not believe in fertilizing vegetables, especially the leaf ones, as it was considered that fertilizer makes them taste more bitter. Most gardeners applied animal manure if it was available although they preferred goat manure to cattle manure because they believed crops grew faster with goat manure. Poultry manure was considered to be even better than goat manure and it was claimed that it softened the vegetable leaves. Ant hills were sometimes broken down and applied to the beds if manure was not available. In general one or two 20l buckets of manure were applied per bed.

In the cooperative gardens, fertilizer and pesticides were bought and either distributed among members or used collectively. Different cup sizes were used to determine the amount of fertilizer to be applied per crop. For example, for tomatoes, cup number 5 was used to apply one cup per planting station of compound "D" (N8 P14 K7) (5.5 g/station) as basal fertilizer, and then the same cup was used to apply ammonium nitrate when tomatoes were marble sized and twice more at subsequent three week intervals. Thus the total applied was 343.1 kg N/ha, 17.1 kg P/ha and 8.55 kg K/ha. For cabbages, cup number 5 was also used and the total fertilizer applied was 100 kg/ha compound "D" as basal, and 200 kg N/ha as topdressing.

3.1.6 Constraints on vegetable production

Constraints mentioned by all gardeners were:

i) Water was not available in sufficient quantities throughout the year;

ii) Inputs such as seed, fertilizer and pesticides were not always available in rural areas;

iii) Damage from domestic animals due to inadequate fencing was sometimes serious;

iv) Lack of money to purchase seed, fertiliser and pesticides.

3.1.7 Irrigation scheduling

Approximately one fifth of the gardeners interviewed determined when to irrigate by looking at the soil; if it looked dry they irrigated. Approximately one eighth interviewed irrigated when they observed signs of crop wilting. The rest interviewed tried to make it a routine to irrigate twice or three times a week unless there was rain. Gardeners believed that young plants needed to be watered more frequently to ensure good establishment.

The frequency of watering generally varied little according to the crop or season. The amount applied depended more on the proximity of the beds to the water source than the crop type. Tables 3.1.1 to 3.1.4 show typical patterns of water application for tomatoes, cabbage, rape and maize. Gardeners generally applied the same amount of water per week throughout the season on their cabbage and rape crops. Tomatoes generally received more water than rape and cabbage while "green mealies" were given less. Many gardeners applied more water during the week after planting and then reduced the amount to a constant number of buckets up until harvest. For all gardeners and for all the crops more water was applied during the first part of the season than was recommended by the FAO (Doorenbos and Pruitt, 1977). For all farmers and all crops except for "green mealies" in some cases irrigation exceeded FAO recommendations from four weeks after planting until harvest.

The scheduling patterns suggest that gardeners were not being economical with their irrigation water, however, some interesting and sensible methods of economising on water use were revealed by some gardeners. These were:

i) Planting at the minimum distance recommended by Agritex so that the canopy between plants closed rapidly, thereby, reducing soil evaporation;

ii) Irrigating late in the afternoon;

iii) Applying the maximum amount of irrigation at any one time, rather than small amounts frequently;

iv) Practising staggered planting so that not all the crops are at the stage of maximum water requirements at the same time;

v) Not planting any more crops than can receive their full water requirements.

3.1.8 Irrigation methods

All irrigation was carried out by basin or flood irrigation using buckets. Several variations of watering using buckets were described by the gardeners. In one situation, where a shallow well was dug within the garden, the gardener filled a bucket and threw the contents as far away as possible onto the beds. He only walked to beds located far away from the well. This, the gardener said, saved carrying the water, although he was aware that distribution of water was uneven and that soil suffered from compaction and some plants were toppled over. He said also that he only did this when his children were not around to help him to irrigate.

The majority of the gardeners spread the water more evenly using buckets. This method was described as being laborious as the water had to be lifted, carried some distance and then spread while walking up and down the bed.

One gardener had built a series of small level beds bounded by earth banks 0.15 m high. Each time he irrigated, he gave each bed a bucketful of water, equivalent to 13 mm of water, regardless of the growth stage of the crop.

In Bedzanhomba garden, a length of flexible hose attached to an outlet welded to the base of a drum was used to deliver water.

3.1.9 Crop yield estimates and water use efficiency

Tables 3.1.5 - 3.1.8 present yield figures from the 14 gardens surveyed. It is thought that these figures might be lower than the actual yields because the amount of produce that went to home consumption was difficult to estimate. It was not possible to obtain yield estimates for okra and carrots because gardeners grew them solely for home consumption and never bothered to check the yields. It can be seen that approximately 50% of the farmers were achieving yields that were comparable with the research station although they were using much more water. This high water use resulted in very low water use efficiency.

Table 3.1.1 *Total water application/tomato crop in number of 201 buckets/4 m x 1.2 m bed*

Frq %	WEEKS AFTER PLANTING															Total	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Buckets	mm
7	10	7	7	7	10	10	10	10	10	10	10	10	10	10	10	141	588
7	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	150	625
14	8	8	8	8	12	12	12	12	12	12	12	12	12	12	12	164	683
57	16	16	10	10	10	10	10	10	10	10	10	10	10	10	10	162	675
7	9	.9	9	15	15	15	15	15	15	15	15	15	15	15	15	192	800
7	8	8	8	8	12	12	12	12	10	10	10	10	10	10	10	150	625

Frq. % = frequency observed in sample

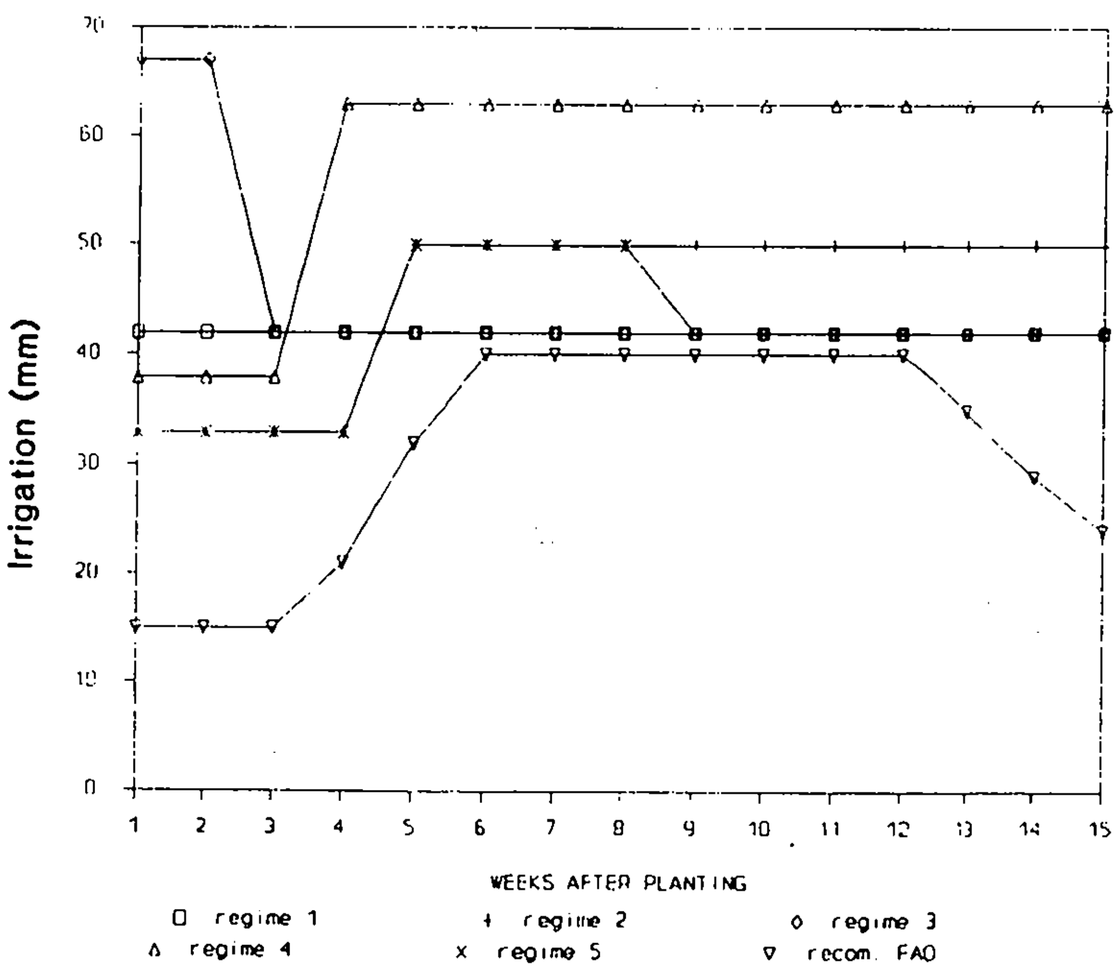


Figure 3.1.1 Pattern of water use for a tomato crop

Table 3.1.2 Total water application/cabbage crop in number of 201 buckets/4 m x 1.2 m bed

Frq %	WEEKS AFTER PLANTING															Total	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Buckets	mm
7	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	180	750
36	14	10	10	10	10	10	10	10	10	10	10	10	10	10	10	154	642
7	8	8	8	9	9	9	9	9	9	9	9	9	9	9	9	550	550
21	12	8	8	8	8	8	8	8	8	8	8	8	8	8	8	124	517
14	8	8	8	8	10	10	10	10	10	10	10	10	10	10	10	142	592
7	7	7	14	12	14	12	14	12	14	12	14	12	14	12	14	184	767
7	12	12	10	10	10	10	10	10	10	10	10	10	10	10	10	154	642

Frq. % = frequency observed in sample

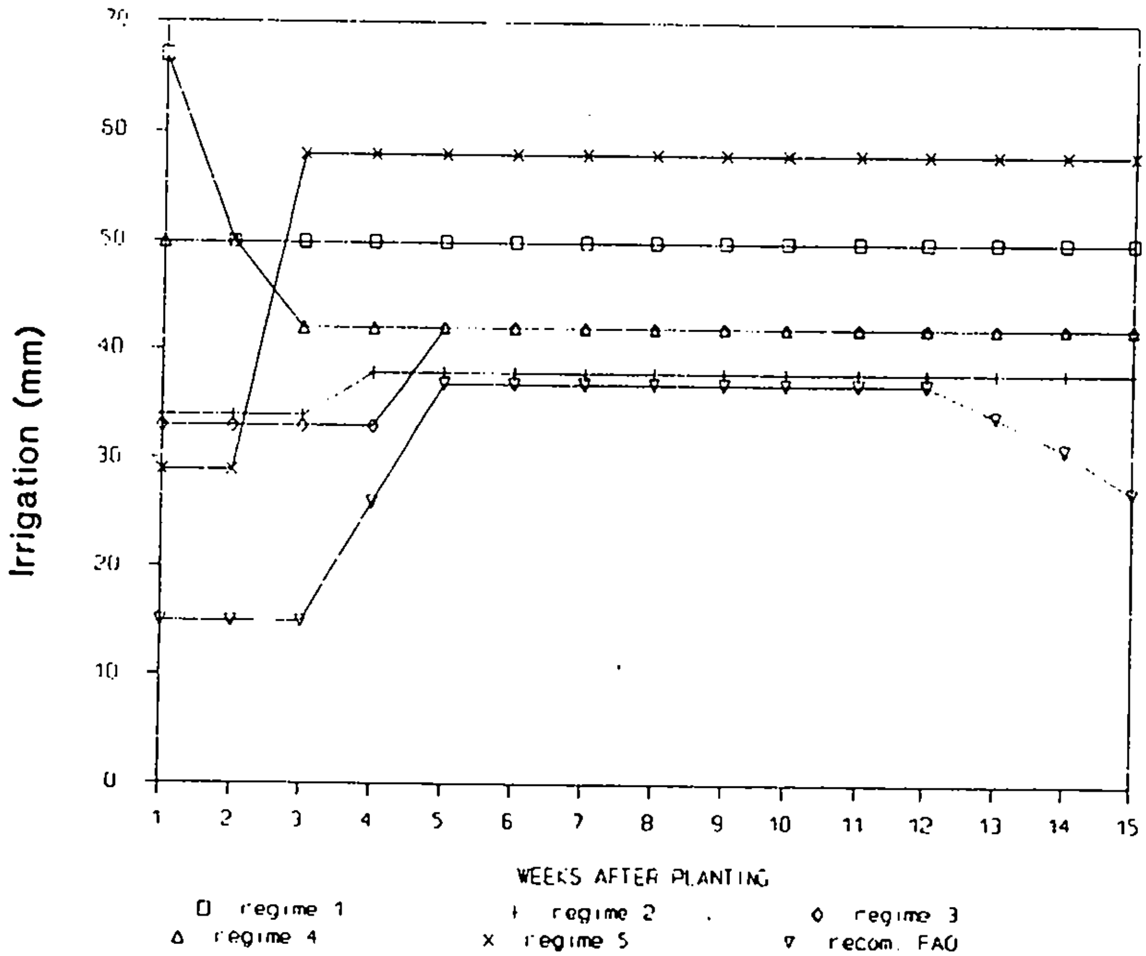


Figure 3.1.2 Pattern of water use for a cabbage crop

Table 3.1.3 Total water application/cabbage crop in number of 201 buckets/4 m x 1.2 m bed

Frq %	WEEKS AFTER PLANTING												Total	
	1	2	3	4	5	6	7	8	9	10	11	12	Buckets	mm
7	10	10	10	10	10	10	10	10	10	10	10	10	120	500
36	14	10	10	10	10	10	10	10	10	10	10	10	124	517
7	8	8	8	9	9	9	9	9	9	9	9	9	105	438
21	12	8	8	8	8	8	8	8	8	8	8	8	100	417
14	8	8	8	8	10	10	10	10	10	10	10	10	112	467
7	7	7	14	12	14	12	14	12	14	12	14	12	144	600
7	12	12	10	10	10	10	10	10	10	10	10	10	154	517

Frq. % = frequency observed in sample

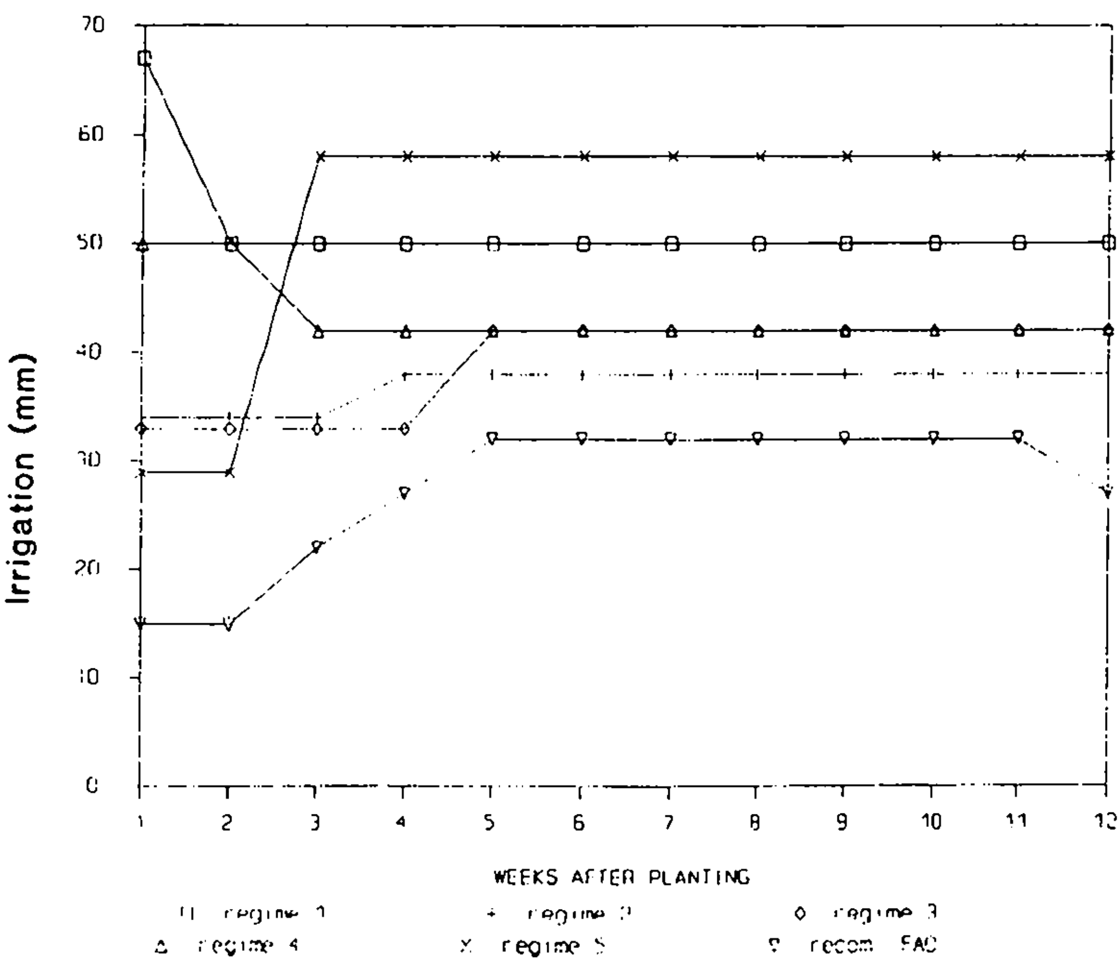


Figure 3.1.3 Pattern of water use for a rape crop

Table 3.1.3 Total water application/cabbage crop in number of 201 buckets/4 m x 1.2 m bed

Frq %	WEEKS AFTER PLANTING												Total	
	1	2	3	4	5	6	7	8	9	10	11	12	Buckets	mm
22	16	16	9	9	9	9	12	12	12	12	12	12	140	583
36	14	10	10	10	10	10	10	10	10	10	10	10	124	517
7	16	12	9	9	9	9	9	9	9	9	9	9	118	492
14	14	10	10	10	10	10	14	14	14	14	14	14	148	617
7	16	12	12	12	12	12	12	12	12	12	12	12	617	617
7	14	14	14	14	14	14	14	14	14	14	14	14	168	700

Frq. % = frequency observed in sample

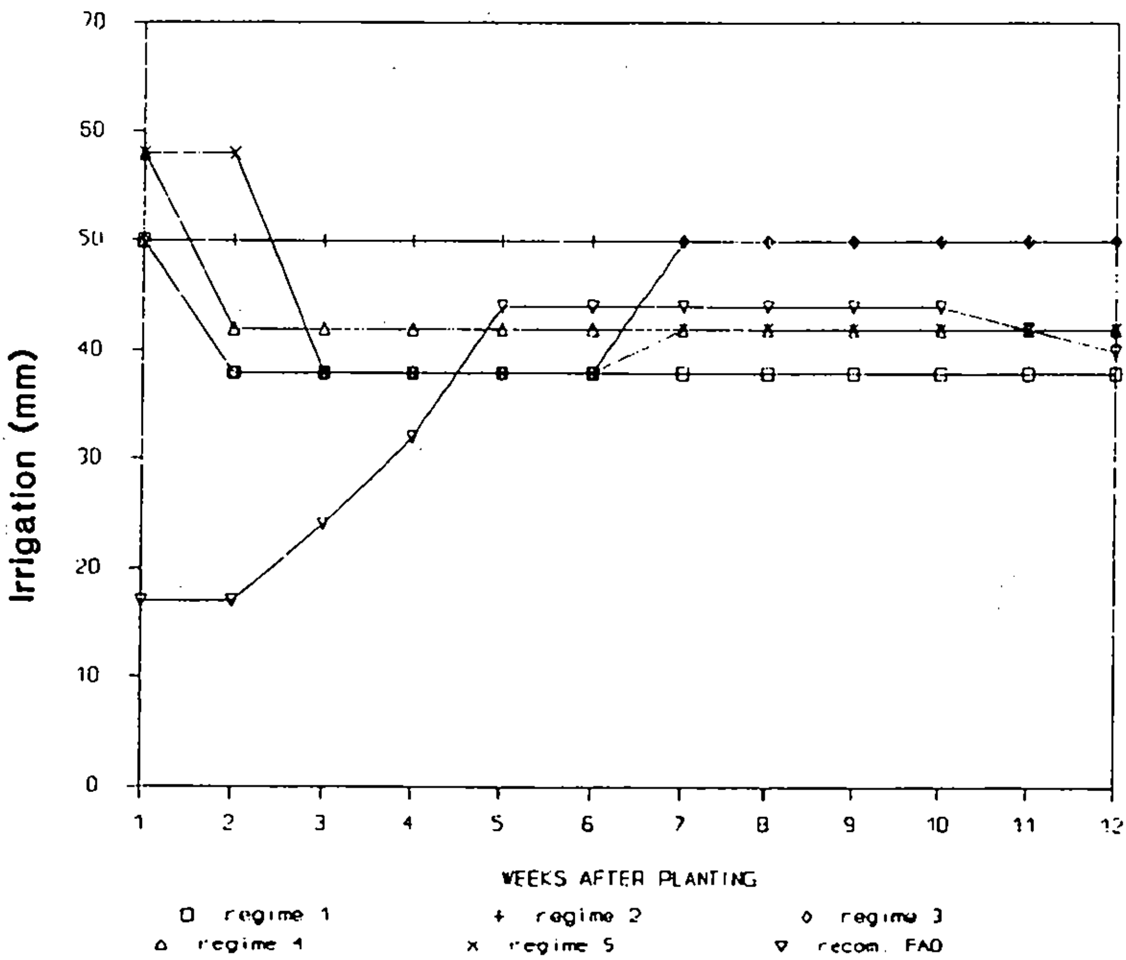


Figure 3.1.4 Pattern of water use for a green mealie crop

Table 3.1.5 Yield and water use efficiency for tomatoes

Frequency in sample	Yield kg/ha	Total water applied mm	Water use efficiency kg/m₃
1	13759	588	2.34
1	25000	625	4.00
8	32266	683	4.72
1	45335	800	5.66
1	18800	626	3.00
2	44000	683	6.44
Mean	29860 (52700)	668 (487)	4.36 (10.8)

(Values in brackets indicate the mean values obtained in Lowveld Research Station Trials from 1989 to date)

Table 3.1.6 Yield and water use efficiency for cabbages

Frequency in sample	Yield kg/ha	Total water applied mm	Water use efficiency kg/m₃
3	10750	517	2.08
2	21250	550	3.86
1	27083	604	4.48
5	33962	642	5.29
1	48000	767	6.26
2	29075	750	3.88
Mean	28353 (77000)	638 (461)	4.31 (16.7)

(Values in brackets indicate the mean values obtained in Lowveld Research Station Trials from 1989 to date)

Table 3.1.7 Yield and water use efficiency for rape

Frequency in sample	Yield kg/ha	Total water applied mm	Water use efficiency kg/m$_3$
2	15789	417	3.79
1	36250	517	7.01
1	16875	438	3.85
3	8947	342	2.62
2	19465	456	4.27
5	22666	500	4.53
Mean	19999 (37632)	445 (336)	4.35 (11.2)

(Values in brackets indicate the mean values obtained in Lowveld Research Station Trials from 1989 to date)

Table 3.1.8 Yield and water use efficiency for green mealies

Frequency in sample	Yield kg/ha	Total water applied mm	Water use efficiency kg/m$_3$
2	7500	420	1.79
1	8900	468	1.90
1	14650	617	2.37
2	12100	617	1.96
5	9600	517	1.86
3	10000	583	1.72
Mean	10458 (13300)	537 (440)	1.93 (3.02)

(Values in brackets indicate the mean values obtained in Lowveld Research Station Trials from 1989 to date)

3.1.10 Conclusions

The study revealed that:

i) There was not a typical garden geometry. Size, number of beds, type of beds etc. all vary, but the most common size of bed was 4 x 1.2 m and the most common number of beds per family was eight suggesting that, in general, one family required an area of 60 m^2 including pathways;

ii) Gardeners appeared to have inadequate knowledge of crop water requirements and irrigation scheduling and this caused them to apply more water than was necessary. Therefore there is a need for more extension advice to be given in this area;

iii) There was a need for more guidance on irrigation methods, manuring and pest management;

iv) Current garden practices were strongly influenced by the existence of reliable water sources, willingness and ability to lift and carry water, and non-availability of seed, fertilizers and pesticides;

v) Gardeners knew some sensible methods of economising on water use, but would welcome ideas for improving water use efficiency;

vi) Every gardener hoped for a reliable source of water that would enable him or her to grow at least enough vegetables for home consumption even in years of drought.

3.2 SITE IDENTIFICATION

3.2.1 Introduction

At the time of the last interim report, an initial survey had been conducted, and five potential sites for the first on-farm trial had been identified within Communal Areas adjacent to LVRS.

These were:

(1) Tamwa/Sihambe/Dhobani Kraals, Ward 22, Chivi Communal Area.

(2) Tsutsekani Kraal, Ward 4, Sangwe Communal Area.

(3) Rata School, Matibi 1 Communal Area.

(4) Rungai Business Centre, Chivi Communal Area.

(5) Mukodi District, Nyajena Communal Area.

3.2.2 Selection criteria

The selection criteria used to help identify these potential sites are listed below :

Geographical

(a) Within a Communal Area of Natural Region V that receives an average annual rainfall of less than 500 mm.

(b) On a basement complex rock or other problem aquifer where extraction of water is improved by use of the collector-well principle.

(c) In an area presently without reliable water, that is, an area remote from dams, perennial rivers, or adequate and reliable groundwater.

Hydrogeological

(d) Where groundwater is found 12 metres or less below ground level, 15 metres if permeable material is found immediately beneath.

(e) The groundwater found is of a quality suitable for irrigation and domestic use.

(f) Where wells can be dug by hand.

Socioeconomic and agricultural

(g) The village group, found to be in need of vegetables, shows a strong interest in developing a community vegetable garden, and a willingness and ability to adopt new crop production techniques.

(h) The village group shows a willingness to allocate an area of land for use as a community garden and collector well site, the area henceforth to be available for the community and not overly influenced by one single party.

(i) Perhaps a history of gardening exists in the area, but previous gardens were abandoned for legitimate reasons (e.g. water at present is insufficient for both domestic and garden use; distant riverside cultivation no longer permitted; gardeners displaced by a land issue with the land "owner").

(j) Though vegetables will primarily be grown for home consumption, access to a market should exist for surplus to be sold locally.

(k) A site chosen should ideally be one of several potential sites in the region, allowing other schemes to be developed following success of the first scheme.

3.2.3 Institutional and community participation

Institutional and community participation played an important part in the choice of site for the first on-farm trial. Strong interest in developing a community garden using water from a collector well was expressed by people at all potential sites identified, but at Tamwa/Sihambe/Dhobani Kraals this interest was exceptional. The immediate enthusiasm of the people, combined with the impressive response of the local Agritex staff, made this site an appealing choice for the first scheme.

When shallow groundwater was first identified at Tamwa/Sihambe/ Dhobani Kraals, the possibility of an irrigated community garden was suggested to members of the community present. Returning to the site some weeks later, it transpired that these people had, themselves, then made contact with the Agritex Extension Worker for this area (Mr Andrew Mahlekete), with the intention of allocating an area of land for such a garden, and to begin organising persons interested in such a project. Shortly afterward, a letter from Mr Mahlekete was delivered by hand to LVRS by Mr Dhiba Tamwa, Head of Tamwa Kraal. A copy of this letter is reproduced in Annex 1 of the Second Interim Report.

Mr Mahlekete confirmed the initial interest shown by the people, and commented that, within the area, these people were amongst those most responsive to new ideas. Mr Mahlekete himself has a sound knowledge of the area, and during the past four years has helped to initiate three small community gardens in other areas. Over 100 families registered immediate interest in the scheme.

3.2.4 Exploratory drilling

Exploratory drilling at the site soon confirmed its suitability for a collector well. Water was found at only 4 m below ground level. Full details of exploratory drilling and technical details of well construction are given by Chilton and Talbot (1992).

3.2.5 Discussion and conclusions

Several impressions formed during the process of site identification were :

(a) Although site identification was time consuming, potential sites for community gardens using collector wells were identified with greater ease than expected during the initial survey.

(b) Each site identified was unique in some way, reflecting the variety of landforms, hydrogeology, agricultural, social and economic conditions that prevail in the Communal Areas of the Lowveld. It will be difficult to put experiences gained at one site into context until data is gained at a number of sites.

(c) The criteria used for site selection worked reasonably well. It is anticipated that they will be improved taking account of suggestions made by Mrs Conyers, ODA Social Development Consultant (Conyers, 1991).

(d) Shortage of water and of vegetables is acute in this region. Strong interest in developing community gardens using water from collector wells was expressed at all potential sites identified.

(e) The site at Tamwa/Sihambe/Dhobani Kraals was notable for the strong local interest in setting up a communal garden, and the enthusiasm of Mr Mahlekete, the local Agritex extension worker. Both factors were central to the choice of this site for the first on-farm trial.

(f) Communication by either radio or telephone between project staff at LVRS and field staff of Agritex is extremely difficult.

3.3 BASELINE SOCIO-ECONOMIC SURVEY

3.3.1 Introduction

A baseline survey was carried out by Edward Mazhangara[2] to assess the social and economic background of the households in the area to be affected by the siting of the collector well garden. It was hoped that the knowledge gained by carrying out such a survey could be utilized in the implementation and the evaluation of the project.

3.3.2 Methodology

The survey was conducted using an informal questionnaire assembled by officers of economic and agronomic backgrounds. Thirty five households were questioned, these being randomly selected by the heads of Tamwa, Sihambe and Dhobani villages. Of these households eighteen were within and seventeen outside the proposed garden. Mr Mazhangara was accompanied by a local young man to facilitate communication between the interviewer and the interviewees. The village health worker was also consulted for her opinion of the state of health of the households in the villages.

3.3.3 Background to the study area

The study area is situated 5 km west of the main Ngundu-Masvingo road and 6 km north west of Ngundu and is set amongst rolling hills that run east to west. Homesteads follow the base of the hills with the vlei occupied by fields. Annual rainfall is generally less than 500 mm, and drought conditions are quite persistent in the area. Maize, sunflower, cotton and sorghum are the most popularly cultivated crops in the area under rain-fed agriculture, which is the mainstay for a majority of households. Until the late seventies the area reputedly had a much more reliable pattern of rainfall which tended to keep the vlei damp for a longer period of the year. In those conditions households were able to obtain water for gardening from shallow hand dug wells which yielded enough water for domestic vegetable production as well as a marketable surplus. From the early eighties however, persistent drought conditions have meant that vegetable production in the vlei has been extremely difficult. The water table to date has subsided to such an extent that hand dug wells last for two or three months in the summer and are then dry for the rest of the winter. Only two private wells and one Lutheran well are functional throughout the year.

[2] Agricultural Economist, Lowveld Research Station

3.3.4 The pattern of garden ownership

The project area has four types of garden, of which three operate throughout the year. These gardens are usually less than fully cropped because of a lack of water. Garden owners are prominent members of the community and generally belong to extended families, consequently areas of their gardens are distributed to relatives for their own production of vegetables (secondary garden owners). The size of land apportioned to relatives will vary according to the number of relatives and the original area of land. Non-garden owners undertake a type of gardening in the fields, the most commonly practised of which is "makeshift gardening". This entails planting vegetables in land proximal to water points that has been harvested of rainfed crops. These gardens are provided free by the farmers and can be relatively productive for those non-garden owners. With more reliable rainfall some "summer gardening" is carried out where vegetables are planted in a few beds amongst the crop planted there. This type of gardening is not common at present.

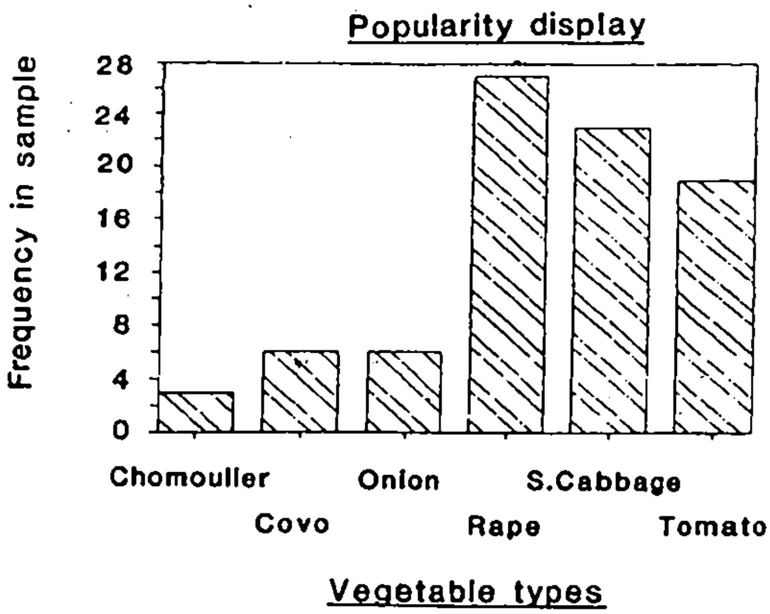
With gardening limited by the availability of land near to water and the decline in the annual rainfall, winter gardening has tended to be limited to a short period. In mid-winter the owners of the wells that are still operational are forced to reduce the frequency of the irrigation of their gardens to support the increased demand for domestic and stock water.

3.3.5 Vegetable production

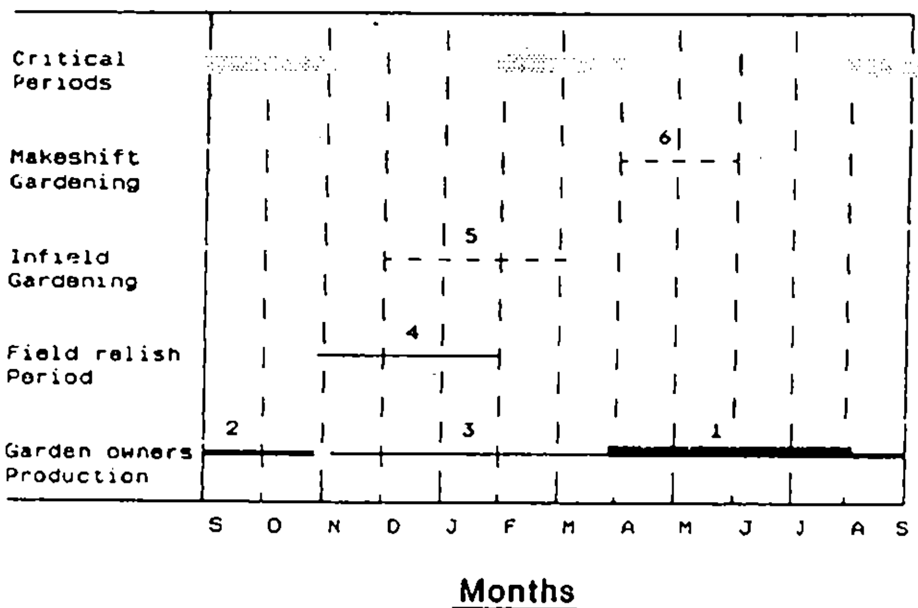
The main vegetables produced in the area are sweet cabbage, rape, choumoulier, covo and onion. Tomatoes are grown in both gardens and in fields under rainfed production. Figure 3.3.5a shows the relative popularity of the most common vegetables. Cabbage and rape are preferred because of their high yield and ease of propagation. The most popular varieties of tomatoes were Heinz and Money-maker. The production of covo was observed to be more common with non-garden owners than with garden owners, while onion and choumoulier were least popular because of the difficulty of obtaining seed. Most seed was in fact purchased in Masvingo because of the poor quality of the local seed supplies.

Villagers are also able to obtain field relish such as cowpea and pumpkin which are planted to coincide with the summer rains. Figure 3.3.5b illustrates the calendar of vegetable production in the area.

Most of the day to day gardening work is carried out by the women of the community, school children help out but men only do the more strenuous jobs such as fencing and bed preparation. Out of twenty seven women interviewed fifteen regarded watering as the most difficult operation, particularly pumping the water carrying it on their heads and then walking what could be a considerable distance. Six women interviewed regarded digging and two mentioned weeding as the most difficult operation in the garden. Figure 3.3.5c gives an indication of the bed sizes and the a)



b)



c)

Descriptive Statistic	No. of Beds per HH	Total Area of beds (m^2/HH)	Number of Waterings per week	Water Application (L/M^2)/week
Average	6.92	26.69	3.81	24.07
Median	6.00	19.50	3.00	21.60
Mode	3.00	18.00	3.00	18.00
Minimum	1.00	3.00	2.00	-
Maximum	16.00	84.00	7.00	-
Range	15.00	81.00	5.00	-
Lower Quartile	3.00	9.00	3.00	15.60
Upper Quartile	9.00	36.00	4.00	30.00

Figure 3.3.5 (a) The Relative Popularity of the most commonly cultivated vegetables (b) The Calendar of vegetable production (c) Bed sizes and irrigation regime

irrigation regime carried out by the women. Perhaps the most important observation as far as gender related issues are concerned is to whom decision-making responsibility is attributed, with respect to what vegetables to grow and how and when to grow them. In 73% of the households in the sample, women were entirely responsible for decisions while in 17% decisions were made by men and women. Men alone were responsible in only 10% of households.

3.3.6 Vegetable consumption

Rape, cabbage and tomato are the most popularly consumed vegetables because of their palatability and cooking quality. During the times when vegetable production is at a critically low level (August-December and February-March from Figure 3.3.5b) villagers consume dried vegetables (mufushwa) and dried fish (matemba). Lacto and dried fish are purchased from local shops for Z$1.20 per litre and Z$1.00 per 500 grams respectively. Three households also indicated that they had used sugar as a relish at some time.

The main sources for vegetables in the villages are the garden owners who sell their produce for between 40 and 50 cents a bundle. Supply, however, cannot match demand during the periods of shortage. At these times the people travel 5 km to Museva where they buy produce from roadside traders whose prices for leafy vegetables are the same but the quantity of which is approximately half. Cabbages are sold for between Z$1.00 and Z$1.50. At these figures it is estimated that the average family budgets is Z$25.00 a month for vegetables, which is high when one considers that the average daily wage is only Z$5.13 a day and work is extremely difficult to find.

The level of nutrition in the community is thought to be poor, and the village health worker attributed this to the poor diet that the people have. Bean seed had been obtained from Agritex to supplement the nutrition of the young children on lower primary and pre-school nutritional programmes, but the crop had failed due to the drought. The health worker intimated that people were keen to undertake gardening and that this would have a beneficial effect on the health of both children and adults. However, the ongoing drought has made both gardening and rain fed farming unrewarding, with the little money made being used to purchase maize-meal to supplement the drought relief. The idea of keeping rabbits was also put forward, specifically to supply more protein in the diet.

3.3.7 Motivation for gardening

The principle motivations for gardening among the villagers were found to be either cash or for relish. Figure 3.3.7 is a tree diagram illustrating the motivation of the members to undertake gardening and their relevant status with respect to being a member of the scheme or not. There were, however, other reasons why people did not join the scheme. Some could not afford the joining fee of Z$10.00 while others missed the relevant announcements. More flexibility as regards these criteria for joining the scheme may have meant that more people could have been involved.

3.3.8 Conclusions

The baseline survey gave a clear indication that water availability and the availability of land near to water are the major constraints on the extent of gardening carried out in the area. The poor diet of the inhabitants and their enthusiasm for gardening suggest that the area would benefit greatly from the scheme.

The ongoing socio-economic analysis should attempt to identify particular parameters of social and economic change such that the impact of the project can be effectively assessed. Key economic indicators may include the degree of reliance on an external market for vegetables, the cash value of the produce sold, the end use of this cash, and the equity of distribution of the income produced by the garden.

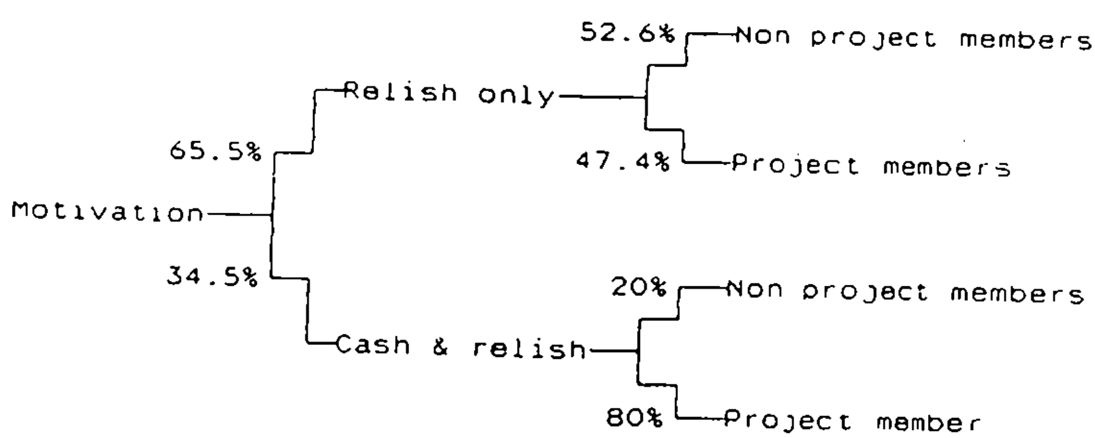


Figure 3.3.7 The motivation to undertake gardening

3.4 INSTALLATION OF FIRST COLLECTOR WELL AND GARDEN AT TAMWA/SIHAMBE/DHOBANI KRAALS

3.4.1 Introduction

As mentioned in section 3.2, the site at Tamwa/Sihambe/Dhobani Kraals was notable for the strong local interest in setting up a communal garden and the keenness of Mr Mahlekete, the local Agritex extension worker. Exploratory drilling quickly confirmed that this site was suitable for a collector well, and construction of the well and community garden began in June 1990.

3.4.2 Site description

Location

Tamwa/Sihambe/Dhobani Kraals are located in Ward 22 of Chivi Communal Area in south-east Zimbabwe (20° 43' S, 30° 43' E, elevation 800 m). The villages are approximately 5 km west of the main Beitbridge - Masvingo road, turning off at km peg 86, 7 km north of Ngundu and 110 km from Chiredzi. The map reference is Map 2030 D4; grid reference 672 037.

Climate

The climate is semi-arid with annual rainfall between 450-650 mm, most rainfall occurring as high intensity thunderstorms during the period November to April. The region is subject to periodic seasonal droughts and severe dry spells during the rainy season. Maximum temperatures in excess of 30°C occur throughout the year and temperatures exceeding 40°C can occur during summer months.

Geography

The three villages are situated amongst granite kopjes, in an area largely used to graze cattle and cultivate rainfed maize and cotton. It is on the basement complex; there are several dykes running north-east to south-west across the area and it is behind one of these dykes that shallow groundwater appears to be held. A preliminary ground survey suggests that the region of shallow water extends for a distance of about 2 km along the line of the dyke. Other hand-dug wells in the area were first constructed in 1978 and, despite several dry years, these wells have not failed and depth to water has not exceeded 6.7 metres.

Prior to construction of the collector well, drinking water for all three villages was provided by a single Lutheran hand-dug well sited on a nearby vlei, and by a private hand-dug well (owned by Mr Mhlanga) sited on the shallow water described above. There was insufficient water for gardening. Tamwa Kraal comprises 36 families, Sihambe Kraal 30 families and Dhobani Kraal 37 families.

Soil

The soil type at the garden site is a very dark grey medium grained sandy clay derived from dolerite and classified as an Udorthentic Chromustert (USDA, 1988).

The site is a lowerslope catenal member, of slope approximately 1%. The natural vegetation is composed mainly of *Combretum imberbe, Acacia polyacantha and Albizia amarra* species. Although a vertisol, the soil is classified in the Zimbabwean Classification as weakly sodic because it has an exchangeable sodium percent (ESP) of 10 and a specific conductivity of less than 4 mS/cm within 80 cm of the surface. Because of accumulation of bases, especially sodium, the pH of the soil is greater than 7 below a depth of 15 cm. Prior to use as a garden, the land was used for grazing cattle and occasionally as a football pitch. A full description of the soil profile and chemical analysis is presented in Appendix 3.

Water quality

Analysis of water sampled at the site was performed by the GoZ Analyst's Laboratory. The water was found to be chemically suitable for human consumption. Results of the chemical and physical analysis are:

Odour	: Odourless
Colour	: Colourless
General appearance	: Clear
Suspended matter	: Trace
Sediment	: None

Table 3.4.2 Water quality analysis

Parameter		Unit	Guideline Value (W.H.O. 1984)	Actual Value (ppm = mg/l)	meq/litre
Ph			6.5 - 8.5	7.9	
Colour		Hazels	15	0.0	
Turbidity		F.T.U.	5	2.8	
Spec. Conduct		mS/m		30.1	
T.D.S.		mg/l	1000	176.1	
Lime Hardness			500	84.2	
Total Hardness				152.5	
Alkalinity				175.5	
Chloride	Cl	mg/l	250	17.3	0.4879
Sulphate	SO_4	mg/l	400	0.9	0.0187
Nitrate	NO_3	mg/l		6.4	0.1032
Bicarbonate	HCO_3	mg/l		213.9	3.5058
Sodium	Na	ppm	200	13.0	0.5652
Potassium	K	ppm		0.3	0.0077
Magnesium	Mg	ppm	150	16.0	1.3158
Calcium	Ca	ppm	250	33.8	1.6866
Iron	Fe	ppm	0.3	0.1	0.0054
Manganese	Mn	ppm	0.0	0.0	0.0000

Total Anions = 4.1156 meq
Total Cations = 3.5807 meq
Error = 7.0%

3.4.3 Scheme installation

The following table presents a diary of events during scheme installation :

Date	Event	Comments
20/03/90	Reconnaissance Survey (see Section 3.2)	Shallow groundwater identified, interest expressed in collector well and garden
05/04/90	2nd visit	People had discussed possible scheme with Mr Mahlekete, local Agritex extension worker (AEW)
24/04/90	Letter received from Mahlekete (AEW)	Delivered by D Tamwa, Kraal Head, letter confirms interest in scheme (Reference Annex 1 2nd Interim Report)
26/04/90	First discussions	Area of land allocated for garden on lower slope
20/05/90	Exploratory drilling	Quickly confirmed suitability of site for collector well at mid-slope position
21/06/90	Digging of well	Vertical shaft completed to 12 m using local labour Depth to water was 4 metres
10/07/90	MCCD[3] participation	First meeting with Mr Mupinga, local MCCD field officer
31/07/90	Land issue begins	Allocation of land on mid-slope near to well becomes sensitive issue because land "owned" by elderly man reluctant for it to be used as a community garden. Problem put to Mr Mhlanga (VIDCO[4] Chairman) for careful discussions with the community and elderly man
28/11/90	Meeting to solve land issue.	Project staff, Mr Mahlekete (AEW), Mr Mhlanga (VIDCO), three Kraal Heads and many members of the community, including elderly man, discuss options for land allocation. Conviction to avoid social conflict sufficient that gesture made by community to buy pipes necessary to connect well with garden sited 100 m away. List of families to participate in garden prepared.
22/01/91	Materials for fence, pipe and tank delivered	46 families pay $10 to join scheme (9 male, 37 female) PVC pipe linking well to garden paid for by community. Damaged contour channel resurveyed by Agritex staff. Community begin construction of water tank in garden (internal diameter 3.7 m, depth 1 m). Garden named "Chidiso changu" (which translated means "My ambition").

[3] Ministry of Community and Cooperative Development

[4] Village Development Committee

25/01/91	Communal garden survey	Miss Murata, LVRS Agronomist, begins collection of baseline data on current patterns of garden irrigation in Chivi Communal Area.
04/02/91	Baseline economic survey	Mr Mazhangara, LVRS Economist, lives with community for 4 days to collect baseline socioeconomic data.
12/03/91	First cultivation	LVRS tractor used to perform ripping and first cultivation of heavy clay soil in area of 0.5 ha. Soil pit dug for soil classification. Tank completed.
15/03/91	Radial drilling of well	Laterals constructed in four directions to create collector well (see Chilton and Talbot, 1992).
28/03/91	Garden management meeting	Community discuss garden operation with staff of Agritex, MCCD and LVRS. Nominations for committee members made. MCCD outlines role of cooperative and asks people to discuss and decide.
05/05/91	Construction continues	All families participate in construction and contribute bricks, sand and gravel. Fence and gates erected. Garden ploughed using 6 oxen. Trench dug from well to garden for pipe. Plots for each family marked on 0.25 ha. Nursery sown near water tank. Two 'B' type bushpumps and water level recorder installed on well. Garden committee Chairman trained in operation of recorder.
06/08/91	1st season begins	46 families cultivate half of the garden (0.25 ha) on a communal basis (see Section 3.5). Bushpumps repaired twice by project staff and community. Garden renamed "Chadiso Chamwari" ("Our ambition").
27/08/91	Official Opening Ceremony	Scheme opened by Mr David Ward (1st Secretary, Aid, BHC) and Mr J Hungwe (Governor of Masvingo Province) and attended by staff of LVRS, Agritex, MEWRD, MCCD, MLGRUD and DDF.
05/09/91	Press release	Opening ceremony reported in local press.
25/11/91	2nd season begins	Serious drought (see Section 3.6).
31/01/92	Monitoring increased	Demand on collector well and garden rises as local wells begin to fail. Garden and domestic water use quantified.
09/03/92	To date	Serious drought continues. There is <u>no</u> rainfed farming in the area. 98 families (1,214 people) take drinking water from the well. 46 families grow vegetables in the garden. Surplus crops are sold to a ready market. Other gardens in the area have failed due to lack of water.

3.4.4 Installation costs

A breakdown of installation costs for the scheme at Tamwa/Sihambe/Dhobani Kraals shows:

Item	Cost (Z$)
Installation of well (see Chilton and Talbot, 1992)	26612
Initial preparation of land	351
Fencing	1150
Tank	1205
Well to garden	579
Monitoring (meters etc)	473
Other materials (taps etc)	478
TOTAL	Z$30848

Full details of all items purchased and cost at the time of garden construction are given in Appendix 4.

Scheme installation costs will vary at different sites. Extra materials were necessary at Tamwa/Sihambe/Dhobani Kraals in order to construct a pipeline between well and garden and a water tank within the garden, but such materials would not be necessary at schemes where the well is sited within the garden. However, fencing provided at the first scheme is a minimum, and some problems of livestock breaking into the garden have been experienced during the present drought. Figure 3.4.1 shows the design of header tank constructed next to the well to allow metering of both domestic and garden water use.

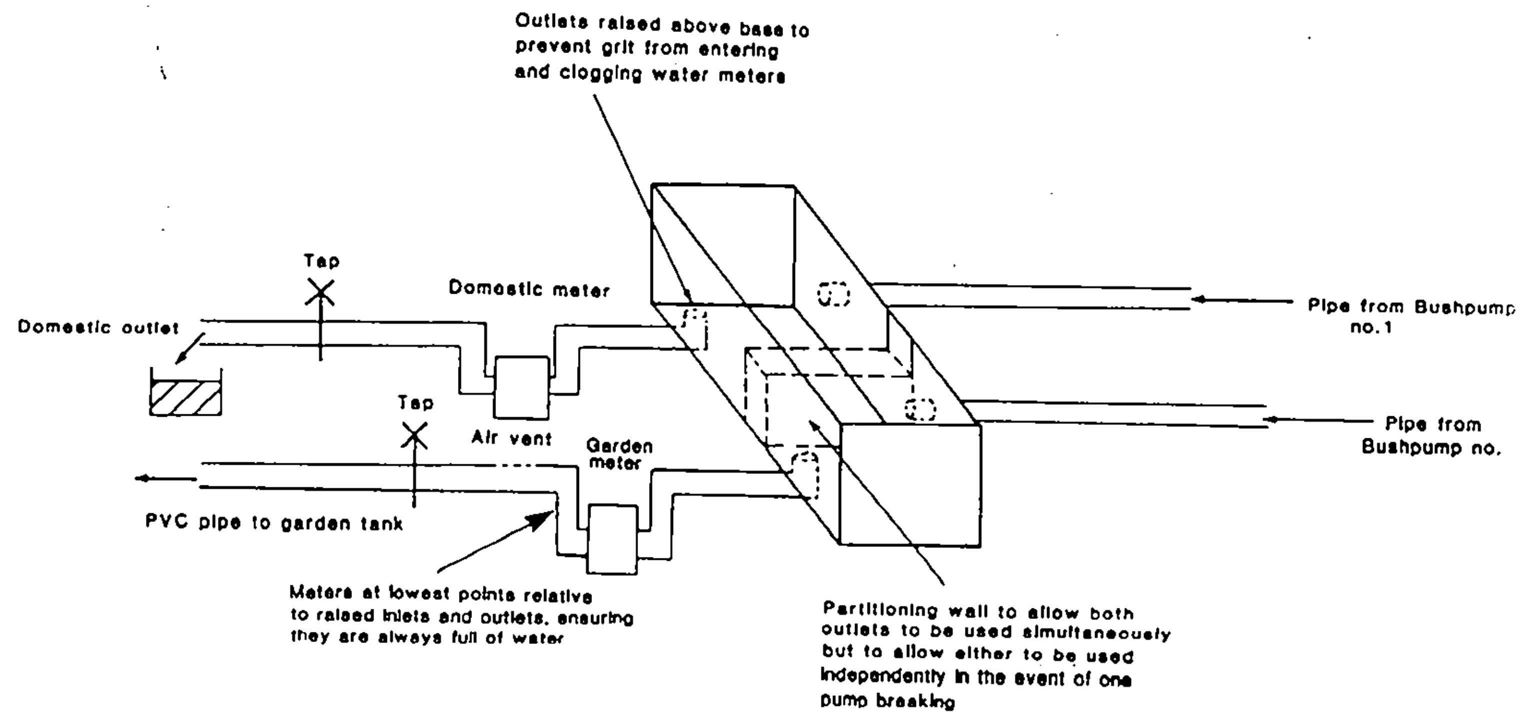


Figure 3.4.1 The design of header tank - to allow metering of both domestic and garden water use

3.4.5 Discussion and conclusions

Several impressions formed during the period of site installation were :

(a) The key role of the local Agritex extension worker, Mr Andrew Mahlekete, in encouraging and organising the local people from three villages to participate and work together in community tasks including construction of fence, tank and contour channel.

(b) The ability of local craftsmen to perform these tasks given the necessary materials, e.g. a fine water tank was constructed by local builder Mr Muposa with assistance from other local people.

(c) Social cohesion is vital to scheme success, and social conflict must be avoided at all costs. Problems of a social nature can pose great difficulties during both scheme installation and operation. During installation, a problem of land tenure arose. In theory, land within a Communal Area is not owned by individuals, and is made available if development of a community scheme (e.g.garden) is proposed. In practice, land tenure has been a thorny issue for many years, and is very often an important issue in development of small-scale irrigation (Underhill, 1990). At Tamwa/Sihambe/Dhobani Kraals, the conviction of some members of the community not to site a community garden on land immediately next to the collector well, land "owned" by an elderly man, was sufficient that the garden was sited away from the well, despite compensation offered by the VIDCO, increased cost to the community and decreased security. If possible, allocation of land for the community garden should be clarified before well construction is started.

(d) To improve acceptance or belief that the scheme is their own, the design should be discussed with the people at all stages, and maximum responsibility given at the earliest possible stage.

(e) The contribution of the people should be as large as possible if they are to feel that the scheme is their own. They can and should contribute before and during construction, partly in kind (materials), partly in free labour (digging) and partly by voluntary fund-raising, in order to promote the sense of ownership and responsibility necessary for scheme success.

(f) Low profile management guidance will still be needed, during installation and when the scheme is operational.

(g) Liaison with staff of MCCD at the time of scheme installation led to confusion amongst the people as to how their garden might be managed. It appears that the people had appealed to Agritex staff for advice on management, and were told of two gardens within the region operating as cooperatives. Visits by staff of MCCD at this time gave the impression that their scheme was also to be run as a cooperative.

(h) Discussions at a very early stage regarding the management responsibilities necessary, and suggesting the need for a Committee, for organisation of water user groups, and for a cash fund to start and maintain the garden, should help to prepare the people for management of their own scheme, and allow them to decide if management as a cooperative is desirable.

(j) Advice on record-keeping given to members of the garden committee by Mr Mupinga, the local MCCD field officer, has been very helpful, and excellent records of both inputs to and outputs from the garden have been kept by the committee since that time.

(k) The Z$10 fee paid by those families wishing to "join" the scheme perhaps excluded some members of the community not able to afford this sum. The method by which interest in scheme participation is registered might be improved if it also included payment in kind either as materials or as free labour.

(l) Potassium in the soil at the garden site is low, and calcium and magnesium are out of balance, high magnesium explaining the hard nature of the soil. Magnesium should not be added. The best fertiliser for this soil would be Single Super Phosphate, this adding both phosphate and gypsum. Gypsum will help to correct the imbalance between Ca and Mg, and also improve soil structure. Use of manure will help to improve the same. Improved soil structure is desirable to aid leaching. If long-term management can ensure leaching once a year to restrict sodium to depth, with time there is potential to develop an excellent soil at this site with good depth and high water holding capacity.

3.5 FIRST CROPPING SEASON

3.5.1 Introduction

This section describes the performance of the garden from the completion of installation (Aug 1991) up until the end of the first cropping season (Nov 1991).

Following consultation and advice from Mr Mupinga of the Ministry of Community and Cooperative Development (MCCD), and Mr Mahlekete of Agritex the scheme participants decided to form a committee to be responsible for decisions related to the garden. Membership of the scheme was limited to 46 families each of whom paid Z$10.00 to join. It is interesting to note that the committee is made up of four men and three women, but that it is the women who undertake almost all the day to day work in the garden.

Initial preparation of the land was carried out by a tractor from the research station that ripped the soil. It is worth mentioning that this was at the request of the members of the scheme although it was not entirely necessary as the land had previously been partly cultivated by them. The tractor was used to facilitate the early uptake of the scheme, and also because the land was very heavy having been grazing land prior to cultivation. Following the tractor's cultivation the members hand-hoed their beds taking approximately an hour over each one. Manure was also applied by one person from each family. The beds measure 6 m x 1.2 m.

Approximately half the garden (0.25 ha) was planted on advice from project staff wishing to monitor well performance before full cultivation began. The cropping pattern and the irrigation schedule instigated by the scheme members are shown in Tables 3.5.1(a) and 3.5.1(b). On a typical day 15 or 16 people worked from 6 am until 10 am; pumping water taking 2.25 hours, pouring water 0.75 hours and weeding, harvesting and other operations taking approximately 1 hour. The cabbage and rape crops were sprayed twice with Dimethoate to counter aphid damage.

Careful records were made of the value of the crops sold, this enabling a gross margin analysis for the first season to be drawn up as shown in the next section (Tables 3.5.2a and 3.5.2b). The committee decided that the proceeds from the first season's sales should be used to purchase seed for the next season.

3.5.2 Results and gross margin analysis

The performance of the first season was disappointing. Cultivation of maize was abandoned in October and whilst crops of carrots, squash, beetroot and onion were planted their success was limited if they did not fail completely. Production from the garden was for the most part sold to people who travelled to the garden from, in some cases, considerable distances.

Table 3.5.2(a) gives the value of the vegetables produced by the garden; crops retained for consumption are valued at their selling price (opportunity cost).

Table 3.5.2(b) gives the gross margin for the first season's production, that is the difference between the gross value of vegetables produced and the variable costs of the inputs necessary for that production.

3.5.3 Discussion and conclusions

The disappointing performance of the garden in the first season may be attributed to a combination of factors.

Perhaps the most pertinent point is that there was collective responsibility for the operation of the garden. This led to disincentives for the participants to contribute maximum effort to the garden management as they were not rewarded directly for their efforts. Shirking and free riding by some members lead to discontent amongst others, this contributing to inadequate weeding and sometimes erratic watering. Also, any produce that was harvested had to be paid for by the participants.

The poor performance of the garden should not be entirely unexpected when one bears in mind the lack of experience that the scheme participants had in the operation of such a communal project. This type of project is a significant departure from the normal individual type of gardening undertaken. This lack of experience led to disorganization in the irrigation schedule with at worst members rushing to apply water to the garden simply because it had been pumped from the well to the tank. These high applications led to relatively high demands on the participants' labour for pumping, watering and weeding. Overambition also manifested itself in the decision by the garden committee to purchase a Z$30.00 packet of beetroot seeds (the average price of a packet of seeds being 50c-Z$1.00), the contents of which failed due to inappropriate management.

A lack of social cohesion and discontent in the community was also created in part by the address of the garden used in the opening ceremony. The garden was simply addressed Tamwa Kraal, whereas the scheme in fact serves the communities of Sihambe and Dhobani Kraals as well. Diplomacy, democracy and equal representation of participants are essential to avoid potentially damaging social rifts. This scheme is to serve several villages, and the efforts made to promote harmony amongst and within them have been vital.

Table 3.5.1 ***(a) The cropping pattern and (b) the irrigation schedule at Tamwa/Sihambe/Dhobani Kraals during the first season***

(a)

Cropping Pattern

Crop	No. of Beds
CABBAGE	26
OKRA	26
RAPE	26
TOMATO	21
MAIZE	72
NURSERY	4
TOTAL	175

(b)

Irrigation Schedule

Crop	Buckets/Bed	Waterings/wk	Number of wks	Total litres
NURSERY	4	2	8	5820
CABBAGE	6	2	16	99840
OKRA	4	2	16	66560
RAPE	6	2	16	99840
TOMATO	4	2	6	53760
MAIZE	4	2	8	92160
TOTAL				417280

Table 3.5.2 (a) Gross production values (b) Gross margin analysis for first cropping season

(a)

Gross Production Values

Crop	Sales	Retained*	Total Value
CABBAGE	94.15	27.60	121.75
OKRA	50.65	-	50.65
RAPE	18.50	23.00	41.50
TOMATO	8.80	-	8.80
ONION	3.00	-	3.00
SPINACH	1.50	-	1.50
TOTAL	176.60	50.60	227.50

(b)

	Gross Margin Analysis		$Zim
OUTPUT: TOTAL VALUE OF VEGETABLES			227.50
VARIABLE COSTS:			
SEED:	ONION 10 x 50 ¢	5.00	
	TOMATO 10 x 50 ¢	5.00	
	CABBAGE 8 x 50 ¢	4.00	
	CARROT 9 x 50 ¢	4.50	
	OKRA 1 x $20 pkt	20.00	
	SQUASH 1 x $4 pkt	4.00	
	MAIZE 10 kg @ $1.60/kg	16.00	
	BEETROOT 1 x $30 pkt	30.00	
	TOTAL SEED COST		88.50
	INSECTICIDE DIMETHOATE 12.5 ml @ $160/l		2.00
	TOTAL VARIABLE COST		90.50
	GROSS MARGIN (0.2082 ha)		137.00

* valued at market value

3.6 ONGOING SECOND CROPPING SEASON

3.6.1 Introduction

This section of the report describes the operation and results of the garden during the period from December 1991 to March 1992. This second season is already considerably more successful than the first and results continue to be extremely encouraging. This is despite the fact that the region is undergoing the worst drought in living memory; rainfall is 80% down on normal levels and no rainfed farming has been possible in the region. As the present drought conditions persist, the collector well and garden will be a lifeline for the people that it serves, providing both vegetables and drinking water.

3.6.2 Land preparation and irrigation scheduling

Land preparation for the second season started on the 6 December with hoeing and manuring taking approximately 1 hour per bed. Sufficient cash was generated in the first season to buy enough seeds for the whole garden to be planted. Transplanting was carried out between the 2-27 December with two groups of 23 people working 2 days per week for 7 hours per day. The members decided to plant the whole garden, an area of 0.4142 ha, despite advice from Dr Lovell to plant only half the garden to assess the potential for further more gradual expansion. Importantly the members took individual responsibility for their plots, to receive the benefits of their gardens directly. Each family group planted seven beds of vegetables, three of tomato, one of okra, one of rape, and two of cabbage.

A more organized irrigation schedule evolved during the second season. Each bed was watered twice a week, each quarter of the garden being irrigated on Monday and Thursday or Tuesday and Friday, morning or afternoon. However, as a consequence of the serious drought and extremely high temperatures, additional irrigation at weekends was sometimes necessary. This, in conjunction with the increased abstraction of water needed to irrigate the whole garden, meant that the level of water in the well fell significantly. In a meeting with the scheme members this fact was explained and there seemed to be agreement that the best solution would be to reduce the number of beds cultivated by each family. In view of this it is likely that the irrigation schedule and the cropping pattern of the garden will be modified appropriately. The irrigation schedules at different times in the growing season are shown below; each bucket contains 20l approx.

10/01/92	Tomato and Okra	-4	buckets per bed
	Rape	-8	"
	Cabbage	-6	"
7/2/92	Rape and Cabbage	-8	"
	Okra and Tomatoes	-3	"
10/3/92	Rape	-8	"
	Cabbage	-6	"
	Okra	-4	"
	Tomato	-0	"

The rape, okra and cabbage crops are growing extremely well, but unfortunately the tomato crop had to be abandoned to reduce water use. This was a disappointment to the people as they had given the crop a great deal of input. Some members are now introducing mulches to their beds in an attempt to further reduce water use.

The committee continues to be responsible for all decision making. Fertiliser and pesticides purchased to date include 1 bag of compound D applied at 1 kg per person to rape and cabbage and 1 bag of ammonium nitrate similarly applied on okra and tomatoes. These both cost Z$38.50.

Carbaryl at 210 g per 13l water and agrithryn at 16 g per 13l water were applied at a cost of Z$103. Contributions to the committee are now payable at Z$1.25 for every day that a scheme member makes a sale from his garden. Selling usually takes place on a Friday, and as the drought has caused a reduction in the supply of vegetables in the region generally, the members are able to sell an appreciable quantity of their vegetables (at present about 65% of total production) at the farm gate. Approximately five of the members are taking their produce elsewhere to sell for a higher price, but people are travelling considerable distances to purchase vegetables from the scheme. More than Z$1700 has been generated so far this season from farm gate sales of vegetables and it is likely that there will be at least two more selling days this season.

3.6.3 Partition of water to domestic and garden use

The partition of water taken for domestic use and for garden use was quantified by physical counting of buckets and by metering.

In the former method, two local people (Martin Tamwa and Christopher Mhlanga) were employed to count buckets taken for each purpose, either directly from the collector well or indirectly from the tank within the garden. To allow for the different sizes of bucket carried by adults and by children, the buckets were classified into three different sizes of 20, 10 and 5 litres. In the latter method, two Kent 40 mm PSM Class C water meters were fitted to the small header tank at the well, as shown in previous Figure 3.4.1.

Table 3.6.3(a) is a summary of results measured during a 25 day period in January.

Table 3.6.3(a) Measurements of water use

	Metered Use (litres)	Counted Use (litres)	Average Daily Use (litres)
Domestic	58,267	59,380	2,353
Garden	271,576	261,155	10,655

The good agreement obtained between metered and measured water use gives confidence in the values obtained. During the period of 25 days, a total of 325 cubic meters of water was abstracted from the collector well. Garden use was typically four and a half times domestic use. The average daily garden use (10,655 litres on an area of 0.23 ha) was equivalent to a daily irrigation of 4.6 mm. This was a reasonable application for the particular stage of crop growth, and might be expected to increase as the crops approach maturity. The average daily domestic use (2,353 litres for 1,214 people, equivalent to only 1.94 litres per person) is extremely low, and a census confirmed that many families do in fact supplement their domestic requirements with water from other local wells (see Section 3.6.4).

Table 3.6.3(b) gives a more detailed analysis of water use during this 25 day period.

Table 3.6.3(b) The partition of daily water use during January, measured using two water meters and by physical counting of buckets taken for each purpose

		Domestic (counted) 6am-6pm				Garden (counted)	Domestic (metered)	Domestic (metered)-	Garden (metered)	Garden (metered)+
		Local	Other	'Garden'	Total	6am-6pm	6am-6pm	'Garden'	6am-6pm	'Garden'
Date	Day	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
06/01/92	Mo	3600	180	1040	4820	14590	4858	3818	12836	13876
07/01/92	Tu	2560	280	3220	6060	15800	7054	3834	13340	16560
08/01/92	We	2960	260	0	3220	0	3360	3360	0	0
09/01/92	Th	4400	280	2600	7280	15815	6084	3484	15404	18004
10/01/92	Fr	3100	200	1860	5160	14220	3536	1676	14255	16115
11/01/92	Sa	340	0	0	340	0	275	275	0	0
12/01/92	Su	2080	0	0	2080	0	2481	2481	0	0
13/01/92	Mo	2380	60	800	3240	14850	3375	2575	15296	16096
14/01/92	Tu	1940	80	660	2680	22950	2769	2109	18822	19482
15/01/92	We	1500	40	0	1540	0	1581	1581	0	0
16/01/92	Th	2660	0	1000	3660	19945	3550	2550	17927	18927
17/01/92	Fr	2780	0	140	2920	10345	3299	3159	11324	11464
18/01/92	Sa	1900	20	0	1920	3755	1932	1932	5062	5062
19/01/92	Su	2900	60	1000	3960	8720	4248	3248	8708	9708
20/01/92	Mo	2300	0	1200	3500	14400	2300	1100	24337	25537
21/01/92	Tu	2080	0	360	2440	12955	2530	2170	9198	9558
22/01/92	We	760	40	0	800	0	784	784	0	0
23/01/92	Th	1460	0	0	1460	19120	2117	2117	17064	17064
24/01/92	Fr	2120	40	0	2160	11200	2192	2192	12391	12391
25/01/92	Sa	1380	0	0	1380	4840	1400	1400	5300	5300
26/01/92	Su	3260	0	0	3260	8280	2541	2641	8426	8426
27/01/92	Mo	1680	0	340	2020	15280	2457	2117	14188	14528
28/01/92	Tu	1980	60	180	2220	14450	2354	2174	12673	12853
29/01/92	we	2780	0	0	2780	0	2031	2031	0	0
30/01/92	Th	2840	40	180	3060	19640	3639	3459	20445	20625
n	=	25	25	25	25	19	25	25	19	19
average	=	2310	66	583	2958	13745	2914	2331	13526	14294
st.dev.	=	883	94	866	1597	5020	1506	921	4983	5302
sum	=	57740	1640	14580	73960	261155	72847	58267	256996	271576

* All figures in litres

Local domestic consumption is by families of Tamwa, Sihambe and Dhobani Kraals.
Other domestic consumption is by families of neighbouring villages, particularly Puche and Matenhese Kraals.
'Garden' consumption counted at the collector well refers to water obtained at the domestic outlet but then carried by hand to the garden.

3.6.4 Census results

A census was carried out between the 6/1/92 and 30/1/92 by two members of the scheme to give an indication of the number of people the well was supplying with domestic water. This is particularly relevant during the present period of drought when other wells in the area are beginning to fail.

It was found that the well was providing at least some of the domestic water requirement for 99 families from the kraals of Tamwa, Sihambe, Dhobani, Matenhese and Puche. The average number of children in each family is more than ten (10.3) and therefore assuming that each family also contains two adults, the number of people being served is more than twelve hundred (1217). Of these families forty four are also using another source of domestic water but this means that for over half the families in the survey (693 people) the collector well is their sole source of water and it is clear that this figure is only going to increase if the drought conditions continue and nearby wells dry.

Figure 3.6.4a. shows the distribution of family size groups.

Figure 3.6.4b. gives an indication of the average domestic water consumption from the collector well by family size group.

3.6.5 Economic analysis

This section aims to give a fair and balanced analysis of the costs and benefits of the collector well and irrigated garden scheme given the location and context of the scheme. It must be pointed out that the scheme is very much at a formative stage with the members of the scheme on a steep learning curve. The second cropping season is not yet complete and as mentioned elsewhere in this report, is characterized by a drought of unprecedented severity. The combination of these make the economic analysis somewhat tentative, however it is hoped that this analysis will provide a sound basic framework for ongoing economic assessment.

The value of vegetables produced by the garden up to the 28/2/92 was as follows:

	Production Z$		
	Consumed	Sold	Total
Rape	388.5	1368.9	1757.4
Cabbage	568.4	360.5	928.9
Total	956.9	1729.4	2686.3

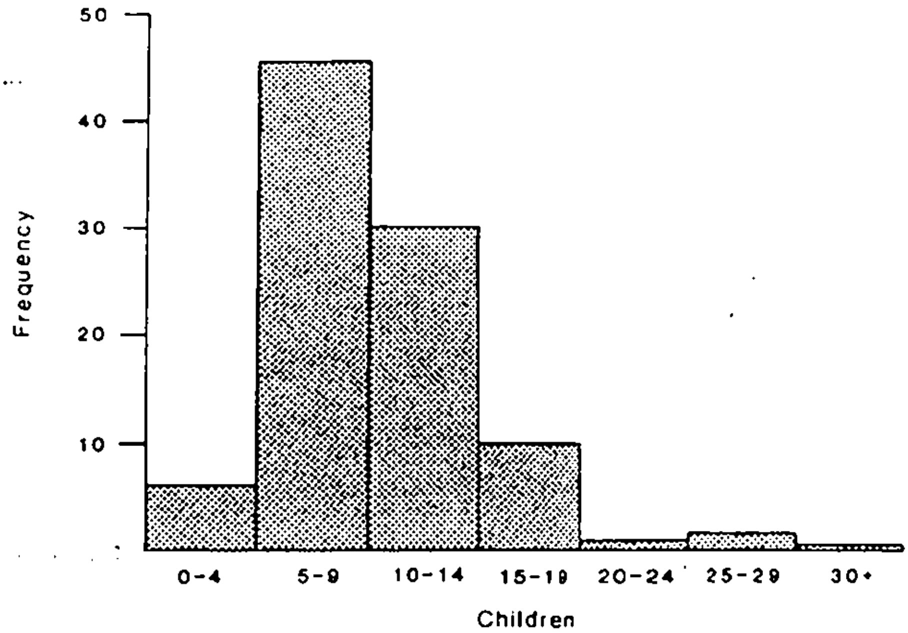


Figure 3.6.4 (a) Distribution of family size groups

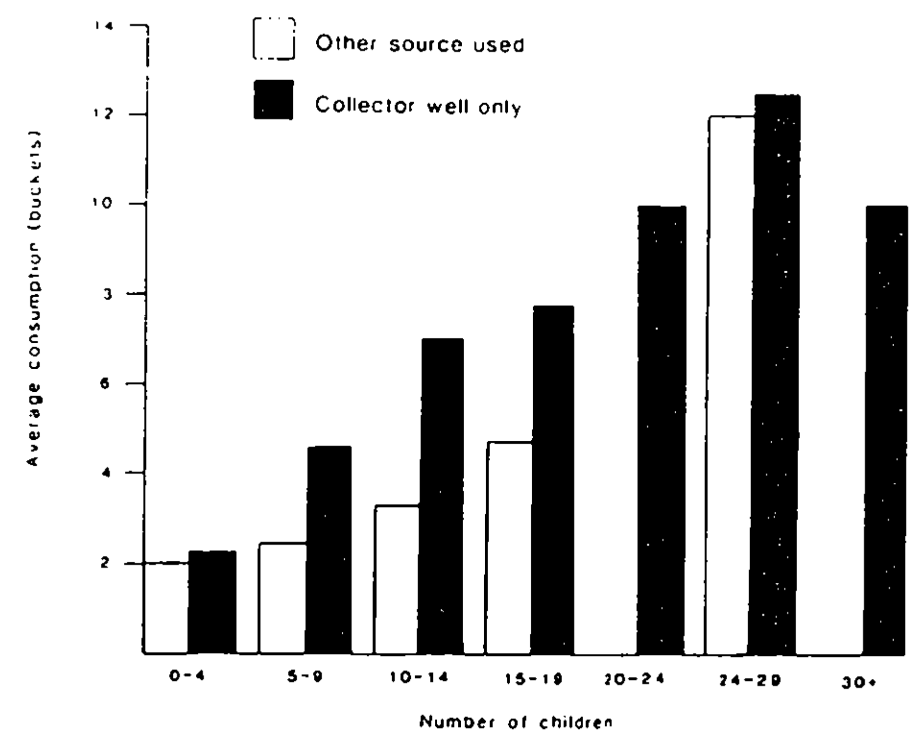


Figure 3.6.4 (b) Average daily domestic water consumption by family size group

As in the analysis of the first season the value of the vegetables produced for home consumption is expressed as the opportunity cost of consumption, which given the high demand in the area for vegetables is their market value. On the two most recent selling days (Fridays) the scheme members grossed Z$330.40 and Z$438.90 respectively. Given that two more selling days this season are expected, one might assume that the value of sales would increase Z$770 and the value of consumption to increase by Z$466. These two assumptions would suggest that the value of the second season's production could be Z$3922.30. Working with this figure the gross margin analysis for the second season would be as follows:

Second season gross margin analysis

	Output Z$
Vegetables sold to date	1729.40
Vegetables to be sold to season end	770.00
Value of consumption to date	956.90
Value of consumption to season end	466.00
Total value of output	3922.30
	Variable Costs Z$
Seed	20.00
Fertilizer: compound D	38.50
ammonium nitrate	38.50
Pesticide/Insecticide: carbaryl & agrithryn	103.00
Total Variable Costs	200.00
Gross margin	3722.30

This makes the assumption that the selling pattern will continue as it has been doing up to date, which is reasonable as there is undoubtedly a high demand for vegetables, a limited alternative supply in the area and the members are keen to generate cash.

The discounted cash flow analysis also has to make several assumptions on projected performance of the scheme given that to date the scheme has been operational for less than two seasons. The calculations are based on data collected in the field but the context of the life of the scheme should be remembered at all times. It is hoped that this analysis will give a good indication of the economic performance of the scheme and a basis for future assessment.

The installation costs of the well do not include the cost of research equipment such as water meters that are used on this scheme specifically for monitoring. These are not necessary for the functioning of the future collector well garden schemes. It should also be pointed out that the well and tank are some distance from each other and this has obviously led to higher installation costs than might be expected elsewhere. It is hoped that for future schemes all inputs necessary will be from domestic sources to eliminate the exchange risk of purchasing foreign inputs. The initial cultivation of the land was also not entirely necessary as described in section 3.5.1, and this figure may be modified for future schemes.

The returns from the production of vegetables are based on the market value of the produce sold and the opportunity cost of the produce kept for home consumption. It is assumed that the amount grossed by the sale of vegetables will remain constant throughout the three growing seasons of the first full year of operation. However this may not be the case for several reasons. The ongoing drought is likely to reduce the supply of vegetables in the region and lead to a rise in the price that the scheme members would receive. At the same time the drought could also reduce the productivity of the garden, a reduction in area of garden that can be cultivated leading to deviations from the trend. Repair and maintenance of the pump are calculated as a percentage of the installation costs of the well. Cropping costs again rely on the data collected in the field for the first season. The fact that the members of the scheme are on a steep learning curve may mean that these costs will steadily decrease as more experience is gained.

Future cash flows are very difficult to accurately determine as it is not yet clear how the garden will perform in a year when traditional rainfed cropping is undertaken or livestock numbers are at a higher, more normal level. It is likely that there will be a shift of labour inputs away from the garden to concentrate on traditional rainfed agriculture, but to what extent is unclear. The valuation of the labour input to the garden is very difficult as there is little work in the area that could generate a legitimate shadow price. It was even suggested that the labour generated by the scheme was a benefit to the people.

The first analysis, Table 3.6.4a, shows labour unvalued, maintenance at 5% of installation costs and the projected constant cash flows lasting for ten years. This gives an Internal Rate of Return (IRR) of 33% and a Net Present Value (NPV) of Z$ 55577.29 at a discount rate of 12%- the standard agricultural loan rate in Zimbabwe at present.

With a substantial shortfall in the expected returns from vegetables of 25% the scheme would still give an IRR of 21% and an NPV of Z$ 38995.86 (Table 3.6.4b).

These analyses are important but should not be the sole criterion for the evaluation of the scheme. The full costs and benefits of these types of small-scale irrigation schemes are very difficult, if not impossible to appropriately quantify using conventional economics. Underhill (1990) points out that these schemes by their very nature tend to have a high social component. The costs of such schemes may be reduced by more self help measures and the benefits are social as well as economic. It is likely, for example that the health of the people of the community will improve due to improved nutrition. There are indications that some of the income generated by this scheme will be spent on education for the children. The benefits of this improved education are again difficult to gauge, and are likely to be long term, therefore would be given little weight in a conventional analysis. More fundamentally the members of the scheme have an improved quality of life that cannot be accurately measured in economic terms.

Table 3.6.4(a) ***Discounted cash flow analysis on projected net annual cash flows of Z$ 9836.30***

DISCOUNTED CASH FLOW ANALYSIS (Z$)		INVESTMENT APPRAISAL (Z$)	
Investment Costs:		Initial investment	(-28114.27)
Installation of well	26612.00	yr1 cash flow	9836.30
Initial preparation of land	351.58	yr2 cash flow	9836.30
Fencing	1150.69	yr3 cash flow	9836.30
		yr4 cash flow	9836.30
Total investment costs	28114.27	yr5 cash flow	9836.30
		yr6 cash flow	9836.30
ANNUAL COSTS & RETURNS		yr7 cash flow	9836.30
Returns from vegetables	11766.90	yr8 cash flow	9836.30
ANNUAL COSTS		yr9 cash flow	9836.30
Pump Repair & Maintenance	1330.60	yr10 cash flow	9836.30
Cropping Costs	600.00		
Labour	0.00		
TOTAL ANNUAL COST	1930.60	IRR	=33%
TOTAL NET CASH FLOW (p.a.)	9836.30	NPV (@ 12%)	=55577.29

Table 3.6.4(b) ***Sensitivity analysis: Returns from vegetables decreased by 25%***

DISCOUNTED CASH FLOW ANALYSIS (Z$)		INVESTMENT APPRAISAL (Z$)	
Investment Costs:		Initial investment	(-28114.27)
Installation of well	26612.00	yr1 cash flow	6894.57
Initial preparation of land	351.58	yr2 cash flow	6894.57
Fencing	1150.69	yr3 cash flow	6894.57
		yr4 cash flow	6894.57
Total investment costs	28114.27	yr5 cash flow	6894.57
		yr6 cash flow	6894.57
ANNUAL COSTS & RETURNS		yr7 cash flow	6894.57
Returns from vegetables	8825.18	yr8 cash flow	6894.57
ANNUAL COSTS		yr9 cash flow	6894.57
Pump Repair & Maintenance	1330.60	yr10 cash flow	6894.57
Cropping Costs	600.00		
Labour	0.00		
TOTAL ANNUAL COST	1930.60	IRR	=21%
TOTAL NET CASH FLOW (p.a.)	6894.57	NPV (@ 12%)	=38955.86

This scheme is essentially a complement to the rain-fed farming of the area, but during the present drought it is clear that the scheme is very much a lifeline for people who otherwise would be in a desperate situation. The significance of the scheme is more apparent in the context of a drought but the benefits are likely to be similar even in a "normal" year.

It would perhaps be more appropriate to combine the conventional economic analysis with a study of the sustainability of the scheme (Tiffen 1989). By its very nature the economic analysis gives relatively more weight to the income stream generated sooner rather than later. This tends to give insufficient weight to the costs incurred in the maintenance of the scheme and to the costs and benefits that occur a long time in the future. It is argued by Tiffen that schemes such as the collector well and garden should be designed to be sustainable through time rather than to give a high rate of return. As such there should be more concentration on the socio-economic and institutional aspects of small-scale irrigation schemes so that they do not fail after just a few years. Social cohesion is essential to the ongoing success of such schemes and measures to maintain this, for example ensuring an equitable distribution of any benefits, and democracy and diplomacy in all areas, are important.

This small irrigation scheme generates costs and benefits that cannot be easily included in conventional economic terms. While the economic analysis suggests that the scheme would have a good rate of return, it is essential to be aware of the other less tangible benefits that make these schemes very attractive for rural development.

3.6.6 Discussions and conclusions

Rainfall throughout Zimbabwe has been extremely low this year, and in the Lowveld a serious drought now prevails. The drought is the worst in living memory. To date, this area (which is a low rainfall area anyway) has received only 70 mm, less than 20% of its normal rainfall. There is <u>no</u> rainfed cropping in Natural Regions IV and V, and many families are now suffering due to this lack of rain for farming. The garden at Tamwa/Sihambe/Dhobani Kraals is one of very few gardens still in operation due to the lack of water, and is providing a vital source of nutrition and income for scheme participants and nutrition for those purchasing the vegetables.

The motivation and determination of the women involved in the scheme is undoubtedly a key element in its success. They undertake most of the day to day gardening operations and are very much involved in decisions concerning the garden. It is essential that potential developments of the scheme are appropriate to them. It is interesting and instructive to compare experiences gained thus far at Tamwa/Sihambe/Dhobani Kraals with the experiences reported by Underhill (1990) in his definitive manual on small-scale irrigation in Africa. Many experiences reported by Underhill are pertinent to this first collector well garden. Impressions formed during the ongoing second season are:

(a) A single collector well and garden carefully sited can serve more than one village and provide water and vegetables for many people, but during periods of drought this single "good" well is placed under extreme pressure as other wells begin to fail.

(b) When a scheme is designed to serve several villages, great care is needed at all stages of design, construction and operation to ensure that each village is equally represented. Lack of social cohesion, for whatever reason, leading to poor management, can pose a serious threat to scheme success.

(c) Feelings of discontent may arise between families that benefit directly from a scheme and near neighbours who do not, perhaps typified thus : "The UK came to give this well (drinking water) for all of us, but you want to grow vegetables while we have no water to drink".

(d) Garden water use is considerably higher than domestic water use. Scope to save water lies predominantly within the garden. A saving of 20% within the garden would represent a very significant saving in terms of domestic water supply. Members of the garden recognise this need and, with time, are able to organise water user groups. They are in need of, and are requesting, advice on ways to save water and ways to use water more efficiently.

(e) Current planting arrangements are very formal, similar to those adopted in much larger-scale irrigation schemes. Water use efficiency could be improved if more informal planting arrangements were adopted. There is a tendency to operate irrigated gardens as scaled down versions of large irrigation schemes.

(f) Local irrigation schedules apply a constant amount of water during a season. Introduction of simple irrigation schedules, that express the increasing water requirements of the main crops (maize, tomato, rape, cabbage and okra) in terms of buckets of water per bed per week, may also help to improve water use efficiency of current irrigation methods, even before additional benefits of alternative methods of irrigation are introduced.

(g) Members of the garden are also requesting advice on pest management, in particular on low-cost safe methods of control for termites, cutworms, aphids, red-spider mites and centre-grubs, and advice on appropriate applications of manure for their vegetables.

(h) Further work by project staff and DRSS is needed to establish the practical guidelines needed for garden irrigation in the Lowveld. These guidelines should include simple irrigation schedules for the main vegetable crops grown, advice on crop establishment, planting arrangements, irrigation methods, pest control, and manuring. Dissemination of this information to people in the Communal Areas is vital. Liaison between staff of DRSS and Agritex, perhaps as a training and visit system, during development of these guidelines is needed.

(i). The system of bi-weekly irrigation in quarters, evolved during the ongoing second season, is successful both because it is manageable, with a maximum of only 13 members irrigating at any one time, and because it allows the collector well water level to recover sufficiently after each pumping.

(j) Participatory monitoring and record-keeping by members of the garden has been very successful thus far, and has contributed greatly to the information gathered.

(k) Pointers to the future success of this scheme and of others are :

* The enthusiasm and hard work shown by the people
* Their ability to organise, to learn, and to respond to change
* Their full appreciation of the benefits
* The ready market for vegetables, both near and far
* Excellent record-keeping
* Initial targets can be low in light of the prior situation
* The schemes once running can be independent of external inputs, with very low recurrent costs and negligible running costs to Government
* Drought (during drought there are very few alternatives)

(l) Potential reasons for temporary scheme failure may be :

* Well failure due to low recharge during prolonged drought
* Well failure due to increased demand during prolonged drought
* Well failure due to over-ambitious irrigation in the garden
* Lack of good local leadership
* Lack of social cohesion, leading to poor management
* Deterioration of groundwater quality (salinity or pollution)
* Declining fertility due to salination.

(m) Self reliance and independence from external inputs is very desirable. The spirit of self-help and self reliance, of the local people feeling that the scheme is theirs, is undermined if success or failure depends on external inputs over which they have no control. Pump maintenance will be an important component in this respect. Independence can be possible by providing only basic training, construction of a simple frame above the well to allow lifting of the pump/s, and purchase by members of the few tools and spare parts needed.

(n) Learning by doing may be slow. It is difficult to estimate at the planning stage the rate of uptake of new ideas by the local people. At Tamwa/Sihambe/Dhobani Kraals, the people have adapted to change and learnt quickly from their experiences. The presence of some members of the community with prior experience of garden irrigation has been important. No prior experience would be a difficult initial handicap. Flexibility during scheme installation and initial operation may be necessary at other sites.

(o) This project is a rural development project, not designed around production but around people, many of whom are very poor with no cash income prior to scheme initiation. Consequently, it is very difficult to assess economically. It is very difficult to quantify all of the benefits of a scheme for people who had very little before and few options if the scheme did not exist. Perhaps scheme appraisal based on conventional cost/benefit analysis, one of the indicators of which is rate of return of the project (heavily influenced by the early years and much less by the later ones) is not appropriate for this type of scheme. In the last resort, it may be better to measure success by whether the scheme is still working and being maintained five years after installation, and whether neighbouring villages are still requesting similar schemes of their own.

3.7 FUTURE ON-FARM TRIALS

3.7.1 Activities funded by ODA Engineering Division R & D funds

On-farm trials during the 1992 "dry" season and the 1992/93 "wet season" will include further evaluation at the farm level of subsurface irrigation using clay pipes manufactured by the scheme participants themselves and the use of simple mulches to reduce soil evaporation losses. Demonstration plots will be set up in the LVRS and Tamwa/Sihambe/Dhobani Kraals gardens to show the advantages of improved irrigation schedules and less formal planting arrangements in terms of water use efficiency and, to a lesser extent, pest management.

The overall performance of the Tamwa/Sihambe/Dhobani scheme will continue to be monitored closely to gain information on water use, water management, crop yields, social cohesion, social and nutritional benefits and economic performance.

Although there is currently no cropping on the gardens at Chamabhuku and Bedzanhomba as a result of the drought, it is planned that data will be collected on these gardens should cropping be possible during the 1992/93 rainy season.

3.7.2 Activities funded by ODA Technical Cooperation funds

The British Development Division for Southern Africa (BDDSA) has agreed to provide ODA Technical Cooperation (TC) funds for the construction and monitoring of a further six collector well gardens. If successful technically, socially and economically, it is envisaged that this project will be the precursor of a much larger project that will aim to install up to one hundred collector well gardens in the drier areas of Zimbabwe.

3.7.3 Activities funded by Plan International

Plan International (PI), which is a non-governmental organisation with an office in Chiredzi, has offered to fund the construction of six collector well gardens as part of their long term development programme in Zimbabwe. The performance of these gardens will be monitored by PI staff. In order to minimise costs, construction of the PI-funded collector well gardens will take place at the same time as the construction of the ODA-funded gardens.

4. Acknowledgements

We are grateful to the Engineering Division of the British Overseas Development Administration (ODA) for the financial support for this project. We would also like to thank the Director of Zimbabwe Department of Research and Specialist Services for permission to carry out this work in collaboration with DRSS, and colleagues in Zimbabwe, Mr I Mharapara, Mr E Jones and Dr H Rendell, for their advice and support. We would also like to thank Mr S Mhlauri and Mr Dube who nobly assisted in collection of all field data, and Mr D J Banga for help in soil analyses.

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Appendix 1 Staff involved in the project during 1991/92

Lowveld Research Stations (PO box 97, Chiredzi, Zimbabwe)

Mr I Mharapara (Head of Station)
Miss M Murata (Agronomist)
Mr E Mazhangara (Economist)
Mr D J Banga (Laboratory Technician)
Mr M Brown (TCO Economist)
Mr E Jones (TCO)
Dr H Rendell (TCO)
Mr S Mhlauri (General Hand)
Mr Dube (General Hand)

Institute of Hydrology (Wallingford, Oxfordshire, OX10 8BB, UK)

Dr C H Batchelor (Head of Agro-Hydrology Section)
Dr C J Lovell (Agricultural Engineer)
Mr A J Semple (Economist)
Miss C L Abbott (Agricultural Water Management)
Mr J P Bell (Soil Physicist)
Mr H Gunston (ODA Programme Coordinator)
Mrs M Turner (Instrumentation)

British Geological Survey (Wallingford, Oxfordshire, OX10 8BB, UK)

Dr R Herbert (Chief Hydrogeologist)
Mr P J Chilton (Hydrogeologist)
Mr J C Talbot (Hydrogeologist)
Mr P Rastall (Contract driller)

Min. Energy, Water Resc. and Dev. (P. Bag 7112, Causeway, Harare)

Mr G Nhunhama (Chief Hydrogeologist)
Mr M Mtetwe (Hydrogeologist)
Mr M Sharpe (TCO)
Mr Msika (MWD, Masvingo)

Agritex The following Agritex officers have assisted the project during 1991/92

Mr J Maswayia (PAEO, Masvingo)
Mr Shumba (Assist. PAEO, Masvingo)
Mr D Pagare (DAEO, Chiredzi)
Mr K Madzikanda (AEO, Chiredzi)
Mr Guni (AES, Chivi)
Mr A Mahlekete (AEW, Chivi)

Appendix 2 Checklist of questions in survey of current patterns of garden irrigation

Name and location of garden:
Cooperative or private garden:
Number of gardeners:
Owner(s) of the garden:
Total size of garden:
How is garden divided (equal plots, ridges, beds ....)?
What is grown in the garden (vegetables, fruit, maize, other)?
Water provided by a borehole, well or river:
Any problems of water shortage, perhaps seasonal:
Are water user groups employed:
Type of pump:
Problems with pump:
Type of water tank:
Distribution of water (by bucket, hosepipe etc):
Name of individual gardener (Mr or Mrs):
Area of garden worked:
Number and type of plots, beds or ridges (eg. bunded, raised, ridged)
Dimensions of beds or ridges:
Soil type:
Crops grown in winter:
No. of beds per crop:
No. of plants per bed:
Estimate of total yield of each crop (kg/bed converted to kg/ha):
Irrigation schedule used:
Estimate of total use of each crop (tins/bed/week)
    early in the season for ? weeks: later in season for ? weeks:
    estimate of rainfall (mm):
Total water (mm)/bed/season converted to cubic meters/ha:
Irrigation schedule used:
Estimate of total use of yield of each crop (tins/bed/week)
    early in the season for ? weeks: later in season for ? weeks:
    estimate of rainfall (mm);
Total water (mm)/bed/season converted to cubic meters/ha:
Calculated crop water use efficiency of each crop (kg/m^3):
Any water saving devices employed at any time eg. mulch:
Any ideas for improving water use efficiency:
Proportion of each crop sold or grown for home consumption:
Where are crops sold?
How are crops sold (as a cooperative or sold privately)?
Estimate of annual income from each crop:
Estimate of annual expenditure on the garden:
    (e.g. for seed, fertilisers, chemicals, fence maintenance etc.):
Estimate of annual profit from gardening:
Any hopes or ideas for the future:

Appendix 3 Soil profile description for the community garden at Tamwa/Sihambe/Dhobani kraals

PROFILE DESCRIPTION

0-15 cm — Very dark grey (10YR 3/1d;3/1 m) medium grained sandy clay; dry hard consistence; strong medium subangular blocky structure; few small quartz stones; good permeability; moderately well drained; fairly numerous roots. Clear smooth transition to :

15-46 cm — Dark greyish brown (2.5Y 4/2 m) clay with faint light olive brown (2.5Y 5/6 m) mottles; many coarse carbonate concretions; few soft, powdery carbonates; dry extremely hard consistence; common shiny pressure faces; strong coarse subangular blocky and columnar structure; few small quartz stones; moderately restricted permeability; moderately poorly drained; fairly numerous roots. Gradual smooth transition to:

46-120 cm — Similar clay with prominent light olive brown (2.5Y 5/6 m) mottles; few coarse carbonate concretions; moist friable consistence; wedge shaped coarse subangular and columnar structure; well developed slickensides; common pressure faces; moderately restricted permeability; poorly drained; occasional small quartz stones; occasional roots.

Chemical analysis of soil probe

			Depth
	0-15 cm	15-46 cm	46-120 cm
Texture	med sandy clay	clay	clay
Clay %	37.00	49.00	61.00
Silt %	16.00	12.00	11.00
Fine sand %	26.00	17.00	14.00
Medium sand %	11\00	8.00	5.00
Coarse sand %	11.00	14.00	8.00
Gravel %		18.00	18.00
pH ($CaCl^2$)	6.20	7.30	8.00
Carbonates %		4.40	1.10
Ex Ca (meq/100 g)	12.60	70.90	38.60
Ex Mg (meq/100 g)	12.30	27.40	31.80
Ex Na (meq/100 g)	0.34	2.53	4.33
Ex K (meq/100 g)	0.22	0.08	0.03
Total Ex Bases (meq/100 g)	25.50	32.50	38.10
CEC (meq/100 g)	26.20	32.50	38.10
Base Saturation %	97.00	100.00	100.00
E/C	71.50	65.70	62.50
S/C	69.70	65.70	62.50

Appendix 4 Breakdown of costs for scheme construction at Tamwa/Sihambe/Dhobani kraals

Date	Item	Cost (Z$)
02/01/91	15 LENGTHS 50 mm CLASS 4 PVC PIPE (BESTOBELL, CHIREDZI)	198.00
	1 RAINGUAGE	11.63
	1 500 ml PVC GLUE	11.58
	1 HACKSAW	30.03
	1 ROLL 16 Ggc BARBED WIRE (960 metres)	147.82
	1 kg WIRE NAILS (FARMERS COOP, HARARE)	6.13
	2 15 mm PSM WATER METERS C/W CONNECTORS (ABB KENT INTERNATIONAL, HARARE)	173.80
11/01/91	20 BAGS CEMENT @ 13.90 (LESS 9.1%)	253.09
	6 ROLLS PIG NET WIRE @ 129.81 (50 m x 3 ft x 3 ins) (LESS 9.1%)	708.06
	12 x 2 m GUM POLES @ 3.25 (ENJAY SALES, NGUNDU)	39.00
22/01/91	16 kg (368 m) 12 Ggc PLAIN WIRE @3.50 (FARMERS COOP, HARARE)	56.00
24/01/91	4 rolls (80 m) 115 mm BRICKFORCE @9.96	39.84
	1 50 mm PVC BP90 BEND	13.51
	2 50 mm PVC BP45 BENDS (PG CHIREDZI)	27.02
28/01/91	12 x 2 m GUM POLES @ 3.25	39.00
	20 BAGS CEMENT @ 13.90 (LESS 9.1%) (ENJAY SALES, NGUNDU)	253.09
30/01/91	2 x 32-15 mm GALV. RED SOCKETS @ 3.36	6.72
	2 x 40 mm PVC VALVE SOCKETS @ 5.60	11.20
	1 x 5 LITRES CARBOLINEUM PRESERVATIVE	21.67
06/02/91	4 rolls 6" BRICKFORCE @ 8.60	34.40
	6 m x 2.4 m REINFORCING MESH (N RICHARDS, CHIREDZI)	40.15
08/02/91	2 x 40 mm BRASS GATE VALVES @ 94.00 (BESTOBELL, CHIREDZI)	188.00
	1.2 m x 40 mm GALV. STEEL PIPE @ 31.35/m	37.62
	2 x 40 mm-15 mm RED. VALVE @ 9.70 (CHIREDZI PLUMBING)	19.41
11/02/91	1 x 5 litres CARBOLINEUM PRESERVATIVE (ENJAY SALES, NGUNDU)	19.03
25/04/91	6 m x 40 mm GALV STEEL PIPE	272.28
	1 x BRASS PADLOCK (PG CHIREDZI)	20.13
26/04/91	3 x 1.5" ELBOWS	45.75
	1 x 1.5" BRACKET	2.62
	5 x THREADING STEEL PIPE (CHIREDZI PLUMBING)	12.50

27/05/91	4 x 40 mm GALV SOCKETS	83.36
	5 x 50 mm PVC-GALV PIPE CONNECTION	43.55
	2 x 50 mm PVC 135 BENDS	27.56
	1 x 125 ml PVC CEMENT (PG CHIREDZI)	4.55
06/06/91	25 m x 1" ANGLE IRON (FREDERICK STEEL, HARARE)	113.98
14/06/91	2 x 8' x 4' BLACK STEEL SHEET (CHIREDZI PLUMBING)	145.20
	5l ALUMINIUM PAINT	94.28
	1l PRIMER FOR STEEL (CHIREDZI AGENCIES)	12.15
04/07/91	5 PKTS CEMENT (PG CHIREDZI)	92.00
15/07/91	2 x 1.5" GATE VALVES (STEWART AND LLOYDS, CHIREDZI)	225.72
15/08/91	20 PKTS CEMENT (PG CHIREDZI)	304.80
		Z$3886.23

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Environment
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Council

Institute of Hydrology Wallingford Oxfordshire OX10 8BB UK
Telephone Wallingford (STD 0491) 38800 Fax 0491 32256 Telex 849365 Hydrol G

The Institute of Hydrology is a component establishment of the Natural Environment Research Council