IRRIGATION OF ACACIA AND EUCALYPTUS SPECIES WITH WATERS OF DIFFERENT SALINITIES IN A SEMI-ARID ENVIRONMENT IN FORMENTERA, BALEARIC ISLANDS.

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VOLUME CONTAINS CLEAR OVERLAYS

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ABSTRACT

The study investigated whether good growth rates could be obtained for trees in a semi-arid environment (Formentera, Balearic Islands) using small quantities of highly saline irrigation water. Soil improvement and avoidance of detrimental long term effects was a prime objective.

Two species, Eucalyptus gomphocephala D.C. and Acacia saligna (Labill.)H.Wendl. were tested with four irrigation treatments. Irrigation volume and frequency were calculated by evaporation pan and tensiometer balance. No allowance other than winter rainfall (approximately 300mm) was made for leaching. Half the trees were watered for two seasons and half for four seasons. The experiment showed that these low demand species survived and grew well on calcareous silt of at least 25cm. depth when irrigated with saline water up to 10dS/m during the first two summers. Mortality increased rapidly on soils less than 25cm deep. Results were confirmed by later plantings.

Analyses showed that the winter rain effectively leached the soil. Exchangeable sodium percentages rose during the irrigation season and fell during the winter. ESPs fell to pre-irrigation levels after irrigation ceased. Monitoring of litter and organic matter demonstrated an improved soil under the trees. Four years after all irrigation ceased, tree height, survival and soil factors were re-examined. Previous trends continued to operate. The experiment demonstrates a low cost and effective technique for rapid tree establishment with low quality water which could have a wide application in semi-arid zones.

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CHAPTER 1. INTRODUCTION AND LITERATURE.

> 'The irrigation water requirement of tree species under specific growth conditions are usually imperfectly known and require research.' Armitage 1985.

1.Aims and Introduction.

The aims of this investigation were:

1. To determine whether establishment and vigorous early growth could be achieved for tree species in semi-arid conditions using water generally considered too saline for agriculture;

2. To determine whether good growth could be achieved using very much smaller quantities of water than has been customary and relying on winter rainfall alone for leaching;

3. If such growth rates could be demonstrated, to determine whether it was possible to maintain them without damage to soils;

4. In the later part of the study, to explore the long term implications of such plantings in order to define the sustainability of benefits, to quantify such benefits by analysis of soil nutrients, litter, organic matter and

soil fauna and to see whether the tree cover achieved constitutes a useful method of environmental upgrading and of turning hitherto unproductive land to better economic use;

5. As a subsidiary study if the initial plantings should prove successful, to plant seed of the same species as those used in the initial plantings, but of local provenance, and compare the growth characteristics with those of the original plantings.

Environmental degradation has been continuing for many thousands of years. Man and his animals have been actively causing changes in the original vegetation cover of the land throughout history. Fire has been used for deforestation from upper Palaeolithic times until the present day. In western Mediterranean lands, goats, sheep and pigs have been important causes of deforestation since the fifth century B.C. The introduction of the camel into North Africa in the fourth century A.D. aided this process. The use of charcoal, in a world where fuel resources are scarce, has been another important factor in the dwindling areas of forest cover. There are reports of flooding and soil erosion since ancient times. Plato (428-348BC) said 'There are mountains in Attica which can now keep nothing more than bees, but which were clothed not so very long ago with fine trees, producing timber....The annual supply of rainfall was not then lost, as it is at present, through being allowed to flow over a denuded surface to the sea.' There is also evidence of increased flooding in the Tiber after deforestation in the second century B.C.(Houston 1964). Environmental degradation is no new phenomenon.

At the present time, Thomas (1993) estimated that in 1992 a global total of 1035.2 million hectares of susceptible drylands were currently suffering soil degradation. Evans (1992) quoting FAO figures gave an estimate of a potential loss of 544 million hectares of rainfed arable land in the developing countries if conservation measures are not taken to prevent erosion and degradation.

The extent of the world's arid and semi-arid lands is shown in Figure 1. In arid and semi-arid lands of the Mediterranean and elsewhere the regeneration of degraded land is, by the nature of the factors involved, more difficult than regeneration in areas where soils and climate are more favourable to plant growth. The most limiting factor is water. Rainfed forestry in these zones is at best slow and problematic and at worst encompasses the possibility of complete failure. For agriculture, irrigation has been introduced where possible to raise low and unpredictable yields. Rainfed trees in arid and semi-arid zones also have low and unpredictable annual

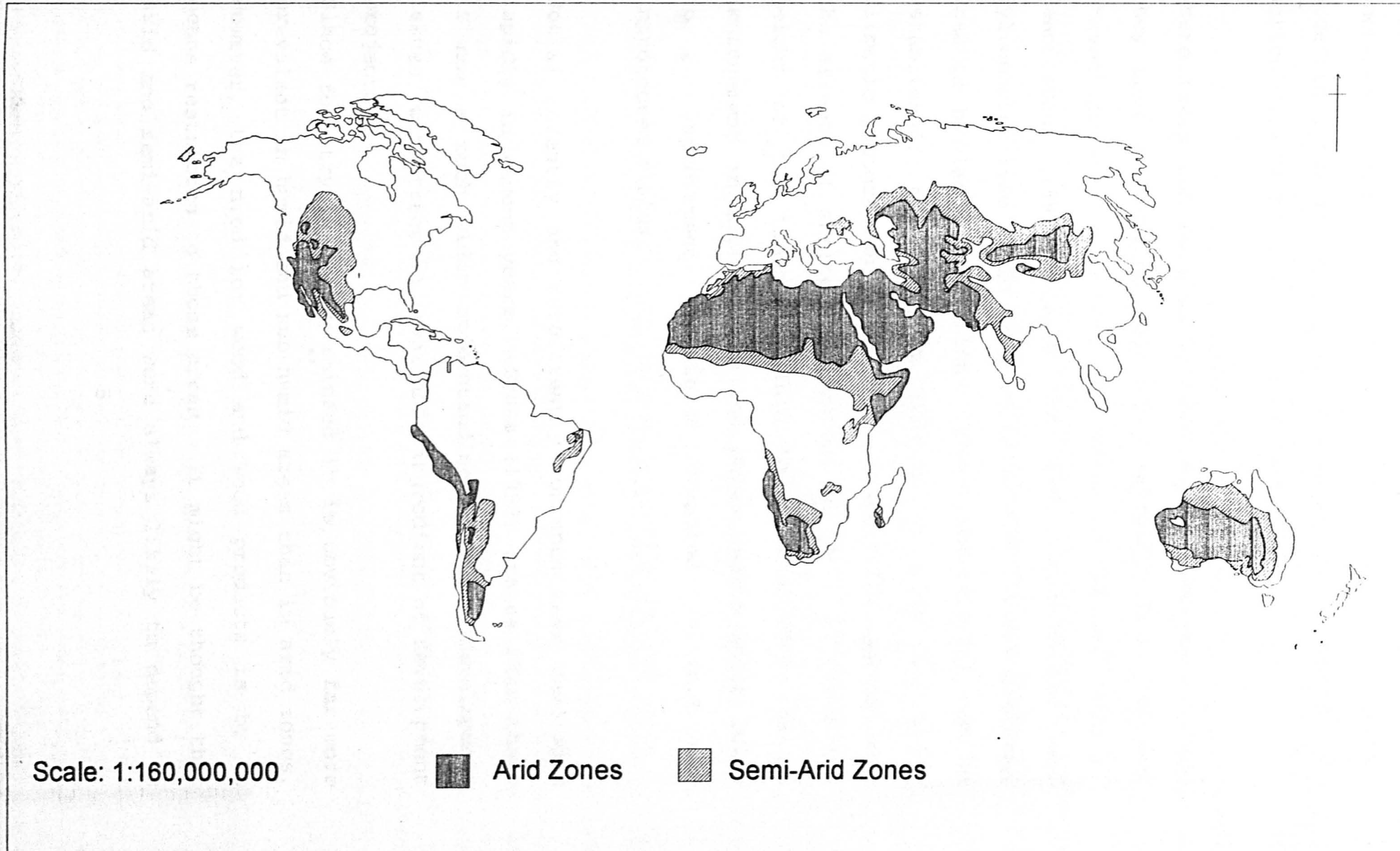


Fig 1. **Arid and Semi Arid Zones of the World** (After Adams et al) 1978

increments, but there is often no good quality water accessible for forestry. Where good water is accessible, agriculture is frequently the preferred use.

Where trees can be planted once more on degraded lands, they have a positive role in stabilising the soil and preventing erosion as well as improving the soil status. LeHourerou (1990) points out that agroforestry and sylvopastoralism could help to solve the various problems created by land degradation. Where shelterbelts can be established, the damaging effects of wind and other climatic factors can be reduced. Zohar (1985) states that the effects of shelterbelts extend up to 12-20 times the height of the trees. Within this range there is an improvement in microclimate and water regime which leads to an improvement in yields compared to open and unprotected fields.

Social forestry and agroforestry concepts have developed rapidly in recent years. Evans (1992) states that there is now a much wider understanding of rural development issues, with trees an invariable ingredient of development projects.

Since forestry is mainly rainfed it is obviously far more prevalent in humid and sub-humid areas than in arid zones. However, the need for wood and wood products is by no means restricted to those areas. It might be thought that arid and semi-arid areas were always likely to depend on

more humid zones for the bulk of their wood and wood products, but in practice it is uneconomic to transport bulky loads
for long distances. Trees in these areas are also necessary and desirable for other reasons. Small plots of trees produce both direct and indirect benefits. Direct benefits include income, food and fodder. Zohar (1988) writes that one of the most pressing needs in the arid and semi-arid regions of most developing countries is an adequate, renewable supply of firewood for local village use. Evans (1992) points out that a simple eucalypt woodlot can provide shade, shelter, soil protection and bee-pasturage as well as firewood and poles. Many researchers (Barragan et al 1978 and Chaturvedi 1984 among others) agree that apart from the benefits of the timber, the planting of forest trees will improve the porosity of the soil and in general have a beneficial effect over adjoining cultivated lands. Ray (1984) and Evans (1992) point out many advantages, among them increased income for farmers, lops and tops for fuelwood, checking of soil erosion, reduction of wind velocity and consequent reduction of water loss. Thus the valuable role of trees in arid and semi-arid areas is well documented. One of the most important indirect benefits of trees is environmental protection. Other indirect benefits are the saving of time and energy spent in carrying fuelwood from distant sources, the ameliorative effect of windbreaks in reducing wind velocity and thus evaporation, shade,

aesthetic values and enhancement of the quality of life. The net deficit of forest biomass production leads to a depletion of the natural resources, severely affecting both human life and the environment. Recent increases and concentrations of human population, especially in arid and semi-arid lands have depleted natural biomass still further and strained the basic means of producing more (Armitage 1985). Demand for trees and wood has increased at least as fast and sometimes faster than human population.

In the cases where irrigation has been used to grow trees on degraded sites, they have often had a spectacularly beneficial impact on the environment (for instance, Boyko and Boyko's Desert Garden at Eilat 1964). However, in low rainfall areas without irrigation, the success of such plantings is problematic. Many trees, even of drought resistant species, die before they can establish themselves securely. Where water is available for irrigation, there is a much better chance of successful establishment. But increasing demands on water resources for human and agricultural use means that irrigated forestry has a very low priority. The intense competition for good quality water in areas where irrigation of agricultural crops is practised means that water available for forest irrigation is often of inferior quality. In many areas supplies of water have been overtaken by demand and no high quality water is available for forestry. Thus the investigation of the use of low quality water for tree establishment assumes increasing importance.

In recent years, arid zone forestry research has focused on the introduction of fast growing tree species and on planting techniques adapted to arid and semi-arid conditions. In spite of great efforts in this direction, lack of water has often limited the performance of these trees. Irrigation remains mainly directed to food production and seldom to tree crops. Various strategies have been employed to compensate for lack of water for forestry in arid and semi-arid areas. Interesting projects include rainwater harvesting (Zohar et al 1988 among others). Sandell et al (1986) report species trials for dryland tree establishment near Alice Springs, Australia with good survival rates for some Eucalyptus species. Weber (1986) and Evans (1992) report a common practice for small scale planting, the insertion of a permeable container in the root zone which is filled with water once a week during establishment, instead of irrigating the trees directly. Muthana and Kolarkar (1984) report a system for tree establishment consisting of a bag filled with water suspended from a pole, to provide a small amount of water in the crucial early phase.

In 1974, the International Development Research Centre funded research to study the effect of irrigation on tree crops. Results were contradictory. Some projects reported spectacular success and some had ended in complete failure. Where pure forestry plantations were concerned, the

likelihood of failure was greater than in projects associated with agricultural crops and those using excess or waste water (Armitage 1985). There were various reasons for lack of success, one of them being the failure to select suitable species for survival and rapid early growth in these conditions.

There are many studies of afforestation for the amelioration of salt affected lands, but few involving the use of saline water for forestry. Irrigation water always contains impurities in the form of dissolved and/or suspended solids. The amount and type of these impurities determines its usefulness for irrigation. Where there are high levels of salts, various strategies are employed to overcome the salinity problems. Salt accumulation under saline irrigation can cause physical deterioration of the soil as a result of high concentrations of exchangeable sodium (Ayers and Westcott 1985). Previous trials of forestry irrigated with highly saline water have usually taken place on very sandy soils (Boyko 1968, Hallsworth 1981, Zohar 1982). The minimal clay fraction and permeable nature of these soils, which allows quick percolation, render them less liable to damage than soils with a greater clay content. Where trials have taken place on non-sandy soils, copious quantities of water have been used to leach the saline water through the soil. Cointepas 1968, van Hoorn et al 1968 and Arar 1975 have reported results that depended on frequent applications of small quantities of water, correct drainage and periodic leaching.

Even where water quality is good, if water has been allocated to forestry in arid and semi-arid areas, large quantities are commonly used. In Pakistan, water allocation for forestry crops in the Indus plain is generally on the basis of 70 cusecs/100 acres (equivalent to 1460 mm of rainfall). Sheikh (in Armitage 1985) gives figures of 910-1220mm for optimum growth for Dalbergia sissoo and Lerche and Khan (1967) suggest 1370mm for forest plantations generally. There have been few studies of water requirement for irrigated forestry. Some work has been done on optimum irrigation regimes (Shalhevet et al 1976). Stewart et al (1986) have reported successful establishment of several large plantations in dry areas of Australia, irrigating with recycled sewage effluent at rates of 800 to 1000mm/year. Evans (1992) confirms that generally, sufficient water is applied to irrigated plantations to raise the total water received by a site to about 800-1000mm.

Most schemes for irrigated plantations are concerned, naturally, with maximum volume timber production. There is very little published work on minimum quantities necessary for survival and growth. When water supplies are limiting, this is surely an important question. Wood (1977) states

that it is logical to raise trees with the minimum water necessary for survival and steady growth.

Criticisms, sometimes well founded, have been levelled at the use of exotic species for forestry in arid and semi-arid lands. In some cases, these criticisms ignore the fact that it would be difficult if not impossible to re-introduce indigenous species. The land has often been so destroyed and degraded that the conditions necessary for the growth of the original species no longer exist. Tough exotics, adapted to extreme conditions, are frequently the only trees that will survive and grow. It is true that, in the race for wood, some countries have removed indigenous vegetation from large areas and replaced them with exotics, often of species which were unsuitable in ecological terms. Where this and other economic and ecological factors (soil and climatic data) were insufficiently studied, results have included not only the failure of the plantations, but also soil erosion and declining water tables (Skutsh 1983, Gartner 1985). It is often postulated that these undesirable effects would not have occurred had native species been used (Gartner 1985).

In spite of such disasters, there is a clear need for irrigated forestry in arid and semi-arid lands. When this is combined with the intense competition for the limited supplies of good quality water, the investigation of the use of lower quality waters for irrigated forestry assumes increasing importance. Armitage (1985) points out the need for forestry in arid and semi-arid areas at all scales from small local shelterbelts to large plantations.

1.2. Literature Review.

The literature was reviewed for findings on salinity levels for irrigated forestry, irrigation rates employed, growth achieved and the effects of such irrigation on the environment in arid and semi-arid conditions.

1.2.i. Salinity of the Irrigation Water.

In the literature, salinity is characterised in a number of different ways. These include dS/m and total dissolved solids (TDS) in ppm (= mg/l). In this thesis, salinity units will be expressed as electrical conductivity (EC) at 25 degrees C in dS/m. Some equivalents given in the literature are as follows:

Table 1. EC/TDS Equivalents.

	EC dS/m	TDS ppm(mg/l)		EC dS/m	TDS ppm(mg/l)
Allison(1964)	0.14	85	Bresler,McNeal	0.40	250
	0.50	496	and Carter	1.20	750
	1.00	741	(1982)	2.25	1450

1.13	753		5.00	3200
1.95	1210			
2.50	1860	Ayers and		
6.00	3775	Westcott(1985)	0.70	450
8.16	5620		3.00	2000
8.62	5900			

These equivalents are roughly compatible. Other reported equivalents diverge where ionic composition of the salts differ. For the purposes of this thesis, an arbitrary conversion factor of 700 ppm TDS per dS/m has been derived from Table 1 and applied to those papers where dS/m figures are not given. This cannot be strictly accurate as the ionic composition of the salts is seldom known, but is done for comparison purposes only. Where figures have been given in ppm or mg/l, these figures appear first and the estimated equivalent EC figures using the above factor afterwards, in brackets.

Saline groundwater is relatively plentiful in arid areas but sweet water is scarce (Yadav and Tomar 1981 among many others). Because of the need, in such areas, to make use of all available water, much work has been done on the possibilities of these waters for irrigation of agricultural crops. Much less has been done on their use for forestry.

Estimates of maximum usable levels of water salinity vary widely. Some estimates are remarkably low. Goor and Barney (1968) state that water containing less than 100ppm NaCl (0.15dS/m) is usually suitable for irrigation but that some species will tolerate waters of 100-400ppm (0.15-0.6dS/m), waters above this level being generally unsuitable.

Neelay and Dhondiyal (1985) used industrial effluent of 1300-1700 mg/l (2 -2.5 dS/m) to raise 13 tree species in Nepanagar, India with good results and Paliwal (1986) reports that water with a salinity of 1000 ppm (1.5 dS/m) can be used for eucalypts in Rajastan. Stewart et al (1986) give an overview of Australian experience of using sewage effluent for tree irrigation and report successful results with waters of 1.2-1.25 dS/m.

In contrast, Firmin (in Boyko and Boyko 1968) in successful experiments in Kuwait used waters of up to 65000ppm (93dS/m) (greater than seawater concentrations) for raising a variety of trees, notably <u>Prosopsis</u>, <u>Zizyphus</u>, <u>Eucalyptus</u> and <u>Tamarix</u> spp. on sandy soils.

Among other work of this period, the outstanding example is that of Boyko and Boyko (1968) who planted about 200 different species, many of them trees, on the sandy gravel hills outside Eilat (rainfall less that 20mm per year) and irrigated them with waters ranging from 2000-6000ppm (3-8.5dS/m). Exact survival rates are not given, but they report that survival was very high and that 15 years later, the area was 'as green and adorned with parks and gardens as any city could ask for'.

It is not in doubt that trees can be raised using highly saline irrigation water. Pot experiments using Acacia saligna with levels of saline irrigation up to 240meq/l NaCl (7.8dS/m) were undertaken by Shaybany and Kashirad (1978) with high survival rates in spite of growth reduction.

Tomar and Yadav (1980) conducted similar experiments on a wider range of tree species with waters of up to 10dS/m. They also found that growth rate slowed and mortality increased with higher salinity but that sensitivity to salinity varied greatly between species and that some survived with the most saline water. The same authors in a later study (Yadav and Tomar 1981) concluded that successful growth of Eucalyptus hybrid could be expected on light textured soils of up to 8.5dS/m, pH9.4 and sodium adsorption ratio (SAR) about 60.

Jain and Muthana (1982) in a nursery study at Jodhpur of 6 tree species found that waters of up to 9dS/m could be successfully used for irrigating trees. Tomar and Yadav (1982) studied Albizia lebbeck under saline irrigation and found early growth satisfactory up to about 6.7 dS/m. Gupta et al (1991) used levels up to 15dS/m for raising Eucalyptus and Acacia spp. In California, Tanji and Karajeh (1993) used waters of 10 dS/m for irrigating eucalypts.

The reports of Wood et al (1975) on indigenous trees and

Hallsworth (1981) on exotics in large scale irrigated plantings in Abu Dhabi state that waters ranging from 2500 to 16000 ppm (3.5 to 22.8dS/m) were used for the successful establishment of trees, among them Eucalyptus spp. Casuarina glauca and Prosopsis juliflora.

Adequate drainage or leaching is vital. Metro (in Kaul 1970) describes the establishment of small amenity plantations and shelterbelts in Algeria where mainly Eucalyptus spp. were planted. Heavy doses of saline water, 1.8g/l (2.5dS/m) were used so that water would penetrate to 1-2m, and large quantities of water were used for leaching where tree symptoms indicated that salts were building up. Growth was rapid and survival high. Jain and Pareek (1989) in Jodhpur, India, irrigated date palms with water of up to 9 dS/m and report that the soil was effectively leached by the seasonal rainfall. They do not give precipitation figures.

Experiments have been carried out using mixtures of saline and non saline waters in different proportions. Gavande et al (in Dregne 1976) working in Mexico with two sources of water one of low and one of high salinity, 0.46 and 6.5dS/m respectively, used different treatments of saline water and best available water (BAW) and alternate irrigation of the two waters and found that growth rate of grapevines and pistachio did not appear to be affected by salinity. The sample, however, was small, two trees for each treatment with replication x2 or x3.

Meiri and Plaut (in Pasternak and Pietro 1985) found no evidence for the widely held belief that a reduced irrigation interval using saline water improved crop yield. They confirm previous findings that the use of better quality water in the seedling stage, where this is possible, may have a beneficial effect on growth and survival of trees subsequently irrigated with brackish water. They found that intermittent but heavier leaching was more effective than leaching at each irrigation.

Most researchers agree that very highly saline waters can only be used for irrigation where soils have an extremely low clay fraction. In the studies mentioned above as using waters of extremely high salinity (Boyko and Boyko 1968, Firmin 1968, Wood et al 1975, Hallsworth 1981) the soils were almost pure sand.

1.2.ii. Secondary Salinity.

A most important environmental problem when using saline water for irrigation is the build up of salts in the soil -secondary salinity caused by irrigation.
Secondary salinity can be caused in several ways. Where water tables are near the surface, irrigation can cause groundwater to rise. Where the irrigation or the groundwater itself is saline, the rise in groundwater will

inevitably bring salts into the root zone.
Where water tables are at sufficient depth to make a rise in groundwater unlikely, secondary salinity can also occur where inadequate water is applied or where a high evaporation rate brings salts to the surface. Though some evaporation from a soil surface under irrigation is inevitable, it is undesirable as it leads to upward movement of salts in the soil profile. A leaching fraction (LF) is normally allowed to wash the salts through the soil.

Cointepas (in Boyko and Boyko 1968) among others reported on a Tunisian project near Sfax (ET 5.5mm/day, Precipitation 220mm/year) where 6.9mm/day of water containing up to 4g/l (5.7dS/m) salts was applied to vegetable crops. (ET = maximum evapotranspiration from a full leaf canopy with water unlimiting). This irrigation rate was in excess of ET and therefore adequate for leaching (approximate LF 0.2) but it caused a rise in the water table (ground water salinity varied between 7-11 g/l (10-15.7 dS/m)) of 3m in 4 years resulting in overall crop reduction and 20% barrenness. The situation was remedied by the installation of tile drains.

Where rising water tables and waterlogging are not a problem, secondary salinity can nevertheless affect soils and tree growth. Shainberg and Oster (1978) explain in detail the theoretical mechanism of the build up of salts resulting from saline irrigation, with depth of soil and changes in salinity due to evapotranspiration (the extent of change depending on amount and frequency of irrigation) as well as uniformity of application and rate of water uptake by plants. With a leaching fraction (LF) of 0.3 the vertical distribution of EC of the soil water (Sw) will be relatively uniform. At lower LFs the ECSw at the bottom of the root zone will be 5 to 20 times that at the soil surface.

Shalhavet (in Yaron et al 1973) gave detailed guidelines for predicting salt build up under saline irrigation and applying the correct amount of water to prevent adverse effects. Ayers and Westcott (1985) gave formulae for the calculation of the leaching requirement and figures for crop tolerance and yield potential of field, vegetable, forage and fruits crops as influenced by irrigation water salinity or soil salinity. Apart from the fruit crops, no figures are given for trees.

Singh et al (1989) in a report on groundwater problems in central India state that anthropogenic salinity-sodicity of the soil is associated with tank irrigation, inadequate drainage and use of poor quality groundwaters. On the other hand Jain and Pareek (1989) - see above - irrigated date palms with waters of salinities as high as 9dS/m and reported that the monsoon rain was adequate for leaching.

Many researchers have studied the problem of salinity build up with or without waterlogging, among them Wood et al (1975) and Yadav (1980) and have proposed methods for overcoming the problems. Wood et al state that when waters of high salinity are used for irrigation it is desirable either to use relatively large quantities in order to minimise build up of salts in the rooting zone, or to reduce surface evaporation to a minimum by mulching and to ensure maximum utilization of water by the plants. They specified a maximum water requirement of 9000 litres/ha/day using waters with salinities of 2500-7000 ppm (3.5 - 10dS/m) for raising Acacia, Prosopsis and Zizyphus spp. in Abu Dhabi on sandy soils with annual precipitation of less than 100mm. 200 trees per hectare were planted and irrigated by drip.

Tanji and Karajeh (1993) in their high salinity irrigation in California state that after several years of drain-water reuse a considerable build up of salinity had occurred throughout the profile and that the leaching fraction would need to be increased. Yadav and Tomar (1981), in pot experiments with Eucalyptus hybrid using waters of 2-10dS/m, found that the addition of gypsum and farmyard manure appeared to minimise the adverse effects of salinity.

Armitage (1985) summarised a large body of work and made the following recommendations:

Flexible irrigation schedules to match the net quantity required to replace ET and meet leaching needs after taking effective rainfall into account

Site grading, construction of watering arrangements and control of application that meet standards which ensure uniformity of irrigation in space and the proper amounts of time

Treatment of water to remove excessive salts, where this is possible

Leaching of excessive salts from the soil

Tile and other drainage systems to remove excess soil water rapidly and carry it out of the area

Effective monitoring of qualitative and quantitative changes in the relevant soil and soil water properties so that action can be taken to deal with problems as they arise, as soon as they begin to lower site productivity.

Prevention of damage rests mainly on design of the system and on irrigation regimes calculated specifically for each site and crop. The balance between sufficient water for leaching and the avoidance of overirrigation which would lead to the build up of salts and, in some cases, to waterlogging, is critical.

1.2.iii.Water Requirement.

Estimating the water requirement of irrigated trees is complicated by the question of the salinity of the irrigation water.

Salt in the soil water decreases the soil water potential and therefore decreases the availability of water to the tree. Excessive soil salinity, whether the soil itself is saline or whether caused by saline irrigation therefore makes it more difficult for water to be taken up by the roots. Hence, a management objective is to improve soil water availability to the crop. Using tolerant species, applying the appropriate fertilizer if necessary, irrigating more frequently and using additional water for leaching are some of the techniques used to achieve this.

The question of quantity of irrigation water and frequency of application is therefore crucial where irrigation with saline water is employed.

As to the actual amount of water needed, Raeder Riotszch (1965) points out that predicting water requirements for forestry is complicated. The very precise prediction methods which have been developed for agricultural crops, most of which are annual, are not usually applicable. He states that in practice irrigation schedules for tree crops are very often based on trial and error or guesswork. Sagwal (1986) says that farmers, in their anxiety for more yield, often irrigate trees either too frequently or excessively which gives rise to low productive efficiency of irrigation water.

Armitage (1985) goes further to say that empirically based approaches are probably the best, as theoretical approaches do not answer vital questions that relate to actual water availability in the field, such as how much water trees actually need, when and for how long and at what times of the year. He also states that it is important to distinguish between minimal requirements for growth and the amount the tree would use if it were available in unlimited quantity but would not give economically meaningful increases in growth rates.

Doorenbos and Pruitt (1977) explain that prediction methods are used because of the difficulty of obtaining accurate field measurements. They give guidelines as a starting point for calculating water requirement and Doneen (1972) provides guidelines for experiments and studies aimed at improving irrigation practice.

With or without saline irrigation, amounts applied vary widely and estimates of need are often vague. Goor and Barney (1968) stated that tree crops require twice the amount of water that agricultural crops do. With reference to the Sudan Gezira plantations, Foggie (1967) suggested 3.5 times, and Edgar and Stewart (1979) 2.2 times more.

Rawitz et al (1966 and 1976) reporting on the effect of irrigation quantity and frequency on poplar growth in the central coastal plain of Israel where precipitation (P) is

600mm and annual pan evaporation 1810mm., describe an experiment where 4 moisture regimes (1,2,3 and 4 week irrigation intervals from May to October with gross water applications of 1530,1350,920 and 720mm) were applied to two and a half year old P.deltoides and P.x euroamericana 1-214 on soils ranging from sandy loam to loamy sand. Two

week intervals with a total seasonal application of 1350mm were found to give the best results.

Khan (1966) in the Sudan Gezira trials with E.microtheca indicated that a total annual application of 1240mm was necessary for optimum growth, applied at two week intervals from July to December and six week intervals from January to March. Comparing tree irrigation in West Gujerat with the Sudan Gezira situation, Gogate (1983) states that gross irrigation in West Gujerat with low efficiency of delivery works out at an even higher rate - to about 3000mm per annum. Lerche and Khan (1967)in Pakistan found that 1370mm applied over six months in the summer time was an acceptable target for irrigated forestry in general though they say that the actual amounts applied varied widely and exact amounts were seldom known. Karschon (1970) found that E. camaldulensis at Ilanot, Israel, did best with 2000-2200mm/year in addition to 600mm rainfall. Metro (in Kaul 1970) describes irrigation with saline water in Algeria of amenity plantations and shelterbelts. He mentions 'heavy doses' and 'copious quantities for leaching'. Armitage (1985) says that it would be interesting to know whether these plantings continued to grow successfully as Metro implied that irrigation may have been excessive. Stewart et al (1986) describing a eucalypt plantation at Loxton, Australia irrigated with recycled water state that when the plantation is fully developed annual irrigation should be at least 800mm. Tanji and Karajeh (1993) used levels of 370mm before 1989, 530mm in 1989 and 1050mm in a recycling project in California in 1990. Hopmans et al (1990) evaluating the irrigation of tree crops with municipal effluent in the Murray-Darling basin, Australia, state that annual irrigation varied between 1190mm and 1750mm. Wood et al (1975 and personal communication 1987) report successful plantings at Abu Dhabi with trickle irrigation at the rate of 45 litres per day per tree and Hallsworth (1981) reports 300l/tree/week for <u>Casuarina glauca</u> also at Abu Dhabi. Although this rate is already very high, Hallsworth states that trees immediately around the pump, where extra water was spilt from time to time, showed a significant height increase. (These litre per tree per day or week figures cannot be equated with mm in the usual way, as it is not known whether the irrigation was year round. If it was so, and the emitters wetted an area of approximately one square metre, then the annual figures would be very high indeed.)

However, Forestry Paper no.8 (FAO 1978) points out that most studies have been related to 'optimum' levels of irrigation and very little is known of response to limited water availability.

Some reports are not very precise as to actual quantities of water used. Boyko and Boyko (1968) say that the amount of water available for their Eilat experiments was always 'far below actual requirements from a horticultural point of view' and that their irrigation system broke down twice, for three weeks each time, during the hottest season. Nevertheless, all but two of their 200 species survived. van Hoorn (1968) gives rates of 200mm/year in addition to 160mm of precipitation for olives in Tunisia - this water contained 4g/l (5.7dS/m) dissolved salts. The age of the trees is not stated, nor is it clear whether these were the amounts considered necessary for increased growth or for survival. Patel (1983) giving guidelines for high density eucalypt plantations in Bhavnagar, India, advises 20 irrigations at 15 day intervals - the amount of irrigation water is not specified.

Some reports of low irrigation rates give more exact figures. Sandell et al (1986) reporting on establishment trials for dryland plantations in central Australia, say that seedlings were irrigated for the first 6-9 months at 20 litres/tree weekly for the first six months and two weekly thereafter depending on rainfall. Burman et al (1991) irrigating <u>Azadirachta indica</u> seedlings in western

Rajastan state that 2 weekly applications of 46 litres per plant led to maximum growth and biomass production, while under 2 weekly irrigations of 12 litres/plant there was still no mortality but growth and biomass were severely reduced. Zohar (1982) in his study of eucalypt growth on saline soils in Israel gave as little as 10-15 litres/tree every 2 months (equivalent to 60-90mm annually if applied the whole year).

Some systematic work has been done on irrigation/growth rate curves, mainly for agricultural crops but with some tree species included in the experiments.

Sheikh (1974) reports very precise figures for Dalbergia sissoo in the Punjab, 910-1220mm/year being sufficient for optimum growth after the second thinning in the tenth year. He reports trials with 450mm, 900mm, 1350mm, 1800mm and 2250mm and irrigation intervals of two and three weeks. He found a significant increase in growth up to 900mm but no corresponding increase at the higher levels. The two weeks schedule produced better results than the three week schedule.

Rawitz (in Shalhavet et al 1976 and see above) showed that an increase in the water application for poplar in the central coastal plain of Israel (P = 600mm) did not result in increased yield after the optimum application of 1350mm had been reached. Delwaulle (1979) in a test of irrigation rates on two year old Eucalyptus camaldulensis

in Niger, used no irrigation and rates of 2700mm and 4600mm. He found MAIs (mean annual increments) of 4.6 t/ha for the unirrigated trees and 12.1 and 12.9 t/ha for those irrigated at 2700mm and 4600mm respectively. Barbier (1978) similarly reported little difference in growth rate between trees irrigated at rates of 2500mm and 5000mm/year.
In spite of the previously noted decrease in water availability to the tree when using saline water, Shalhevet (in Shainberg and Shalhavet 1984) points out that with deficit irrigation (applying less water than cumulative potential ET) a considerable saving of water can be achieved without reduction in yield. He found insufficient evidence for shortening irrigation intervals with saline water.

On the question of irrigation intervals, Willens (1978) held that constant wetting of the roots avoids stress and that this is particularly important when using saline water. When the root zone can be maintained at or near field capacity water of much higher salinity can be used than can be employed when the soil is allowed to dry out. For leaching, van Hoorn (in Boyko and Boyko 1968) and Arar (1975) found that seasonal leaching was more effective than leaching at each irrigation.

Wood et al (1975) state that when waters of relatively high salinities are used for irrigation it is desirable either to use large quantities in order to minimise salt accumulation in the rooting zone, or to reduce surface evaporation to a minimum by means of mulching and to ensure maximum utilization of water by the plants. In the highly successful Abu Dhabi plantations very large quantities of water were used on sandy soils.

Moore (1983) reporting on irrigation of eucalypts in southern California states 'Inasmuch as no research data from field experiments have been developed, we do not have scientifically based irrigation recommendations to offer'. He, like Willens (1978), suggests a system using tensiometers to monitor soil moisture to calculate irrigation requirement. In general, Evans (1982) states that the aim of irrigated forestry is to raise the level of the total water received at a site to about 800-1000mm rainfall equivalent. But Wood et al (1975) point out that it seems logical to raise forest plantations with the minimum water required for survival and steady growth. Although faster growth might be obtained by using more water, this could in time lead to a disastrous accumulation of salts, and would certainly be criticised on the grounds of water conservation.

Some of the variation described above can be accounted for in the search for 'optimum' irrigation levels for wood production. When this is not a prime objective, other considerations apply. The amount of water that should be applied must depend on the purpose of the plantation. If amenity and conservation are the main aims, rather than timber production (where straightforward cost benefit analysis can be employed) then it could be argued that minimal rates should be applied on economic grounds. Water application should not be more than is necessary for survival and steady growth, but must be enough to minimise plant stress and salt accumulation.

1.2.iv.Growth and Yields.

Mean annual increments (MAIs) are difficult to compare because of curvilinear growth rates with age. Information in the literature on growth and yields is often similarly difficult as important data (age of stand, irrigation regime, etc) are frequently omitted from the reports. Moreover, some reports are estimates and projections, whilst some conclusions are based on carefully measured data. Nevertheless, it is clear that very high levels of production can be achieved.

FAO Forestry Development Paper no.16 (1963) states that for <u>Eucalyptus camaldulensis</u> (the most successful species in terms of timber production in arid areas) on fair agricultural land with 400-600mm rainfall a year, MAIs of 10-15 m^3/hectare/year can be expected. With irrigation, the MAI should increase to over $25m^3$/ha/year.

Karschon (1970) reports irrigation trials with E. camaldulensis in the central coastal plain of Israel where total water inputs of 970-1290mm/year (including 600mm rainfall) resulted in MAIs by the 4th year of 14.3-15.8m^3/ha compared to unirrigated controls with MAIs of 7.2m^3/ha. Irrigation thus doubled the yield. Barrett and Woodvine (1971) reported results from small unreplicated trial plots in Zimbabwe where E. camaldulensis achieved MAIs of 14.9-65.5m^3/ha and E.gomphocephala 15.0-18.9 m^3/ha. E.camaldulensis near Lake Chad in Nigeria watered by sprinkler for the first year (until the roots reached the water table) produced MAIs of 21.8m^3/ha at 4 years for the fastest growing provenance, Jackson (FAO 1976) and Allen (1977). Pryor (1970) stated that the 17 month dbh of 10cm and height of 11m of these trees was the most rapid growth of Eucalyptus reported anywhere.

More recent reports include Gogate (1983) who noted 58m^3/ha for 5 year old Eucalyptus hybrid in Gujerat and Ray (1984) who stated that the same species at eight years old in Coonoor, India produced 100m^3/ha. Hamel (1985) in Niger reported rates of 16m^3/ha at two years for E. camaldulensis at a spacing of 3x3 metres and 38m^3/ha for 1x1 metre. Shyam Sunder (1988) stated that improved practices had raised MAIs in Brazilian eucalypt plantations from 15 to 100 cm/ha/yr. Karpur and Dogra (1989) in a study of plantation spacing of eucalypts in the Punjab mention 29.48 m^3/ha achieved at 3.5 years. Birk and Turner (1992) report intensive cultural practices (including flood irrigation) for Eucalyptus grandis in Australia which produced 274 m^3/ha after 9.25 years as against unirrigated controls producing 133 m^3/ha.

Yield predictions include those of Wood and Synnott (1977) who predicted MAI for E.camaldulensis at Kuwait under irrigation with sewage effluent of 25m^3/ha at ten years for fully stocked stands. In Iraq Busby (1979) forecast that E.camaldulensis would achieve 16m^3/ha/year at ten years under irrigation. In Uttar Pradesh E.hybrid was expected to yield 12m^3/ha by 5 years and Acacia nilotica 6-8m^3/ha/year (Armitage 1985). In the Sudan Gezira, Ali (1979) noted MAIs of 6.6m^3/ha under irregular and infrequent irrigation. He believed that with improved practices, rates should rise to 12m^3/ha/year for E.microtheca. Foggie (1967) recorded MAIs of 0.5-0.6 for natural woodland adjacent to these same plantations without irrigation.

Although the present investigation was not concerned with producing timber in commercial quantities, these figures are useful, in spite of their wide range and lack of background information, as they show that tree irrigation, even with poor quality water, can significantly increase production.

1.2.v. Litter and Organic Matter.

There is an extensive literature on litter accumulation, decomposition and the production of organic matter in the soil, particularly under tree cover.

Newbould (1967), Phillipson (1971) and Proctor (1983) give guidelines for the calculation of litter accumulation and decomposition rates. Woods and Raison (1982) make an appraisal of techniques for the study of decomposition.

Balagopalan and Jose (1986) state that following clearance and cultivation of forested areas in Atrippa, India, a loss of 9% organic matter in the soil was observed. Singal (1986) discussing the nutrient status of Dehra Dun forests, states that in comparison to Sal (Shorea robusta) the quantity of organic matter humidified was more under Eucalyptus. Jha and Pande (1984), writing on the impact of growing Eucalyptus and Sal monocultures in the Doon Valley, state that as far as the accumulation of organic matter is concerned, Eucalyptus has proved a better species than Sal. Dancette and Poulain (1969) quoted by Felker (1981) in Sahelian Africa, found a several fold increase in soil nitrogen, organic matter content and soil water-holding capacity under Acacia albida.

Gill and Abrol (1991) discussing amelioration of salt affected soils in the Indo-Gangetic plain, give figures for annual litter yield of Acacia nilotica and

Eucalyptus tereticornis, showing that soil organic carbon content almost doubled under Eucalyptus and tripled under Acacia. George (1986) writing on the nutrient status of Eucalyptus plantations in Uttar Pradesh, points out that since E.tereticornis is a fast growing species, it produces more litter than other slower growing species. He gives a figure of 6.180 tons/hectare/year for litter production in a eucalypt plantation. This is quite a high figure. Gill and Abrol (in Prinsley and Swift 1986) and Gill et al (1987) report nutrient recycling through litter production in six year old plantations of Acacia nilotica and Eucalyptus tereticornis on highly alkaline soil at Karnal, India, give litter production figures of 1.027 to 1.125 tons/ha/year for eucalypts and 2.537 to 5.746 tons/ha/year for acacias. Lamb (1985) reporting on litterfall and nutrient turnover of two woodlands growing near Narrabeen Lagoon N.S.W. reports litter production of 0.540 tons/ha/year for an Angophora costata - Eucalyptus gummifera dominated community and 0.745 tons/ha/year for an E.botryoides-E.robusta-A.floribunda community. He states that there was a summer peak in litterfall but that some species show peaks in spring and autumn. Lamb, in the study mentioned above, reports a decomposition rate of 22 -28% over five years. This was a five year study, but Woods and Raison (1982) warn against extrapolating initial decomposition rates (e.g.as measured in litterbags over a 12-18 month period) to predict long term rates of decomposition. O'Connell (1986) in south western

Australia, gives far higher decomposition rates for E.marginata 37% of initial dry weight in 8 months and 44% after 20 months.

In examining the accumulation of organic carbon O'Connell found levels of 3.62% for E.marginata without understorey and 4.74% for the same species with understorey in existing forests. Birk and Turner (1992) looking at the response of E.grandis to intensive cultural treatments at Coffs Harbour N.S.W. found that 15-20 tons/ha accumulated as forest floor organic matter in six years.

1.3. Development of the Experiment.

Of the authors cited above, Weber (1986), Evans (1992) and Muthana and Kolokar (1984) have reported the use of small quantities of water for raising trees. Boyko and Boyko (1968) and Tanji and Karajeh (1993) among others, have described the use of saline water for the same purpose. Many studies including those of Cointepas (1968), van Hoorn (1968) and Meiri and Plaut (1985) have described periodic leaching to reduce salts in the rooting zone.

It was impossible to find, in the literature, more than a few studies of tree irrigation using small amounts of saline water. The idea of relying on precipitation alone for leaching hardly seems to be explored.

In view of the foregoing, this study sought to combine the ideas of using small amounts of water for tree establishment with the use of highly saline water in a semi-arid environment (particularly Mediterranean type dry lands). Unlike previous saline irrigation experiments where large quantities of water have been used for leaching, this study relied on winter rainfall (mean annual precipitation 400mm of which 300mm falls in winter).

The study was directed especially at the establishment of small scale local plantations of the type described by Zohar (1988) and Evans (1992). If the experiments were successful, the techniques could have a very wide application.
In particular, these small blocks of trees would be valuable for their physical ameliorative effects and for soil conservation in local plantations and shelterbelts on areas which are already eroded or in danger of becoming so, or on areas where wind protection would be especially beneficial.

The choice of species to be irrigated presented a problem. As has been mentioned, criticisms have been levelled at the use of exotics, particularly <u>Eucalyptus spp.</u> in semi-arid areas. These criticisms are generally concerned with the effects of large areas of monoculture. For the purposes of this study, which is concerned with the environmental protection, in terms of tree growth and soil protection and amelioration, of small areas of land, the best indicators of species value are ease of establishment and rapidity of growth (Evans 1992). The small scale nature of this and many other forestry objectives (local plots, shelterbelts, etc) means that it is not necessary to cover the whole landscape with trees. This in turn means that the negative impacts often associated with large scale planting of exotics, such as the removal of indigenous vegetation and the risks associated with monoculture can be avoided.

An integral part of the study was the careful monitoring of environmental effects in terms of soil nutrient status and build up of litter and organic matter. Tree growth alone would not have been regarded as a satisfactory outcome. By using smaller amounts of saline water than is customary, and that only for a limited period and with winter leaching, the aim was to avoid the deleterious effects on the soil structure that have been noted in previous studies where large quantities of saline water were applied (Cointepas 1968 and Tanji and Karajeh 1993 among others). The examination of litter and organic matter - the accumulation of which could lead to a positive improvement in soil structure - was regarded as a most important part of the study.

Thus in summary, the aims of this study were first, to see whether establishment and vigorous early growth could be achieved for tree species at a small scale local level in a semi-arid environment using highly saline water in smaller quantities than has been customary. Secondly the study sought to investigate whether such growth could be achieved without permanently salinizing the soils. Thirdly, if these two aims could be achieved, an integral part of the study was to see whether the production of a tree canopy constituted a valid measure of environmental upgrading in terms of improved soil structure derived from increased organic matter.

CHAPTER 2. LOCATION AND PHYSICAL BACKGROUND.

Two sites were available on Formentera, Balearic Islands.

2.1. Location

The island of Formentera forms part of the Balearic archipelago (Fig.2) which emerges from the Western Mediterranean as north eastern outliers of the sub-Baetic range. The island has an area of 83 square kilometres. A low-lying narrow central region joins two higher extremities (Fig.3) The eastern promontory is the highest, rising to 192m above sea level.

2.2. Geology

The Balearic Islands are incorporated in the sub-Baetic range, which forms part of the Hercynian orogenic belt. The land mass was submerged and re-emerged on a number of occasions, although the details are still a matter of debate. Thereafter there is general agreement as to the course of events from the middle Miocene to the present which is outlined in Fig.4 (after Colom 1964).
The geological map (Fig.5) differentiates five classes of parent material. To clarify these groups, rock samples were taken within each of the groups and examined in the laboratory with the help of Dr. K. O'Reilly and Dr. M. Pedley of the University of North London.
From all these sources it appears that the parent material is fundamentally pure limestone. The Tertiary limestone which underlies the whole island is made up of shallow marine deposits containing many echinoid fragments.

The limestone crust and calcareous silt are limestones which, while they may be remnants of a Pleistocene marine episode, show evidence of a sub-aerial environment. The bioclastic limestone is well rounded with pores which appear to be a legacy of Pleistocene vegetation. The dunes and dune deposits are beach deposits with rounded fossil fragments.

While there may be small differences in the trace elements (some of them possibly wind borne) between the limestone classes and possibly a little dolomite in the Tertiary limestone, in general there is no significant chemical difference between them and geologists agree that they would form nearly identical parent material, consisting as they do of 99 per cent calcium carbonate.

Some authorities (notably Colom 1964 and Houston 1964) postulate the pervious nature of the limestone parent material as an important factor contributing to the poor flora of the islands. They point out that the ground dries out more rapidly and therefore conditions of drought are more severe than on non-calcareous rocks with similar precipitation. On the other hand, Houston 1964 and Harrant

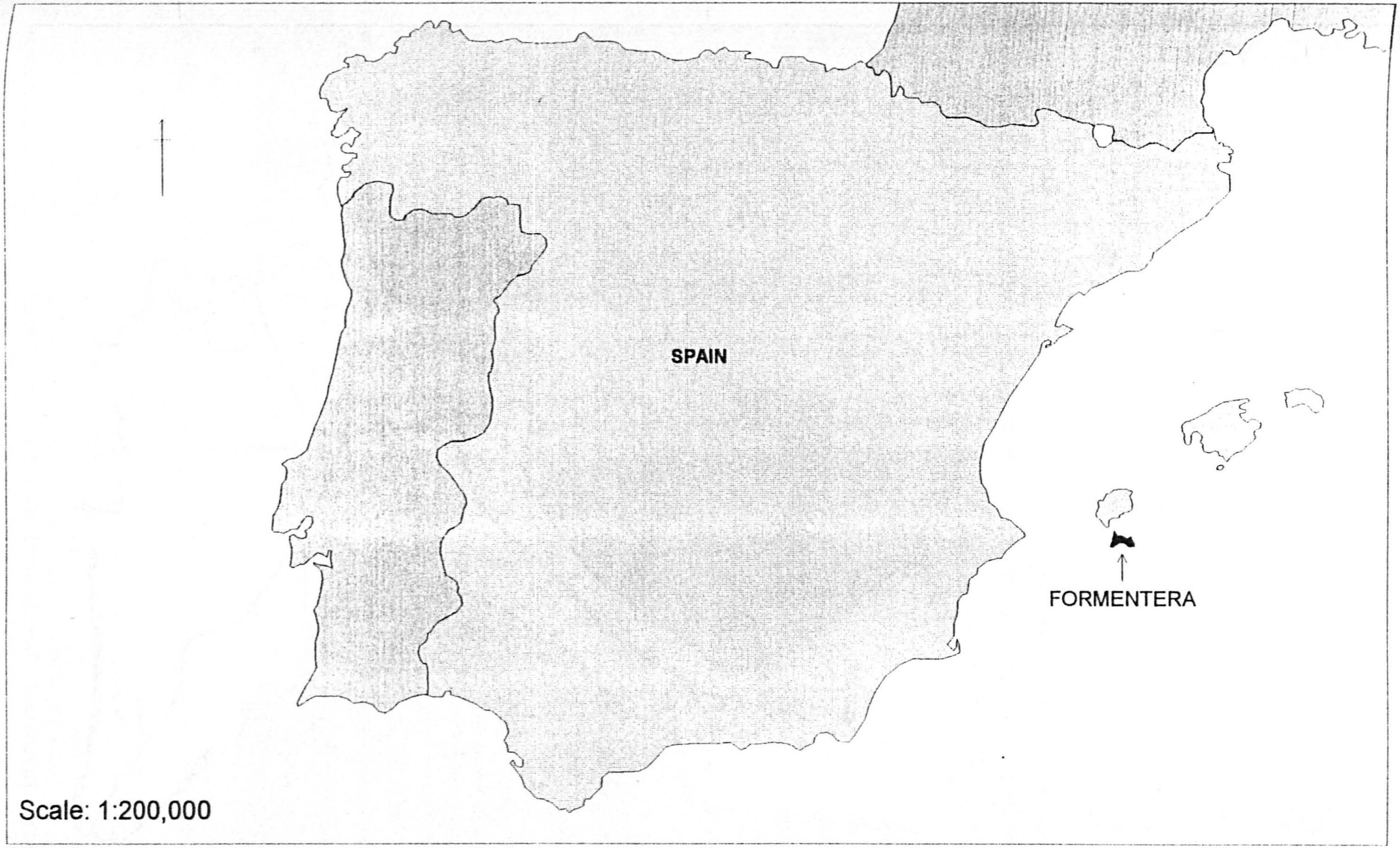


Fig 2. **Location**

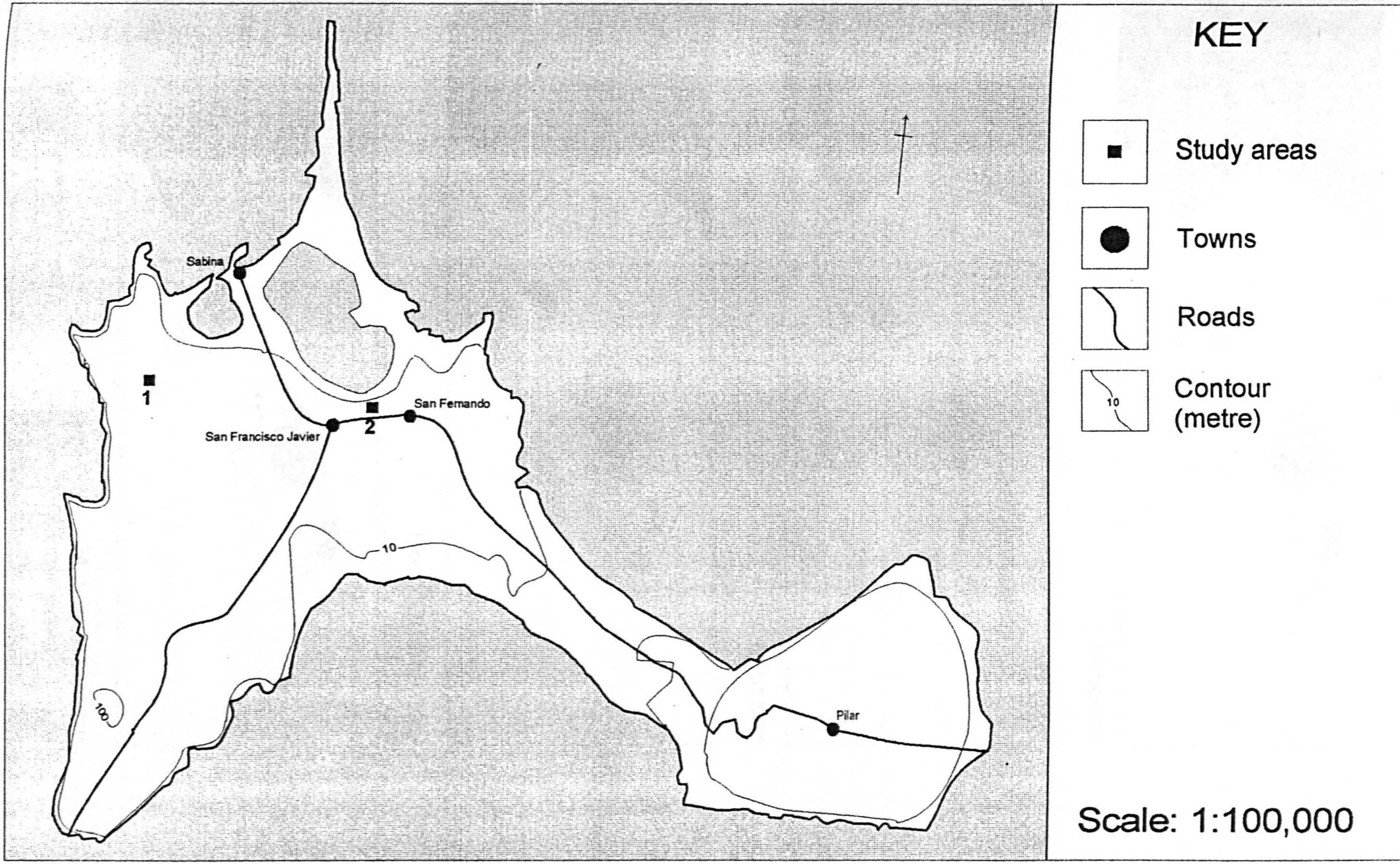


Fig 3. **Study Areas**

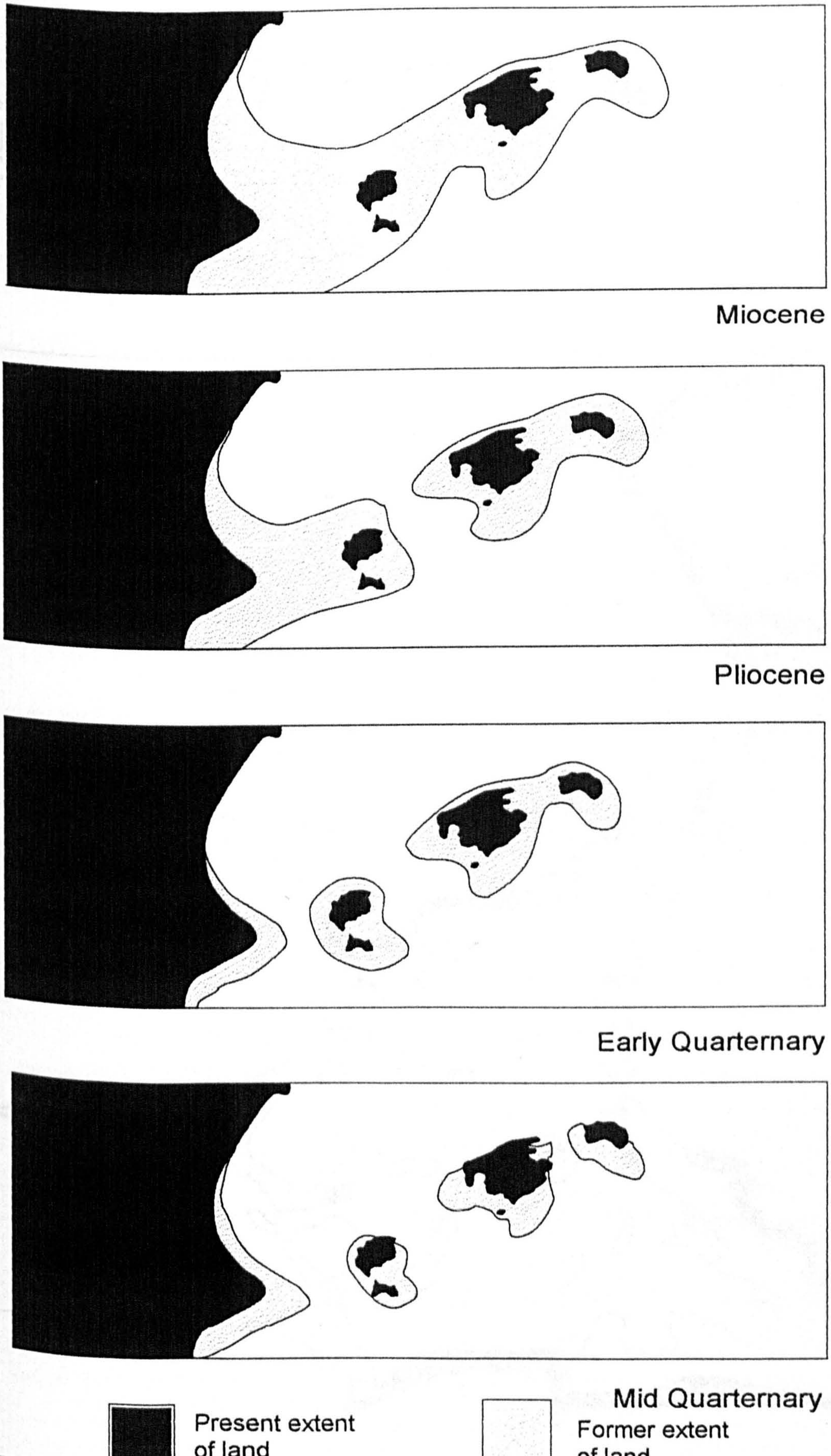


Fig 4. **Island formation** (After Colom)

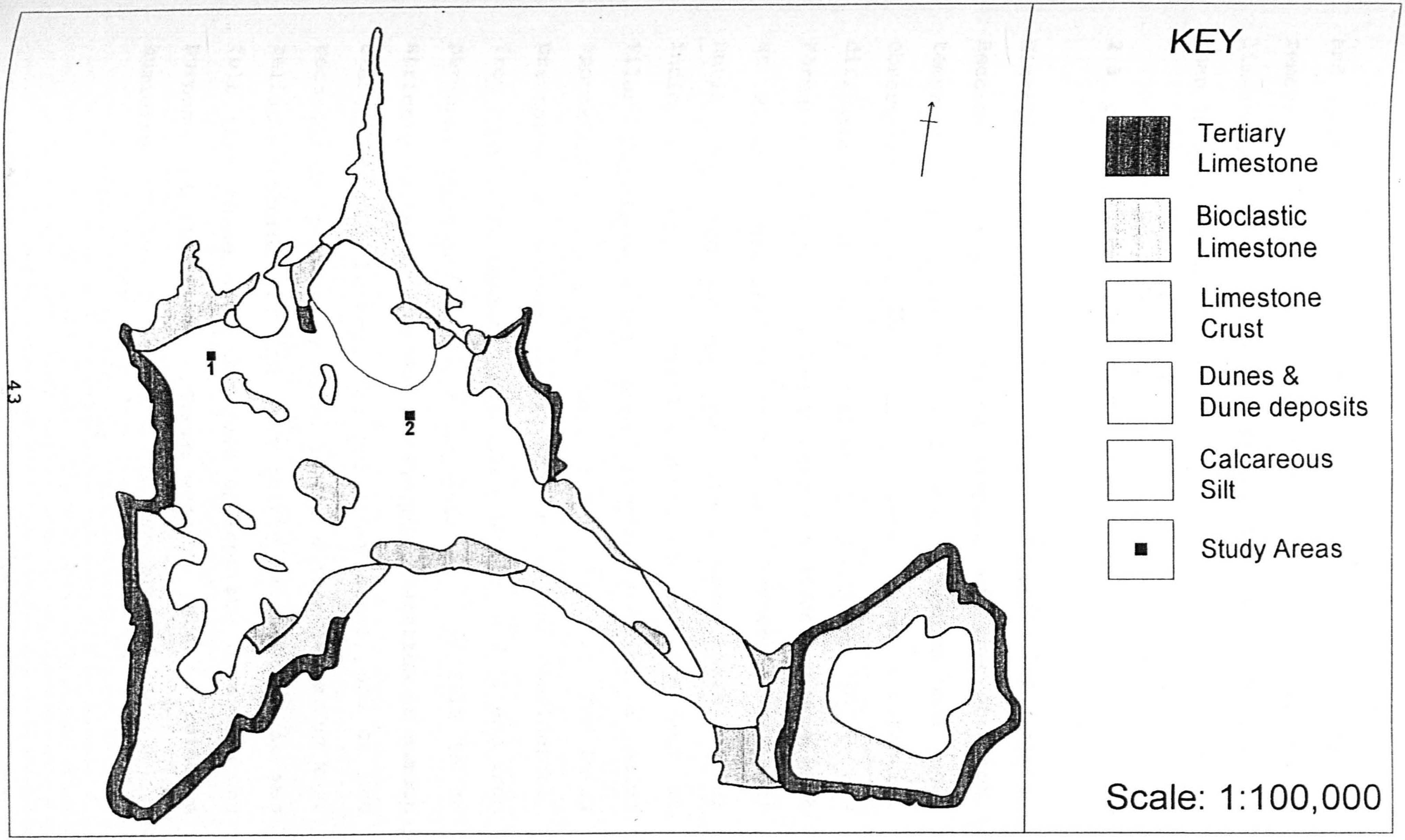


Fig 5. **Geology**

and Jarry 1967 argue that if the vegetation cover is removed the physical 'softness' of these particular limestones allows a greater degree of plant regeneration than is attainable on 'harder' limestones.

2.3. Climatic data available.

Historical climatic data were difficult to obtain. Records are kept at Ibiza airport of precipitation, temperature and insolation. It was suspected (and later observation confirmed) that there were substantial differences in these variables between Ibiza and Formentera. Records of wind speed and direction were kept at Pilar lighthouse on south east Formentera (Fig.3) until 1977 and it was felt that these were useful indicators (Fig.6). Precipitation records are kept at Pilar lighthouse, at Ibiza airport and at a point approximately 1 kilometre west of San Francisco. The Ibiza precipitation pattern was thought to differ considerably from that in Formentera (See below Section 4.8.i) and from personal observation the Pilar data was not felt to be strictly reliable. As the San Francisco station is almost exactly halfway between the two study areas, and as the recorder was personally known to the author as having kept reliable records for the past thirty five years, it was felt that these were the most appropriate data for the purposes of the study. There were no data on relative humidity.

2.3.i. Air masses.

In winter the Mediterranean lies between the cold Asian anticyclone and the Atlantic anticyclone of the Azores. It is a zone of relatively low pressure over the sea basin of the Balearics, making it one of the centres of the greatest frequency of cyclogenesis in the whole northern hemisphere. In summer the anticyclonic cell of the Atlantic is developed but the continental cell disappears and the Mediterranean is under the former's control. Consequently, in winter the area is dominated by the advection of air streams of markedly different characteristics and coming from distant sources, whereas in summer it has sluggish, much more uniform conditions.

2.3.ii. Perennial Streams.

There are no perennial streams on the island. Water is obtained from rainwater cisterns and from wells, where depth to groundwater allows. Groundwater is at sea level.

2.3.iii.Precipitation.

Mean annual precipitation at the San Francisco station over a 35 year period is shown in Table 3. The annual mean of 388.85mm should be treated with caution as the very large co-efficient of variation indicates. In general, the greater part of the rain falls in the autumn months (October to December) with light winter and spring rains making up the total. Summer rainfall is negligible. Over a 15 year period (1975-1989 inclusive) there were an average of 48 rain days a year. Here too averages should be treated with caution. Autumn rains are often torrential. On September 13th 1970 a total of 155mm was recorded in 24 hours - more than one and a half times the yearly total for 1983. Of the exceptionally high rainfall (805mm) of 1975, 220mm fell in October and 222mm in December. The erosive potential of such precipitation is high.

Table 2. Annual Precipitation at San Francisco, Formentera.

Calendar year	mm.		mm.
1953	574	7	440
4	328	8	348
5	418	9	329
6	280	1980	426
7	544	1	410
8	521	2	398
9	563	3	97
1960	462	4	400
1	144	5	608
2	344	6	318
3	416	7	352
4	298		
5	155	35 Year Mean	388.86mm
6	292	CV%	35.8
7	340	Range	97-805mm
8	258		
9	373		
1970	336		
1	420		
2	549		
3	447		
4	246		
5	805		
6	371		

2.3.iv. Dew.

Many local farmers believe that dew promotes plant growth in dry weather.

Slayter (1960) showed that foliar absorbtion of dew during the night may reduce water deficit and accelerate growth and that evaporation of dew from leaves may reduce transpiration in the early morning, but he points out that dew evaporates in a few hours and plants with inadequate soil moisture reserves will endure severe water stress during the hottest part of the day.

Gates and Brown (1988) in their study of *Acacia* and *Prosopis* spp. at the Wahiba Sands in Oman observed that tree foliage became thoroughly saturated by dew and that water running down the trunks amounted to 0.5mm rainfall equivalent on some nights - over what area is not stated.

Dew has been observed to be heavy during the summer months in Formentera but is unmeasured. It is not known whether dew is a significant factor for tree growth.

2.3.v. Temperature.

Official temperature records are not kept on the island and so must be inferred from readings taken at Ibiza airport. Over the three years from 1988-1990 inclusive the monthly mean for January was 12.6 degrees C, with a mean maximum of 16.1 and mean minimum of 9.2 degrees. The monthly mean for July over the same three years was 26.1 degrees with a mean maximum of 30.3 and a mean minimum of 21.5 degrees. The maximum daily temperature ever recorded in Ibiza was 42 degrees C on July 30th 1945 and the minimum -3.2 degrees C on January 8th 1891.

2.3.vi. Insolation.

Again the readings are taken at Ibiza airport. From 1988-1990 inclusive, the mean number of sunshine hours per month was 154.8 in January and 325.3 in July.

2.3.vii. Wind.

Wind direction and velocity (on a type of modified Beaufort scale) were previously recorded daily at Pilar. Data were only obtainable for the four years 1974-77. With this method of recording, it is impossible to analyze wind patterns in any detail. However, the frequency and cumulative anemographs (Fig.6) demonstrate that the prevailing wind is from the south west. It blows fairly constantly throughout the year, coming out of Africa, and is gentle and of low humidity. North and east winds blow only in the winter months and accompany much of the precipitation. As the cumulative anemographs show, these winds blow with less frequency but with considerable force. More information was sought from the Hydrographic Office at Taunton and the Meteorological Office at Bracknell, but without success.

2.3.viii. Water Balance.

No data were available on relative humidity or potential evaporation. However, temperature and precipitation figures (see above and Table 2) suggest that there will be a large moisture deficit for the greater part of the year.

2.4. Soils.

The most distinctive feature of the soils of the island are their shallowness and lack of horizonation. They appear to be skeletal lithosols developed from the limestone parent material. The only soil map of the island (in Colom 1964) shows Formentera as a uniform area of xerrorendzina. Colom describes the soils as 'poorly developed, with little humus, supporting a limited flora at a very low level'. However, he acknowledges that the lack of detail may reflect a lack of study in an area whose small size and lack of importance has not merited much attention.

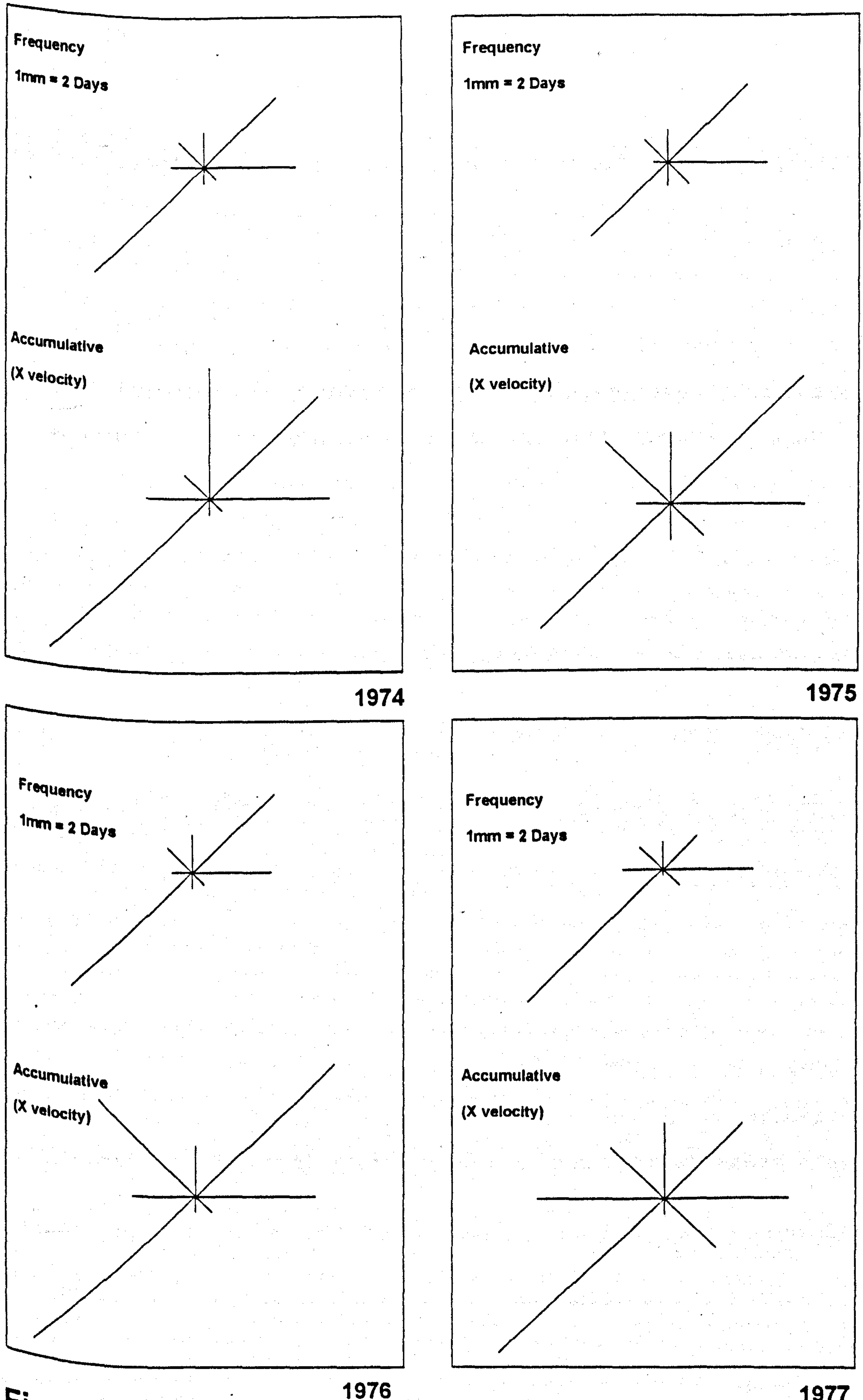


Fig 6.

Anemographs

from Pilar lighthouse

2.5. Vegetation.

Very little can be said with certainty about the original vegetation cover of the island. Rivas Goday and Rivas Martinez (1967) among others assert that the 'climax' vegetation would be evergreen forest dominated by Quercus ilex. Polunin (1970) suggests that in dry limestone areas the climax may be dominated by Pinus halepensis. There is some evidence for this view in the ancient Phoenician name for Ibiza and Formentera - Pityusas, the pine islands. The vegetation has been disturbed for many thousands of years.

The western slopes below Pilar have the greatest tree cover and are dominated by Pinus halepensis Mill. with some Pistacia lentiscus L. and Juniperus phoenicia L. There are other small areas of P.halepensis but at the north western promontory J.phoenicia becomes dominant. The understorey in both cases is usually dominated by Rosmarinus officinalis L.

Garrigue areas are found in all parts of the island. They are characterised by low woody aromatic shrubs less than a metre tall, many with sclerophyllous adaptations. Rosmarinus officinalis is often dominant. These areas are interspersed by outcrops of bare rock. In some of the more windswept and steep areas, where soil development is inhibited, it may be that these communities are natural.

Most of them, however, must be classed as anthropogenic, being formerly cultivated areas that have been abandoned either because increasing erosion rendered them useless for agriculture or because the farmer has abandoned his land in pursuit of more profitable occupations. Garrigue has also resulted from former wooded areas where the trees have been felled for charcoal burning or have been themselves burnt by accidental fire. In some instances the garrigue is a form which has degenerated from pine forests and in others it is a stage in the regeneration back to wooded land (Colom 1964).

The flora of Formentera is held by all authorities to be low in diversity and, while this is partly attributable to the limestone parent material and poorly developed soils, insularity is held to account for the absence of many species found in identical conditions on the Iberian peninsula.

Colom gives figures for the total number of species of higher plants for the four Balearic Islands as follows: (in contrast with the Iberian peninsula with its 10,000 species)

	Area	No.of species
Mallorca	3640 km2	1800
Menorca	701 km2	900
Ibiza	541 km2	400
Formentera	83 km2	120

The very low figures for Ibiza and Formentera are certainly an under-estimate and are probably, as Colom points out, a function of the fact that they have been very little

studied. Many of the celebrated 'Balearic endemics' are confined to the mountainous region of Mallorca.

2.6. Land Use.

The land is now used mainly for the arable cultivation of cereals and legumes. Tree crops include Prunus communis (L) Fritsch, Ceratonia siliqua L, Ficus carica L. and Olea europea L. The trees intersperse the arable cultivation, but are not planted in groves.

Charcoal made from pine was until quite recently (ca 1960-1970) the main fuel for domestic cooking and until the same date extensive lime-kilning took place for house building purposes. Thus, forested areas were a necessary part of the economy. With the advent of bottled gas for cooking and portland cement for building, the forested areas were no longer necessary. Some forested areas are being cleared - a few for agriculture and very many more for tourist enterprises. Others, previously felled and replanted at intervals, are simply being abandoned. As far as can be discovered, there was no particular tradition of forest plantation beyond the rather casual and haphazard replanting of areas felled for charcoal or lime-kilning.

Some land has been abandoned since the twenties, when drought and over-population forced much emigration to Cuba; and some since the 1930s when political events forced the exile of many families. Their land was not confiscated, however, and remained abandoned until quite recently. Garrigue has resulted from some wooded areas where trees have been felled for charcoal burning and not replanted and also from some accidental fires, although there is surprisingly little history of large scale accidental fire in the wooded areas. The understorey is not dense.

There are almost no cattle on the island and very few sheep. Donkeys and mules, once the main labouring animals, are no longer in use. At the end of the island's south western promontory wild goats graze freely and are retained in the area by a high wall. There are no wild goats in other parts of the island and domestic goats are hobbled and so unlikely to graze in areas forbidden to them. However, domestic goat numbers are increasing, due to tourist demand for meat, and the erosive effect on the areas they graze is very noticeable.

Of the Leporidae, only the rabbit (Oryctolagus cuniculus) and the brown hare (Lepus capensis) are known to exist. The brown hare is extremely rare and it is thought that it may now be locally extinct. Even the rabbit is becoming scarce. It is extensively hunted. Information on the grazing patterns of rodents, invertebrates, insects and birds in the area is extremely scarce.

CHAPTER 3. EXPERIMENTAL DESIGN.

3.1. Aims and Constraints.

The first aims of the investigation were to determine whether establishment and vigorous early growth could be achieved for tree species in semi-arid conditions using water generally considered too saline for agriculture and whether such growth could be achieved using very much smaller quantities of water than had been customary.

Decisions had to be made on species to be tested, levels of salinity and the design and layout of the experiment.

Ideally, five or six species would be tested with five or six levels of salinity, planted at different spacings and irrigated with graduated amounts of water, the whole laid out in a randomised block design.

There were constraints of land, labour and finance. As has been stated above, two plots were available on Formentera. These plots were approximately 1000 square metres each, of which about 300 square metres each could be used for the initial plantings (See Fig.7). For labour, the author only was available with occasional help for fencing and ploughing. The financial constraints were severe.

With these constraints, it was clear that the ideal large scale investigation described above could not be undertaken. Nevertheless, it was felt that useful results could be achieved.

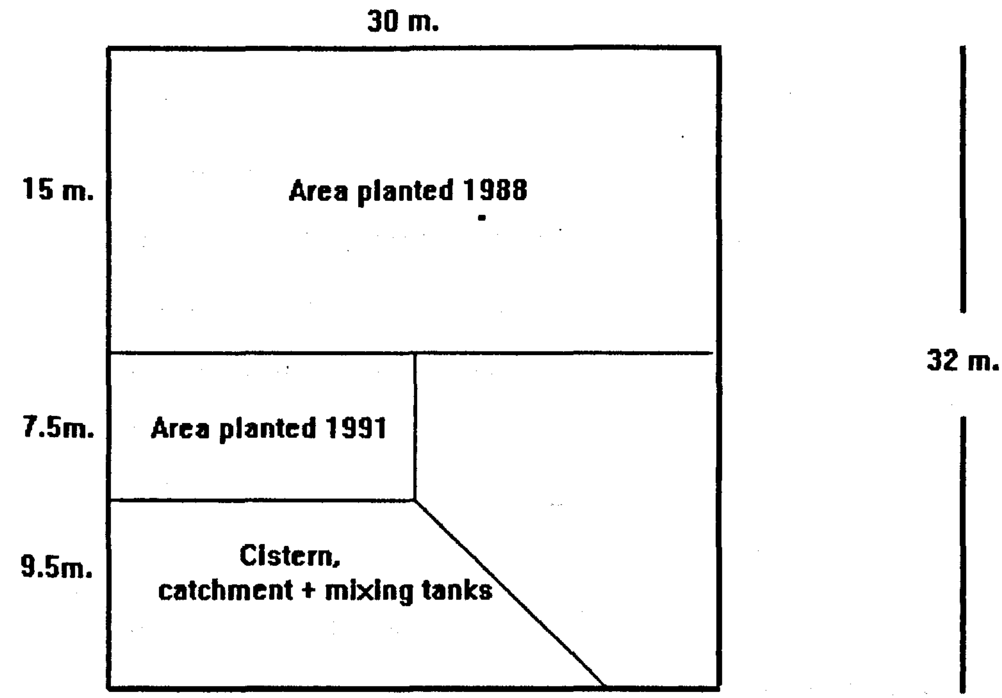
The sites and their restrictions were "givens" at the start of the study, not susceptible to alteration. The restricted area of the sites forced either closely spaced small plots, and so possible spill-over effects between plots, or if the plots were large or widely spaced, too few replications for plot based statistical analysis.

However, one or two species could be tested with three or four water treatments and the spacing and amounts of water applied kept constant. It was not necessary to vary the spacing as the effects of competition were not being examined. This experiment was not concerned with establishing an optimum irrigation regime. It was therefore not necessary to apply differing amounts of water as separate treatments.

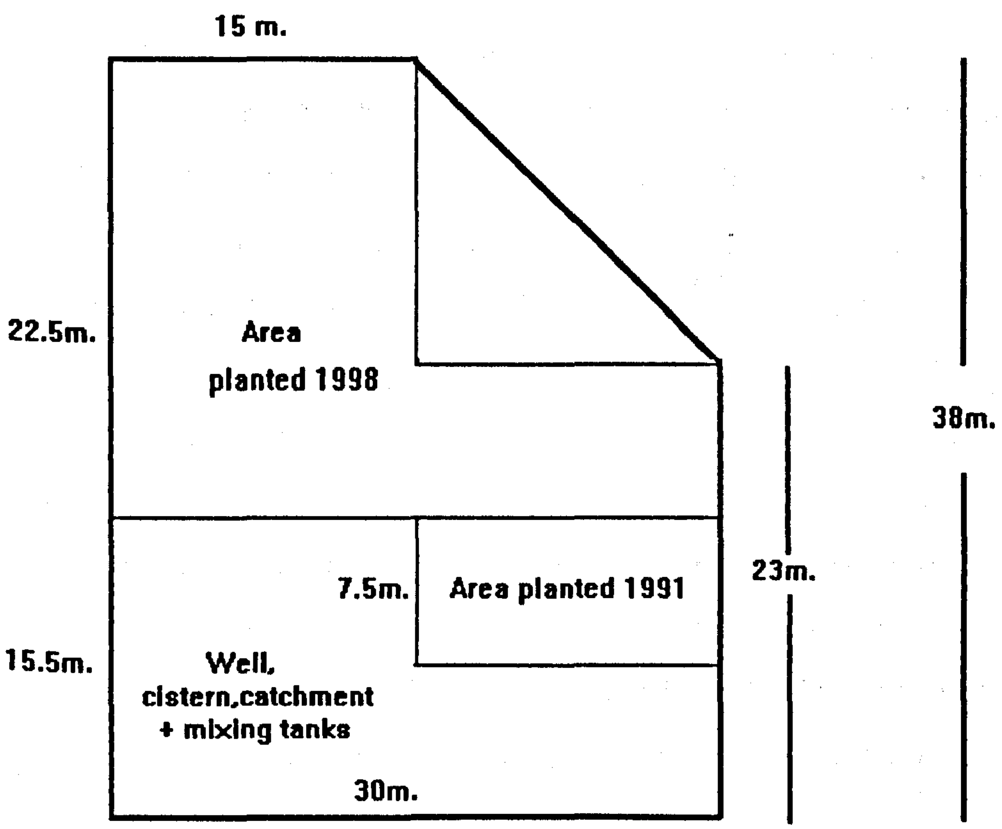
With closely spaced plots, there was room for two species with four replications. It was felt that two species would give more benefits than one species with additional replications. Results that were only applicable to one species would be too narrowly focused.

Fig.7. Dimensions of Sites 1 and 2.

SITE 1.



SITE 2.



In forestry terms, very small amounts of water were to be used. It was felt that the innovative use of small doses of saline water in place of the usual high volume irrigation treatments or capital expensive drip treatments justified examination of a wide range of salinities. This is also important since with small doses, it is not known where the salinity level becomes critical in terms of height growth, survival or changes in leaf characteristics. Additionally, with small doses, it was unnecessary to invest large sums in equipment or water supplies.

Because of practical constraints, plot size was much smaller than in conventional rainfed forestry experiments. In every design choice, there is a balance between the ideal world and the actual circumstances. There are benefits and costs to be assessed. Ideally, a randomised design should be chosen for a number of reasons, the main one being that results can be presented with the confidence that possible confounding variables have been accounted for. The results can be analyzed by a conventional analysis of variance and significant differences confidently assessed.

Randomisation is a defence or insurance against the accidental or deliberate coincidence of factors. For example a low salinity plot might coincide with deep soil and so give rise to unexpectedly good growth, while a high salinity plot might coincide with shallower soil and so result in stunting or death. Overall, the magnitude of the differences between such plots would be exaggerated. Alternatively, two factors might tend to cancel each other out. The randomised assignment of experimental treatments to plot locations avoids such coincidence. If treatments are not assigned at random the probability that observed differences between treatments were due to those treatments rather than to random effects can not be assumed, and thus statistical tests which assume randomness should not be used on a systematic design.

However, site constraints made the layout of a randomised design extremely difficult. The literature was reviewed to explore the possibilities of other types of design.

2.2. Design Literature.

Wright (1976) gives an historical review of experimental work in silviculture. He states that most of the early work in silvicultural research, particularly spacing and thinning, was carried out on unreplicated plots either singly or in a series. The first designs, although allowing for replication, used systematic arrangements of the plots such as sandwich pairs, e.g. ABBA or BAAB, or simple chessboards, e.g.

ABCDEAB

CDEABCD

EABCDE etc.

The development of random designs for field experiments in agriculture by Fisher and others in the early nineteen twenties was fairly rapidly taken up by foresters, especially in the English speaking countries. For workers using the systematic designs, the latin square obviously had great appeal. In the United Kingdom, latin squares and randomised block designs were at first used for short-term experiments such as those associated with nursery investigation (Steven 1928). By 1932 the Forestry Commission had installed some 31 latin squares and 98 randomised blocks which included several long term experiments, one of which was the Bowmont Norway Spruce Thinning Trial, using a 4 x 4 latin square.

At the 1932 IUFRO Congress MacDonald (1933) said, "In experiments in which different treatments are compared it should always be possible to distinguish between the variation due to different treatments and the variation due to other causes".

However the problems of site uniformity and the difficulty of obtaining sufficiently large areas of homogenous stands, together with the considerable amount of work involved in controlling and assessing experiments, acted against the use of adequate replication. It was considered necessary to have a large plot for silvicultural experiments which was not compatible with a high degree of replication. Wicht (1934) concluded that the study of numerous different thinning treatments in an experiment was not effective - one should limit the number of treatments and use replication.

An attempt at standardization of permanent sample plot investigations was made by an IUFRO Committee in 1936 (Fabricus et al 1936). When referring to comparative treatments they recommended a bare minimum of replication and noted that even this might have to be omitted.

These difficulties led to an attempt by O'Connor (1935) to provide in his correlated curve trend (C.C.T.) technique a practical alternative to the replicated designs. In O'Connor's words the problem was "to devise a system of research which, while involving the use of only a limited number of plots, will yield for a given locality and species all the information required for a complete exposition of the effects on the development of trees of the growing space provided for them"

The use of graphical and regression methods, implicit in the C.C.T. technique, was also recommended by Wicht (1948,1952) and Smith (1959) for the analysis of spacing and thinning data. The return of systematic designs, again from the agricultural and horticultural field, such as those proposed by Pudden (Dawkins 1960) and Nelder (1962), although deplored for spacing and thinning research by Scott (1962) as a retrograde step, stimulated the use of regression analysis rather than the conventional analysis of variance techniques. Many experiments were established throughout the world incorporating one of the Nelder fan designs.

Huxley (1983) reports that systematic field layouts have been used by agriculturalists, horticulturalists, foresters and forage specialists for a good many years. Even so, he feels that such designs are not often enough included in the field experimenter's choice of field layouts, especially at the early stages of experimentation when it may not be quite clear what is likely to be "on target" with regard to a treatment variable which is susceptible to a very wide range of levels and even more particularly when these are being tried in a "new" situation.

Huxley asserts that systematic designs can be most useful in the early stages of experimentation where a survey of plant response to a variable is required (i.e.effects on growth, flowering).

Systematic designs have been suggested in the MPT (multi-purpose tree) manual (Huxley 1983) for consideration in the "management trial" stages of MPTs where plant spacing is a prime variable to be investigated. It should be noted that when spacing is a variable being investigated, there are special problems of plot size. Plots must either be very large or contain differing numbers of trees. Systematic designs have also been suggested as a particularly valuable and space saving method for the preliminary investigation of suitable MPT/crop mixtures.

Thus, the "systematic" approach has been extensively held to be valuable for space saving and ease of management. Since forestry, by its nature, occupies large areas of land and consequently a large amount of labour compared to other crops, this is an important consideration, particularly in an experiment where limited land and labour were available.

Two kinds of systematic design have commonly been used to investigate single crop spacing and dose rate problems with a wide variety of plant material from vegetables to tree species. These are the "fan" designs (Nelder 1962) and "parallel row" layouts (Bleasdale 1967). Parallel row designs are easier to lay out in the field.

Discussing experimentation on plant densities for vegetable crops, Bleasdale stated that conventional randomised block designs would involve carrying out experiments of enormous size, in which more than half the plants were guards. He stated that such large experiments are not statistically desirable.

Huxley (1983) lists the advantages and disadvantages of systematic designs as follows:

Advantages

1. Systematic designs occupy a much smaller space than randomised block or other conventional designs.

2. Relatively fewer plants will be needed.

3. The effective experimental area is proportionally much greater than in conventional layouts.

4. The range of levels of the experimental variable under test (i.e.spacing) can be greater than in a conventional layout, and it can easily incorporate extremes so as to obtain a better appreciation of plant responses to "density stress" or any other imposed management factor.

5. They can provide an easily observable response to a treatment so that they are useful as demonstrations.

Disadvantages:

1. Systematic designs require a greater level of skill to lay out in the field.

2. Each plot must be sited on an area that is environmentally very uniform.

3.They are susceptible to damage and need consistent care and attention so as to maintain a high level of management.

4.Although they can and should be adequately replicated the data is basically evaluated only by using regression analysis.

5. Unwanted variability will occur if either:

- the genetic material used is itself variable,or
- extreme care is not taken at planting, together with early and proficient gap up.

In addition, particular rows or parts of rows in a systematic spacing layout may sometimes show a degree of unexpectedly dominant or suppressed growth. Any such effect can be obviated by displaying the data in the form of running means.

6.All the outer rows of plants in a systematic design are usually discarded as "guards" - especially in spacing trials.

Huxley gives examples of systematic designs for various situations. He states that for initial "compatibility" experiments to decide on the selection of suitable tree/bush species and agricultural crop associates, a simple parallel row design for the trees with replicated strips of the various agricultural crops sown across this at right angles could be suitable. Such a layout could also involve different management treatments on some or all of the agricultural crops. When there are two known species of trees and agricultural crops about whose association a considerable amount more information is required, he suggests a more complicated double superimposed parallel row design. Huxley states that this is really only suitable for a research station where it can be carefully supervised and additional instrumentation and data sampling undertaken in order to get the most useful information. A simpler type of "on farm" systematic layout - in the example given, to test the value of a chosen MPT species as a provider of woody mulch - is also recommended. Huxley concludes that although these designs lack the possibility of statistical analysis unless the design is replicated manyfold, nevertheless, such designs can provide useful results at low cost. They are the least demanding in terms of establishment and maintenance.

The first four of Huxley's list of advantages are all derived from space considerations. They concern space, number of plants, experimental area and range of experimental levels. Essentially, Huxley postulates that with such designs more can be accommodated in a smaller area. It is supposed that this is based on the assumption that guard rows and separation distance between treatments can be very much reduced with such designs. These were all important and relevant points in the present experiment. The fifth advantage listed - the provision of an easily observable response to a treatment - also seemed a desirable attribute.

It is unclear what is meant by the first disadvantage listed - that systematic designs require a greater level of skill to lay out in the field. It is true that on rolling or rough ground, systematic designs can be very difficult to lay out as exact spacing is of great importance, but it would appear that both random and systematic designs require skill to lay out properly. It was thought that the second disadvantage, that each plot must be sited on an area that is environmentally very uniform, would be partially met by the very small ground area involved in this experiment. As the experimental area was to be intensively managed, the third disadvantage did not seem to be strong in this context. The statistical disadvantage is a strong one. However a number of forestry experiments have based their analysis on the use of regression for evaluation of growth with time. Since all seed was obtained from CSIRO, it seemed unlikely that excessive genetic variation would occur. The last point - that outer rows should be discarded as guard rows could not be met in this experiment. However, a number of forestry researchers have dispensed with guards when using systematic designs (Evert 1971).

To sum up, in describing the advantages of systematic designs, Huxley mentioned the ability of the design to be accommodated in the space available, ease of management, low cost, and the suitability of such designs for imposed management strategies. He gave time of planting and fertilization as examples.

Although features of large scale spacing trials were not directly applicable to the present experiment, the advantages listed by Huxley above seemed to outweigh the disadvantages in this particular situation.

Nelder (1962) describes a series of designs developed by himself for spacing experiments, using grids which could be defined by the intersections of parallel or concurrent straight lines and the arcs of concentric circles. Nelder discusses the statistical pros and cons of these designs as follows:

Randomised:

Pro	Con
No biases from systematic gradients in plots.	Large block size because of numbers of guards required with consquent risk of loss of accuracy.
Valid error (estimation) if treatment plot additivity condition satisfied.	High proportion of plants and experimental area

used No interaction between plots for guards.
if adequate guards used.

Systematic:

Pro	Con
Very compact designs reducing heterogeneity and proportion of guards.	Risk of systematic gradients biasing estimates and error. Risk of misleading interaction between neighbouring rows.

Nelder discusses the development of rather complicated principles of analysis of systematic designs, but says that graphical methods will often suffice to evaluate the plots. Again, the size considerations seemed relevant to the present experiment.

Burley and Wright (1985) in their paper on experimental design in multipurpose tree research note that while the standard replicated randomised complete block designs with 4-6 replications of 9-49 trees per square plot are the most widely used, cost considerations in terms of plants and land may pose difficulties and there are many other designs worthy of note.
They list: 1.Alley planting

2. Alternate row designs
3. Parallel row designs
4. Nelder designs
5. Modified Nelder designs
6. Constant spacing designs

They state that analysis of these designs is by regression analysis since it is an estimate of the response surface that is the objective and that checks should always be made on the possibility of clinal site variation coinciding with the systematic layout of the spacing.

Whilst none of the six designs listed above have direct relevance to the present situation, it can be seen that a wide variety of systematic designs are considered acceptable in forestry. The emphasis on space saving mentioned by most of the authors cited are summed up by Evert (1971) who describes a large number of systematic designs used in the field and states that the greatest single disadvantage of randomised block designs is that they require large treatment plots. He quotes Nyyssonen and Vuokila (1969) who assess the minimum width of the isolation strip around yield plots as 6 metres. Evert states that the clinal layout of plots involves the placement of the treatment plots systematically in serial order of intensity. It is argued that interference between plots can be compensated for by having a greater intensity treatment on one side and a lower on the other.

Hence, surrounds of plots can be discarded and the experimental area considerably reduced as compared to the area requirements of randomised block design.

The overwhelming disadvantage of systematic as opposed to randomised designs, is the risk of confounding variables. Conventional analysis of variance cannot be used. However, for all the space and labour saving reasons mentioned above and especially for their utility in exploratory situations, systematic designs have frequently been used in forestry experiments.

Among examples of systematic designs used in field situations, the well known experiments of Cameron et al (1989) relied on regression to analyze tree growth with time in their Brisbane agroforestry study of Eucalyptus grandis in a Setaria dominated pasture, while Smith (1977) used coefficients of variation for comparing amounts and sources of variation on plots of four tree species.

There are large numbers of fertilization and spacing trials in many countries which are laid out clinally according to systematic designs devised at the National Vegetable Research Station, Wellesbourne. It therefore appears that there is no presumptive objection to systematic design by biometricians.

3.3. Design Options in Relation to the Formentera Study.

In view of the above, it was felt that the space saving aspect and the reported appropriateness of systematic designs to preliminary studies or those where, to quote Huxley (1983) "it is not clear what is likely to be 'on target' with regard to a treatment variable which is susceptible to a very wide range of levels and even more particularly when these are being tried in a 'new' situation" were important considerations. In the present study, these advantages, particularly the ability of the design to be accommodated in the space available, and the management factors (the observation of lateral flow in the unirrigated sections) were taken into consideration, as was the imposition of a management strategy (in the case of the present study, salinity of the irrigation water). Huxley mentioned as a disadvantage the necessity of intensive management, but these plots were in any case to be intensively managed.

Taking into account the pros and cons listed above, the constraints of plot size, the minimisation of the possible effects of lateral flow and the observability of this, a systematic design and clinal layout seemed the best option. It was felt that valuable results could be achieved in spite of the site limitations.

The areas of the two plots available were approximately 1000 m^2 each. Of this, less than half could be used for

the initial planting because of the need to leave space for the subsequent plantings and for catchment, mixing tanks, etc. The above factors were taken into account and professional advice was taken (Dr.I.Baillie 1986 pers comm) which indicated that the small size and logistically constrained design would still produce useful results.
It was not that it was judged unnecessary to randomise; but rather that given the site and labour constraints, it was difficult to see how a randomized design with adequate borders around the assessed core of each plot could have been fitted into the space available. The limited area of land available and shape of the boundaries were fixed constraints as was the labour available (the author only).

Randomization could not have been achieved without potential severe interference between treatments. It was therefore decided to take the views of the authors cited above into consideration. The advantages listed by Huxley (1983) seemed particularly appropriate.

It was hoped that this preliminary investigation would give indications of where to concentrate in the future. From review of the literature it had seemed that foresters favoured a pragmatic approach, accepting the design best suited to the nature of the problem. Although systematic designs may not be considered satisfactory in the strict statistical sense, they appeared to be considered useful for precisely this sort of study, where the ultimate aim was to demonstrate any trends which could serve as guidelines for future work.

Ploughing showed no apparent discontinuity or trend in the soils which would have made a systematic design inappropriate at either of the available sites. There was good reason to expect lateral flow, since the sites were almost flat but surface water drained off to the east at Site 1; the soils were very shallow; the rock was probably quite permeable. Matching treatment orientation to drainage direction was not feasible for reasons of space and would in any case not have eliminated lateral flow. Gradient effects were in fact noted as the experiment progressed (Section 5.15). In fact, the spatial limitations of the sites precluded a really satisfactory layout for either systematic or randomized designs, but a systematic design fitted better.

Had a randomised design been used, the height growth data could have been analyzed by analysis of variance, and in doing so it would have been possible to analyze specifically for the experimental variable - in this case water quality. Systematic designs may be interpreted by regression analyses, if there are enough levels of the independent variable, but this still offers no defence against confounding variables.

Even given the spatial limitations of the sites, it would have been possible to achieve randomisation either by reducing the spacing between the trees to 1 metre, and/or by randomising the four water treatments within the four blocks at each site. In either of these cases, there would certainly have been considerable costs.

If 1x1m spacing had been used, eucalypt height growth from the second year on would probably have caused self-thinning. Gogate (1983) cautions against this and also states that in high density plantations of this type, where saplings had been observed to be lanky, they had pronounced crown suppression and appeared to have no chance to reach the top canopy. Also, from about the second year, root overlap was to be expected and this again would have confused the situation in a randomised design, particularly with 1x1 spacing.

Randomising the four water treatments within the blocks would have obscured the effects of spill-over between the plots and made it very much more difficult to observe the effects of lateral flow to the extent that the chosen design allowed. The layout of the experiment was designed to minimise interference between treatments since it was financially impossible to prevent all lateral flow by engineered barriers (Figs.8a and b). The layout was designed to allow clear observation of the effects of lateral flow, which would not have been possible with a randomised design of this size (Section 5.15). Had a randomised design been adopted and a "No Water" plot been assigned to a position inside a block (instead of at the edge), the results of analysis would have been statistically valid but would not have reflected the real situation in the field. Effectively there would not have been a "No Water" plot in such a block as the water received laterally would have confused the height growth figures so much as to make them meaningless.

3.4. Design of the Experiment

Two species, an acacia and a eucalypt (see below Section 4.2 Choice of Species) were tested with four water treatments; no water, best available water (rainwater of less than 1dS/m), and waters of 5 and 10dS/m salinity. The salinity levels, 5 and 10dS/m were chosen, on expert advice, to cover the range of many groundwaters in arid and semi-arid zones (Dr.I.Baillie pers.comm.1986)

The seedlings were raised from seed in the nursery and then planted out in a block design as shown in Figs.8a and b. At each site, there were two replicate blocks of 32 trees of each species. Thus with 32 trees in each block there were 128 trees at each site. Within each block, there were eight trees for each water treatment (no water, best available water and waters of 5 and 10dS/m) planted in a double line and the water treatments arranged systematically so as to minimise the effects of lateral flow of the irrigation water. In three of the four pairs of blocks (replicates), treatments were run in opposing directions. Only at Site 2 in Blocks 1 and 2 (Replicate 3) did the four water classes run in the same direction (Figs.8a and b).

Spacing was 1.75 metres within rows and 1.75 metres between rows. This spacing was seen as the best compromise between a normal plantation spacing (2-3 metres) and pot trials or high density plantations (1 metre). Given the constraints of plot size, it was desired to keep spacing as close as possible. However a 1x1m spacing, which would have allowed square treatment plots of 25 trees with the inner 3x3 measured, would not have been feasible for a long term experiment. With the extremely shallow soils, the soil volume available for roots at a 1x1 spacing would be only .25 m^3. The water holding capacity of extremely stony soils is difficult to measure as satisfactory cores cannot be taken. Nevertheless, it was felt that .25 m^3 was almost certainly too little soil for satisfactory growth. Water use of eucalypts is high. A ten month study at Dehra Dun showed a monthly consumption of over 500mm for eucalypts in the juvenile stage (Jacobs 1979). Dabral and Raturi (1985) and Calder (1986) also give very high figures. In addition, it was thought that eucalypt height growth from at least the end of the second year would lead to self thinning and excessive competition leading to uneven growth, as mentioned above. The possibility of high mortality from inadequate soil volume and/or excessive height growth threatened probable consequent difficulties in interpretation due to variable growing space per tree. It was important that the trees should be as free growing as possible.

Trees were individually watered with water of the appropriate salinity (Figs.8a and b). Irrigation quantities were determined by estimated need, based on tensiometer readings (Figs.9a and b and Section 4.8.iv).

After two years, irrigation was withdrawn from half the trees whilst the remaining half remained under irrigation for a further two years in order to quantify growth differences due to irrigation duration.

Blocks at each site for continuing irrigation and no further irrigation were randomly chosen with dice (Figs.10a and b). Although it was desirable that base heights in the two categories should not be significantly different, it was impossible to ensure this, as the experiment was continuing with existing trees. In the event, there was no significant difference in ten of the twelve pairs of blocks. There were two pairs which showed significant differences. In the eucalypts at Site 1 irrigated at 5dS the block selected for continuing irrigation was significantly taller than the block where irrigation was to be withdrawn. In the acacias at Site 2 irrigated at <1dS the block selected for continuing irrigation was significantly less tall than that where irrigation was to be withdrawn. Significance levels were calculated by Mann Whitney U and are shown in Table 3.

Table 3: Tests of Differences between Blocks Selected for Continuing Irrigation and No Further Irrigation at October 1989. Mann Whitney U Tests.

Site 1		U	N	Site 2 U	N
Acacia	10dS	29.5	16	22.5	16
	5dS	14.0	16	18.5	16
	<1dS	22.0	16	5.0*	15
Eucalypt	10dS	25.5	16	24.0	15
	5dS	8.0*	16	19.0	14
	<1dS	20.0	16	22.0	14

* = significant at p <.025

It had been planned to make a second planting with trees of the same species but of local provenance in 1990. In the event, this planting was made in the third year of the experiment (1991) instead of the second, due to circumstances in the field. The growth characteristics of these trees were compared to those of the trees of Australian provenance.

This design was the best compromise seen at the time between the need for replication, adequate plot size, sufficient range of treatments and logistical constraints. Less than four treatments would allow only a slight enlargement of plot size because of the need for increased replication, whilst more than four treatments would require

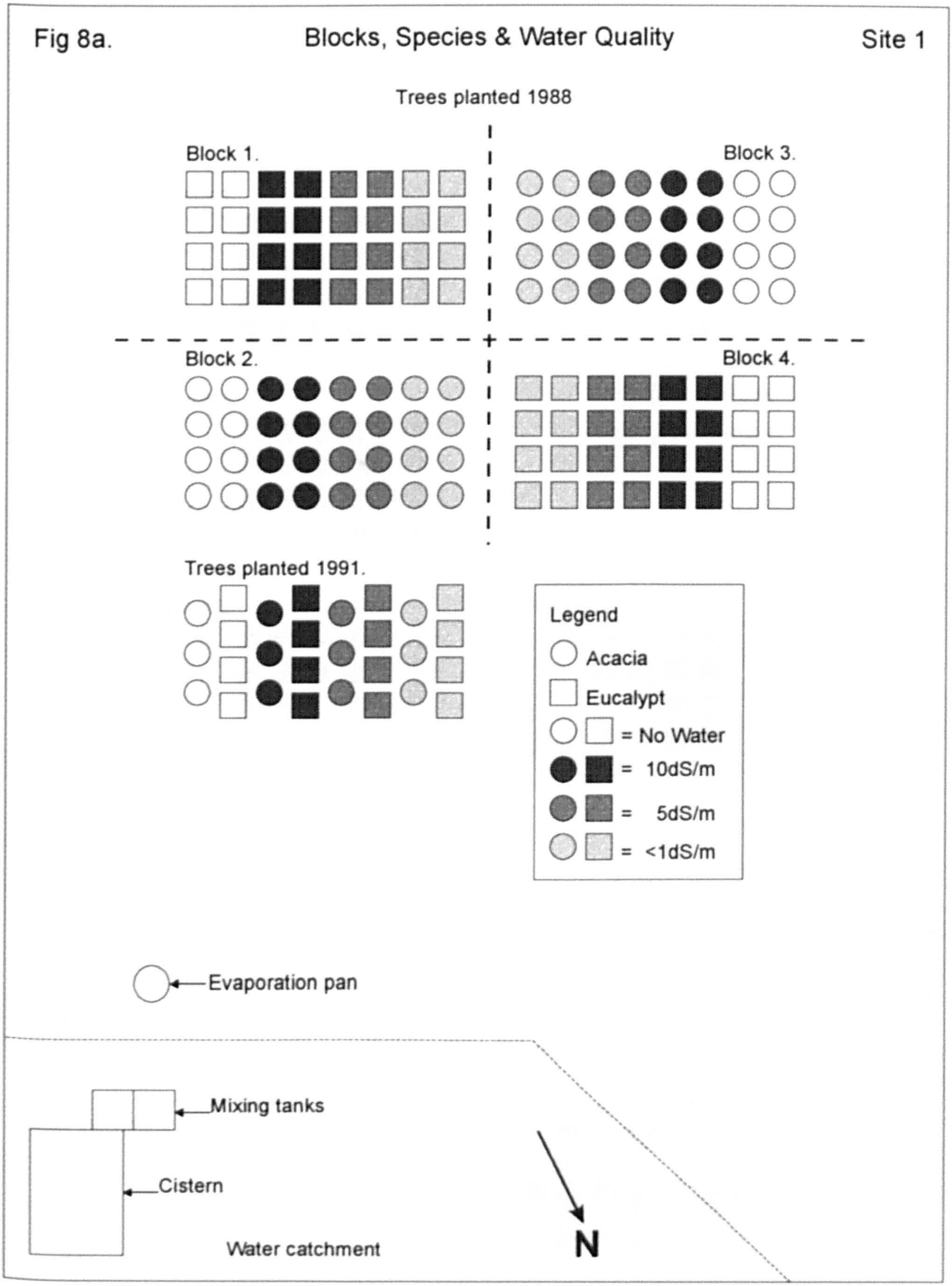


Fig 8a.
Blocks, Species & Water Quality
Site 1
Trees planted 1988
Block 1.
Block 3.
Block 2.
Block 4.
Trees planted 1991.
Legend
Acacia
Eucalypt
= No Water
= 10dS/m
= 5dS/m
= <1dS/m
Evaporation pan
Mixing tanks
Cistern
Water catchment
N

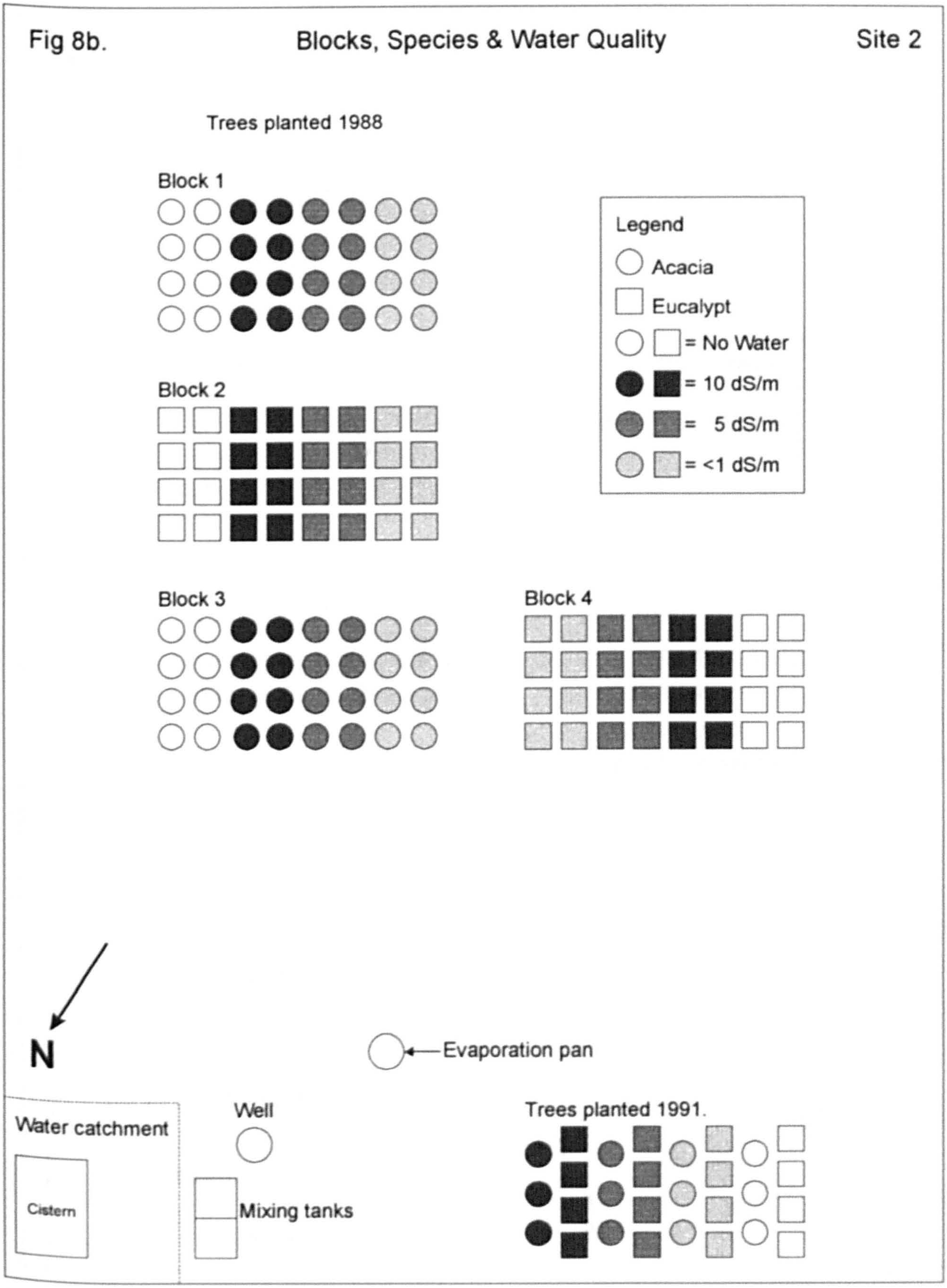


Fig 8b.
Blocks, Species & Water Quality
Site 2
Trees planted 1988
Block 1
Block 2
Block 3
Block 4
Legend
Acacia
Eucalypt
= No Water
= 10 dS/m
= 5 dS/m
= <1 dS/m
N
Evaporation pan
Water catchment
Cistern
Well
Mixing tanks
Trees planted 1991.

Fig 9a. Blocks, Species & Sampling Spots Site 1

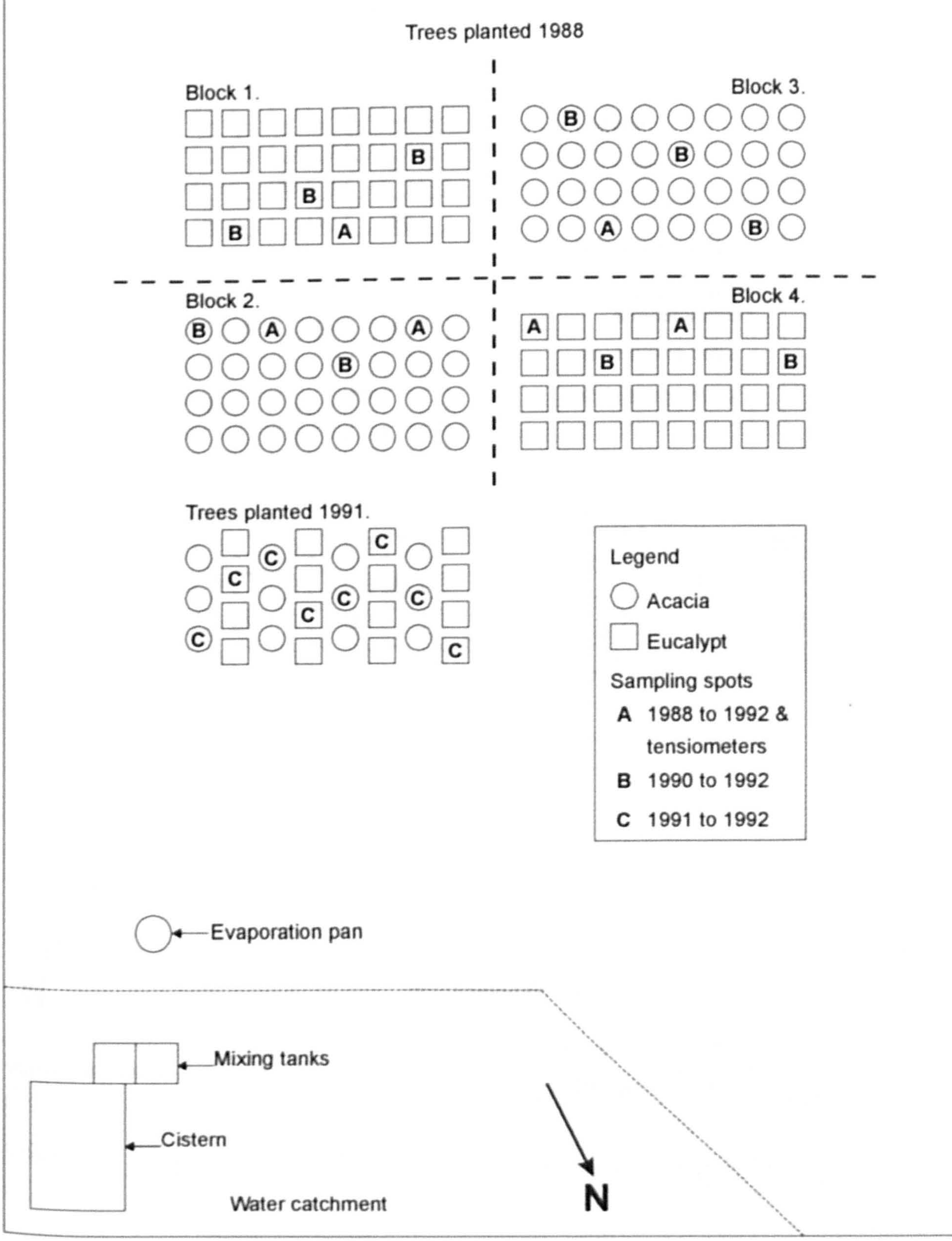


Fig 9b. Blocks, Species & Sampling Spots Site 2

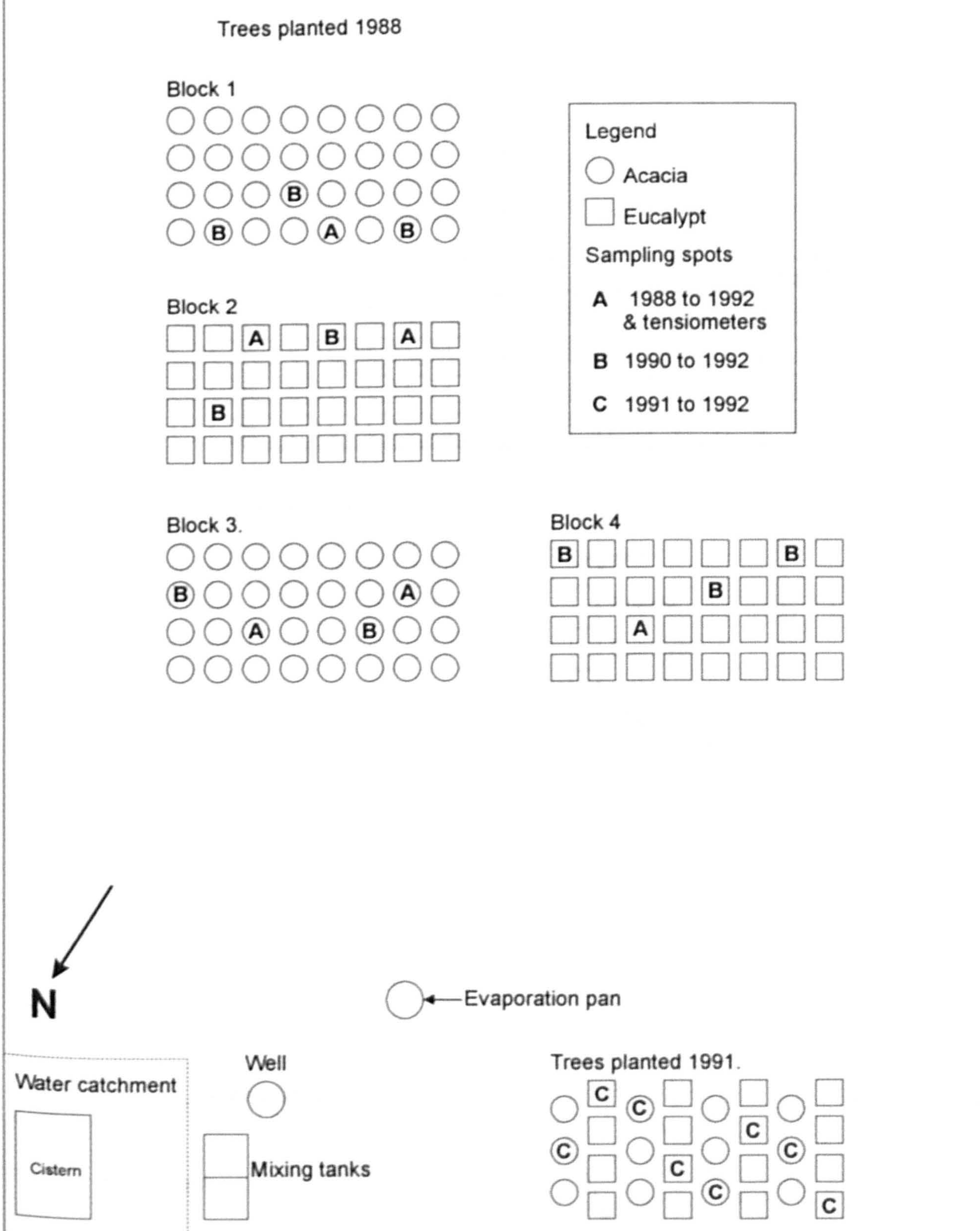


Fig 10a. Blocks Withdrawn from Irrigation Site 1

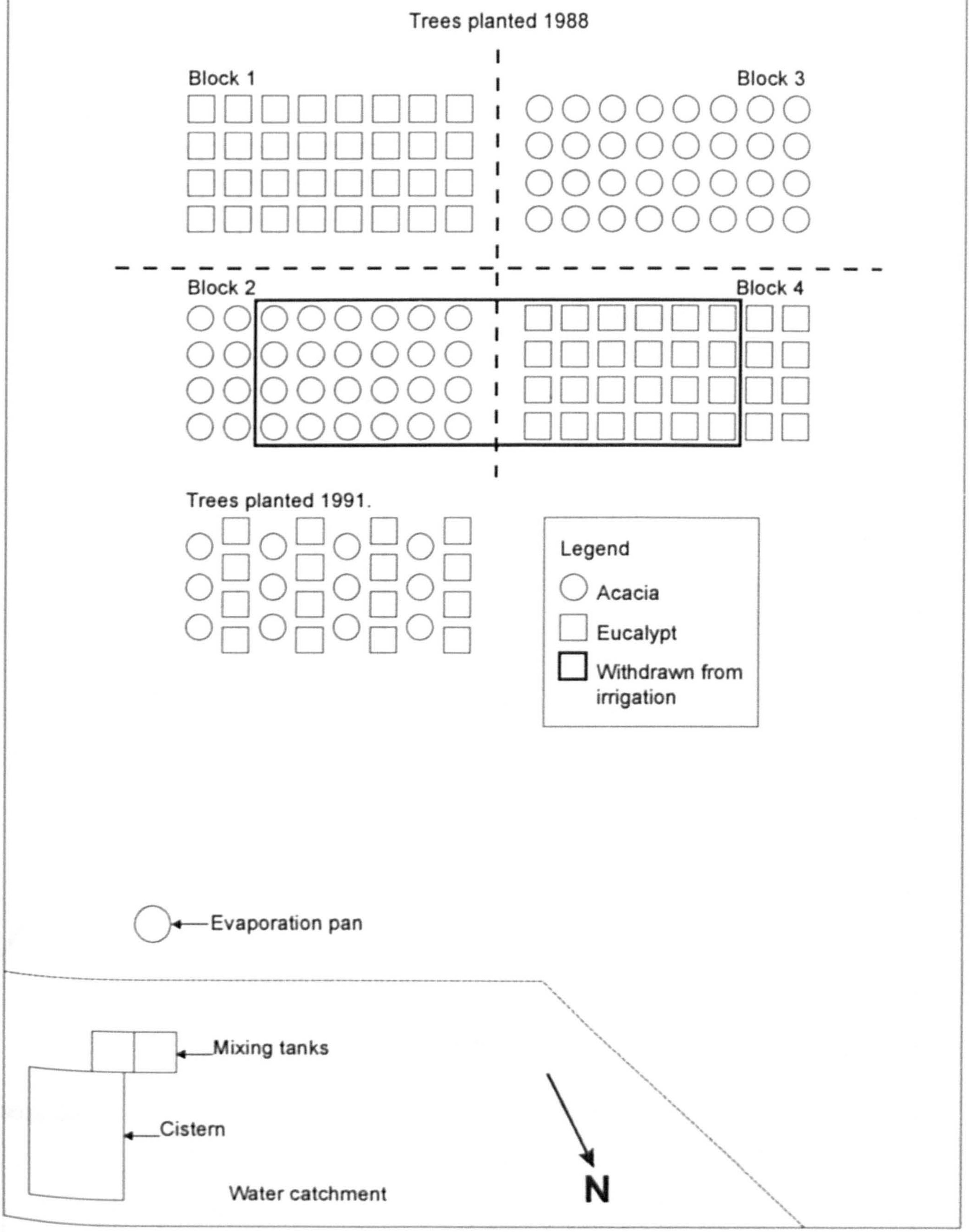
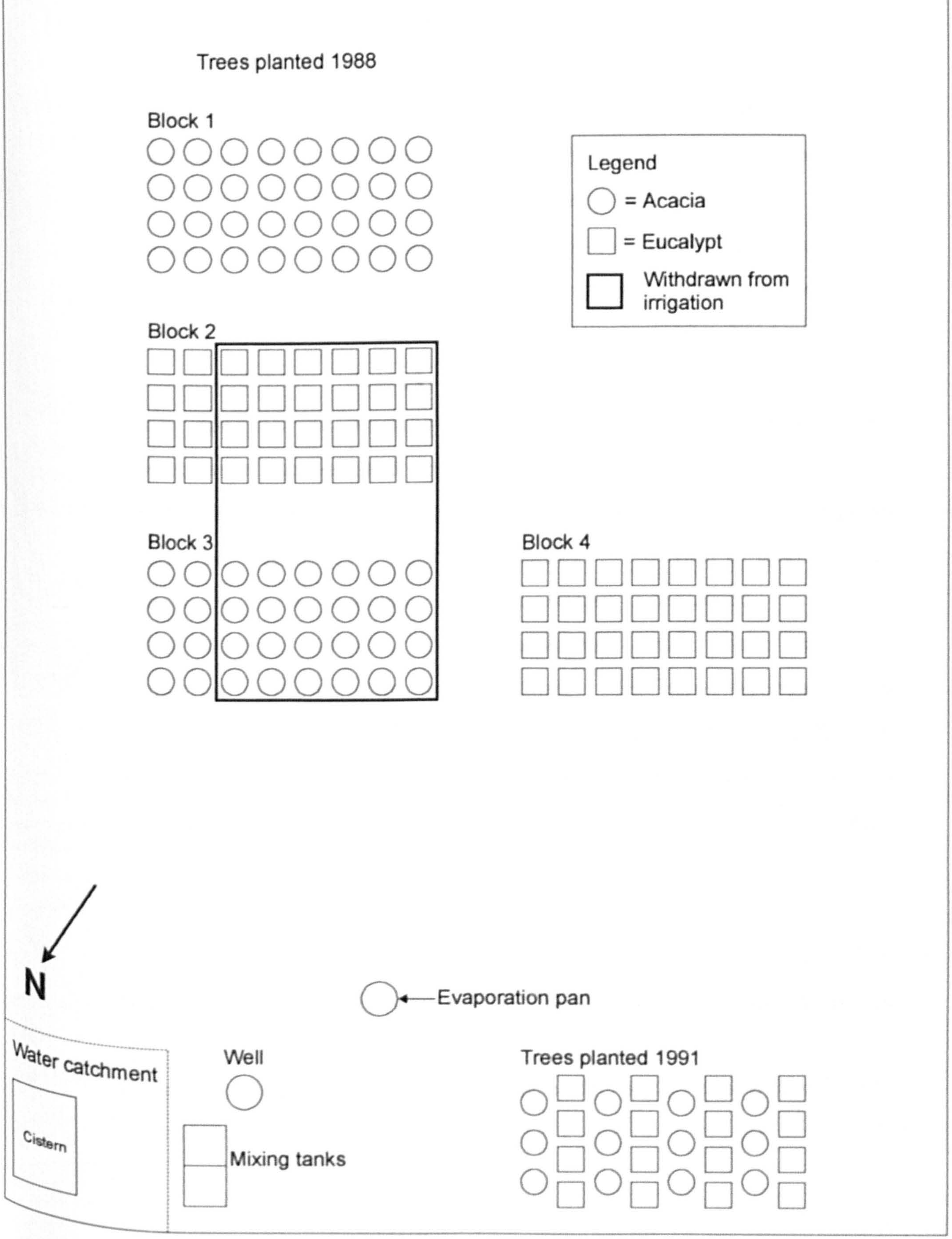


Fig 10b. Blocks Withdrawn from Irrigation Site 2



an unacceptable reduction in plot size. Space considerations dictated that there could not be more than 2 replicates at each Site.

If an opportunity occurred to repeat the experiment and there was an unlimited area to work on and funds available for additional labour, then with a larger site, randomisation would have been feasible and desirable. If, for instance, approximately 5000m^2 of land was available at each of two sites, then it would be possible to lay out a randomised block design for two species with two blocks of each species at each site. There would be four water treatments randomised within each block, with twenty five trees for each water treatment (planted in a 5x5 square with the inner 3x3 to be assessed). Using a spacing of three by three metres in each water treatment, with six metre strips between the treatments, this would give an area of 1260m^2 for each block, if the blocks were rectangular. As well as the land, additional funds for stock and labour would be necessary as it would be clearly impossible for one person to undertake all the work involved in raising seed, planting and maintaining an experiment of this size.
With additional funds for soil sampling and analyses, then more soil analysis before the experiment started would be desirable. A preliminary soil survey and site map would allow minimization of variance in soil characteristics within blocks.

3.5. Data Analysis.

Parametric tests were used where possible for the statistical analysis in the study (e.g.Pan Evaporation and Lateral Overlap data). It was found by applying Kolmogorov-Smirnov tests that the height data was not normally distributed at planting. Thereafter it became normal. Where data was normal, simple linear regression analysis was used for the height growth data with time. Where data was non-normal, Kruskal Wallis or Mann-Whitney U tests were used. In some cases Mann-Whitney has been used for height growth comparisons between sites where data were normal. This has been done for consistency with earlier, non-normal data.

CHAPTER 4. MATERIALS AND METHODS.

4.1. Sites and Experimental Plots.

As has been stated above, two sites were available on Formentera, but constraints of finance, land and labour influenced the area that could be planted and the number of species and watering regimes that could be tested.

4.1.i. Sites.

Formentera, as has been mentioned, is a low lying island on Tertiary limestone. It is approximately eighteen kilometres long by six kilometres wide at it widest point, narrowing to two kilometres wide in the 'neck' of the island.

The two sites, of approximately one thousand square metres each were available on the island (Fig.3). Site 1 was approximately one kilometre inland in the western part of the island and about 40 metres above sea level. It was a nearly flat field (very slight slope from west to east) which had lain fallow for about ten years, having previously been used for wheat. Soil depth was variable, generally between 20 and 40 centimetres. Immediately before planting it was covered with rough scrub grasses. The site was walled on the northern and western sides and beyond the western wall the soil was shallower with large outcrops of rock at the surface. Between these outcrops was a cover of *Juniperus phoenicia* and *Pinus halepensis*.

Site 2 was also approximately one kilometre from the sea and nearly in the centre of the island. It was 20 metres above sea level and was also a flat field, that had been used intermittently in the past ten years for raising maize and beans. Soil depth was less than at Site 1, generally thought to be about 20-30 centimetres. Before planting it was also covered with rough grass and there were some old almond and carob trees in other parts of the field. It was walled on all sides and beyond the walls were some *J.phoenicia* and *P.halepensis* amid rock outcrops as at Site 1.

Site 1, although walled to the north and west, was unfenced on the other two sides and there was no water supply, either from well or cistern. It was impractical to sink a well on this site as the water table was approximately 40 metres below ground level.

Site 2 was walled and there was a rainwater cistern holding about twenty cubic metres of water and a well, 22 metres deep, giving highly saline ground water (generally in the region of 10dS/m but varying throughout the year).

Although the area of each site was approximately $1000m^2$, only about $450m^2$ at each could be used for initial plantings, because of the space needed for cistern catchment and mixing tanks and also to allow space for later plantings. Thus it can be seen that plot size was very constrained.

4.1.ii. Site Preparation and Initial Water Mixings.

Both sites needed preparation before planting and irrigation could take place. First, the two unwalled sides of the land at Site 1 were fenced with chain link fencing. A rainwater cistern with a capacity of approximately thirty five cubic metres was dug and rainwater from another cistern brought to fill it initially. Two open concrete tanks of approximately 1 cubic metre each were erected at each site for mixing waters of different salinities. At Site 1 these tanks were adjacent to the cistern. At Site 2 they were equidistant between the cistern and the well.

The fields were ploughed. Both fields were nearly flat - a slight gradient from west to east was observed at Site 1 - and ploughing did not alter this. In some cases the ploughshare cut down to the rock and in many cases very large stones were thrown up by the plough. The colour of the ploughed earth at Site 1 appeared rather lighter and the texture thinner than at Site 2. Although it was clear that the soils were shallow and stony at both sites, it was not possible to determine soil depth at that time.

For Site 1 where sea salt was to be used, salt was hacked out of a pile by the former salt works and transported to the site. It was then further smashed with a hammer and weighed. After that it was added to the two mixing tanks into which water from the cistern had been pumped, and mixed to the desired salinities. From experiments with weighed salt and buckets of water, stirred, left to stand and tested at intervals, it was found possible to mix the water to within +/- 0.5 dS/m of the desired conductivities of 5dS/m and 10dS/m.

For Site 2, well water was pumped into the 10dS/m tank. This water was never less than 10dS/m, sometimes more. In cases where it was above 10dS/m it was diluted with cistern water. In the same way, the 5dS/m tank was filled with a mixture of well and cistern water until the desired salinity was achieved and checked with the conductivity meter.

Test mixings were made. Water samples of the three water types to be used (well water, rainwater cistern water and the same cistern water with the addition of salt obtained from the former saltworks) were taken and transported to London where they were analyzed in the Laboratory at the University of North London for conductivity,pH and soluble Na, Ca, Mg and K.

Soil samples from both sites were taken at random points at the surface and at 20cm depth. They were bagged and taken to London where they were analyzed in the same laboratory for conductivity, pH and exchangeable Na, Ca, Mg and K.

Black semi-rigid polythene hosepipe of the type generally used for drip irrigation was installed in preference to conventional soft hosepipe, as it was less liable to tangle. Hoses and mixing tanks were colour coded, orange for 10dS/m, beige for 5dS/m, and green for best available water (hereafter referred to as <1dS/m) to avoid confusion and possible inadvertent connection to the wrong pipes.

One electric pump was installed at Site 1, powered by a generator, and three at Site 2 where mains electricity was available. At Site 1 it was relatively easy to move the pump between the cistern and the two mixing tanks. The situation was different at Site 2 and three pumps were installed; one in the well, one in the cistern and one for the two mixing tanks Tests were made of the pumps' rate of delivery.

4.2. Choice of Species.

It was necessary to choose species that were capable of fast growth in adverse conditions. The species should also be salt tolerant and, in view of the highly calcareous soils, tolerant of alkalinity.

Forestry Development Papers nos.5 and 6 (FAO 1955) give notes on many species and suitabilities to various conditions of site and climate. The papers note that E.camaldulensis, the outstanding plantation tree for a wide variety of arid zone sites, is not suited to calcareous soils.

Forestry Development Paper no.13 (FAO 1958) devoted to choice of tree species and Forestry Development Paper no.16 (FAO 1963) 'Tree Planting Practices for Arid Zones' give extensive lists of possible species and their suitability to site and climate.

Eucalyptus spp. are recommended by an overwhelming number of papers for arid zone planting particularly where salinity is a problem, (e.g. Chaturvedi 1984, Jha and Pande 1984, Sandell et al 1986 and Bisht et al 1989). Dabral and Raturi 1985 note that eucalypts use less water per unit of biomass increase than other species. Eucalyptus gomphocephala is more particularly noted by Shrivastava and Lal 1989 and Nahal 1989.

Leguminous species are also thought extremely valuable for arid and semi-arid lands and saline conditions (Felker 1981 and Johnson 1992). Among these species, Acacia saligna has received favourable reports from Sheikh 1981, Morris 1984, Hyde et al 1990, working in southern Spain, and Tiedeman and Johnson 1992, among many others. El Lakany (in Turnbull 1987) states that A.saligna has been the most successful Australian Acacia in North Africa.

Species of both Eucalyptus and Acacia are known to grow well in the more arid parts of the Iberian peninsula. Bolonos (1955) recommends E. gomphocephala for its general utility and greater tolerance of calcareous soils than E. camaldulensis. Heth et al (1967) confirm E.gomphocephala as a suitable choice for alkaline conditions, while Karschon (1964) suggests two species of Acacia, A.raddiana and A cyanophylla (now saligna) for arid conditions. Both E.gomphocephala and A.saligna did well in Boyko and Boyko's (1968) Eilat experiments. Eilat is hotter and drier than Formentera. In terms of temperature and pan evaporation, Formentera is similar to the coastal plain of Israel, but has less precipitation. (Meteorological data from Shalhavet et al 1976).

E.gomphocephala and A.saligna were chosen as the test species after review of the literature and consultation with the Volcani Institute, Bet Dagan, Israel, the International Council for Research in Agroforestry (ICRAF) Nairobi and CSIRO, Canberra, Australia. The species were chosen particularly for reported tolerance of salinity and alkalinity.

Both these species had been observed growing in Formentera as individuals, presumably imported as exotics at some time in the past. Those which had been noticed appeared to be rainfed and relatively slow growing. However, although they were clearly tolerant of calcareous soils and the existing climate, the salt tolerance of these provenances was not known. It was therefore decided to order seed from CSIRO in Australia where the salt tolerance of particular provenances is known.

At the time of first planting (1988), it was decided to repeat the treatments with seeds of the same species but of local provenance, should the initial experiments prove successful in terms of establishment and growth.

4.3. Seedling Production.

Seed of both species was obtained from CSIRO in Australia. Eucalyptus gomphocephala DC was of Ludlow SF provenance. Acacia saligna (Labill.) H. Wendl.formerly known as A.cyanophylla Lindl.was of Lake Muir provenance.

The seed was sown in Hado no.2 plastic pots with drainage holes in the lower third (20 x 10 centimetres flat,15 x 8 x 10 centimetres filled) on May 13th 1987 for the eucalypts and May 18th for the acacias.

The acacia seed was first treated with boiling water to encourage germination (CSIRO advice). In this technique, the seed is placed in a jar and boiling water poured over it. It is left in the water for twenty four hours and then planted.

Half the seed of each species was sown in a potting compost obtained from a local nursery and made from garden earth and well rotted seaweed. The other half was sown in earth obtained from under Ceratonia siliqua L.trees which is locally considered to be particularly good for potting. Although C.siliqua is not planted commercially, most farmers have a few trees, using the beans for fodder. The trees are generally isolated specimens with field crops planted around them. Although an average height would be perhaps two metres, some old trees grow to as much as six metres and it is from beneath these specimens that the farmers collect earth well mixed with litter if they need it for potting purposes. Seeds were sown at three seeds to a pot for the acacias, and a small pinch of seed for the eucalypts (these seeds being too small to handle singly). 500 pots for each species were sown. The pots were placed in wooden slatted boxes which were raised slightly off the ground on stones to facilitate root pruning should this be necessary. The boxes were placed in four blocks, two blocks of acacias and two of eucalypts. Each block consisted of two rows. A wooden frame was constructed to cover the rows and woven detachable mats attached to the top of the frame for shade. These mats could be rolled back if necessary. The installation was made beside a rainwater cistern and the pots were watered daily by hand held sprinkler throughout the summer of 1987 with the best available water of low salinity.

The objective was to achieve sufficient growth for planting out in the autumn of that year. Where more than one seed germinated, the superfluous plants were thinned.

Germination was poor, especially among the acacias. The reasons for the poor germination remain unclear. A much lower germination rate was observed in the nursery compost pots than in those filled with earth from beneath the Ceratonia siliqua and this may have been a contributing factor. The amount of water applied may have been insufficient, due to the rapid drainage of the plastic pots in raised boxes. (Subsequent plantings have been made with the pots placed in concrete tanks and these have been much more successful). However, it was thought that the primary cause of the poor germination was that the hot water treatment had been insufficient to break the dormancy of the acacia seed. By August it was clear that there would not be enough trees for autumn planting and more seed was ordered from CSIRO.

Advice as to planting techniques for acacia was sought

from the same source and from OFI. Both advised that whilst the boiling water treatment was commonly used, a higher rate could be achieved by manual nicking (Doran, and Doran and Gunn 1987).
The second batch of seed were manually nicked (Doran, Doran and Gunn 1987) and planted in September 1987. The planting procedures detailed above were repeated, except that Ceratonia siliqua earth was used for all pots. By December 1987 it was clear that the autumn sowing had germinated well and was growing at a much better rate than the previous batch. Whether this was due to the nicking, the uniform use of C.siliqua earth or to less drying out of the pots in autumn conditions is not known.

The autumn sown seedlings remained in the pots and were planted out in the spring of 1988. The spring sown seedlings were given away.

4.4. Planting.

Between May 2nd and 6th 1988 trees of the most uniform possible size and sown the previous autumn were allocated randomly to treatments and planted out at both sites, the plastic pots being stripped off at planting. All trees were between 10-40 cm in height. Size mixture between treatment plots showed no significant differences when tested by Kruskal-Wallis tests. Holes of approximately 30x30x30 cm. were dug where possible (soil depth was observed to be variable) and by each tree hole, a section of polythene pipe, approximately 10x60cm was inserted as deeply as possible at about 30 cm from the tree bole, slanted diagonally inwards towards the tree.

4.5. Other Growth and Management Factors.

4.5.i.1988-1989 Growth Problems.

At the end of the first winter at Site 1, leaf burn was observed on the western side of nearly all the eucalypts. Although not severe, this was worrying as E.gomphocephala is supposedly resistant to wind and salt burn. The site is one kilometre from the sea but the prevailing winds are predominantly westerly and thus wind or salt burn seemed the only explanation of this damage.

At Site 2 the acacia leaves appeared rather thin and pale. Samples of the eucalypt leaves at Site 1 and the Acacia leaves at Site 2 were sent to Mr. Palmer at the Oxford Forestry Institute, for advice. He replied that in the case of the acacias the absence of any distinct colour difference between the veins and the lamina suggested that lime-induced chlorosis was unlikely, but that leathery phyllodes quite often looked unhealthy and later recovered without treatment. He said that in any case, the application of iron sulphate could do no harm.

25 grams of iron sulphate per tree was subsequently

applied to all the acacias at Site 2 (between May 4th - 12th 1989). All the acacias subsequently recovered, whether as a result of the treatment or of their own accord is not known. No other possible cause for the eucalypt leaf burn was suggested except for wind or salt spray. Samples were accordingly sent to CSIRO for their comments, but were seized by the Australian quarantine service, and destroyed. The cause of these two phenomena is thus unknown.

In 1989-1990, the previous winter's leaf burn at Site 1 was not repeated, nor was the poor appearance of the acacia leaves at Site 2. All the surviving trees looked healthy.

By 1990, the form of the eucalypts at both sites was excellent, but the surviving acacias had generally a distinctly bad form - very irregular in height growth and frequently leaning to one side (not necessarily that of the prevailing wind). Form may be irrelevant when the object of the planting is environmental protection rather than timber production, for instance, but it seemed worth noting. CSIRO were consulted and replied that this habit 'might be a result of genetic factors such as inbreeding. Abnormal progeny are often produced from plants that have a breeding system that is capable of selfing (acacias have a mixed mating system - outcrossing and selfing occurs).'

4.5.ii. Pruning.

In January 1991, the lower branches and forks of the existing trees were pruned off to approximately 1 metre above ground level, where height growth allowed. They were cut close to the main stem, and the wounds treated with tar compound. This operation was performed because some of the trees appeared liable to fork. Since height was the most important growth variable to be tested in this experiment, it was felt that excessive forking might confuse the issue.

4.5.iii. New Plantings.

The trial of seed of local provenance had had to be postponed from the date originally planned (planting out in spring 1990). It was now proposed to plant out in spring 1991.

The previous June, the author had collected new seed of A.saligna and E.gomphocephala from specimens of these species which had been observed growing on the island and had stored it in a wooden box. During the winter of 1990/1991, this seed was sown, as before in Hado no.2 plastic pots. Earth from beneath Ceratonia siliqua trees was used as potting compost and all pots were placed in a cement tank with a drainage hole for ease of watering. All acacia seed was nicked. The first sowing of 100 pots each of eucalypt and acacia seed was made on November 21st. 32 trees of each species were needed, 16 of each species at each site.

By mid-January, the eucalypts had germinated well, but the acacias again showed a poor germination rate and a subsequent sowing of 75 pots of acacia was made on January 24th. The eucalypts grew vigorously and needed thinning by late March. Although the acacias had finally germinated successfully with the second sowing, they remained small and were not ready for planting out in April as had been desired. The eucalypts were therefore also kept in their pots so that all seedlings should be planted out at the same time. In January, part of the fields at both sites were ploughed in preparation for planting the new trees.

24 of the winter 1990/1991 sown acacias were finally judged large enough (minimum of 15cm tall) to plant out at the beginning of June. Rather than wait for an unacceptably late planting date, it was decided to plant 12 acacias and 16 eucalypts at each site instead of the 16 seedlings of each species originally planned.

Planting at both sites accordingly took place on June 7th, each tree receiving 2 litres of water at planting. After this they were irrigated according to the pan/tensiometer readings on the first year's formula of litres/tree = mm.

They received a total of 144 litres/tree in 18 irrigations of 8 litres.

Because the seedlings of local provenance had been planted a year later than planned, it was decided to prolong the experiments for a further year to allow a second year's irrigation for the new plantings. This also gave time for

further soil analysis and monitoring of environmental factors in the earlier plantings.

4.6. Soil Depth Survey.

The soil depth survey which was undertaken between May 1st and 8th 1992 produced most interesting results. It had been known from the start of the experiment that the soils were shallow and stony. However, the relationship between survival and soil depth became much clearer in the light of the final figures.

Lines were laid out surrounding each of the plots and marked off at one metre intervals. An iron stake, ringed every 10 cm. was driven into the ground with a sledge hammer at each metre mark. The lines were moved progressively down the plots until a complete grid covering the entire plots at one metre intervals was measured (Figs.11a and b).
The survey confirmed the extreme shallowness of some areas

of soils. It had been known at the start of the experiment that the soils were extremely shallow in places. It was not then possible to determine depth across the field systematically. Sometimes a particular spot would appear to be shallow but the removal of a stone or stones would reveal greater depth. After the survey it was clear that

mean depth at Site 1 was 32.3cm. The Site 2 mean was 25.8cm.

Although some of the soils would seem to be too shallow for any tree growth to take place, it should be emphasised that a survey of this sort cannot give a complete picture. There are always small fissures in the underlying rock. Tree roots will find their way through the rock in a remarkable number of cases. Even on extremely shallow soils, irrigated trees will survive and grow.

4.7. Tree measurement.

Tree height was measured in 5cm intervals and diameter at 10 cm above ground level in 0.5cm intervals at the beginning and end of each irrigation season for five years. At October 1995, height and diameter of all surviving trees were measured.

At this time, all acacias were examined for branching habit and branch numbers. Orientation and angle of the trees was also recorded. Data sheets were constructed to show branching of the trees together with orientation and angle and a note made of the authors subjective assessment (good/not good). An index was devised to show the branching habit of acacias as follows: first order branch counts were divided by second order branch counts, second order branch counts were divided by third order branch counts. These two totals were added together and divided by two to produce and index figure:

Fig 11a. Soil Depth Site 1.

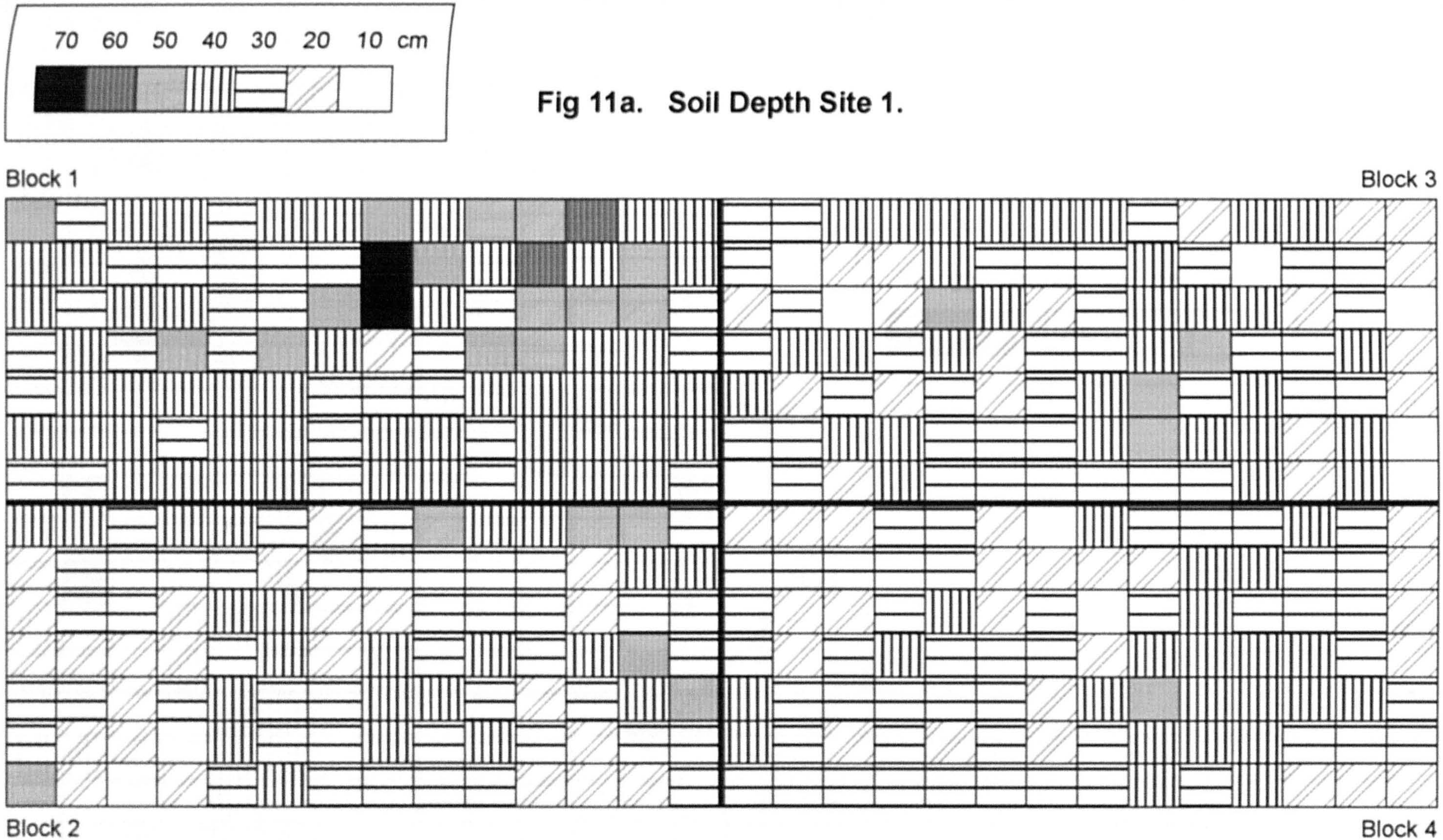


Fig 11b. Soil Depth Site 2.

$$I = \frac{N1/N2 + N2/N3}{2}$$

Where N1, N2 and N3 are first, second and third order branch counts respectively.

4.8. Precipitation and Pan Evaporation.

This section contains results of investigations. Since they were used to determine the form of the experiment, they are presented here and not in the Results Section.

Precipitation has been mentioned briefly above (Section 2.3.iii). For the purposes of this study, where the water balance is of great importance, it is necessary to examine the pattern of precipitation and evaporation in more detail. Although precipitation figures from the San Francisco station were available for previous years, of necessity the detailed examination could only be undertaken during the period of the study when the author was also taking her own pan evaporation readings.

Monthly meteorological records were obtained from Ibiza airport. Whilst useful as backup it was felt that these data were not strictly applicable to Formentera, where from observation and hearsay it was thought that precipitation was significantly lower, and temperatures higher than in Ibiza in spite of its proximity (17 kilometres). Later monitoring confirmed that these suspicions were justified and data recorded at the test sites differed substantially from that recorded in Ibiza. Other data were taken from Pilar and San Francisco for comparison purposes.

It was therefore necessary to monitor relevant meteorological variables at the experimental sites. A screened maximum-minimum thermometer and a raingauge were installed at each site. Class A evaporation pans were constructed locally and one was installed at each site. Readings were taken from the beginning of April 1988, one month before the date of planting. At first, considerable difficulty was experienced with the pan readings. It was almost impossible to gauge how much water should be added as the slightest breeze disturbed the surface of the water. This problem was overcome with the addition of stilling wells (Jensen 1980).

4.8.i. Differences in Precipitation Pattern between Ibiza and Formentera.

Year-round records were obtained from the San Francisco raingauge (midway between the two sites and about two kilometres from each). From January 1988 to September 1990, the differences from the Ibiza readings are shown in Figs.12a,b and c. Precipitation figures at San Francisco from 1953 to 1987 are shown in Table 2 and the number of rain days per year in Table 4. Monthly Rainfall Probability by Percentiles and Quartiles are shown in

Table 5.

From 1975 to 1987 the number of rain days was as follows:

Table 4: Rain Days at San Francisco Javier.

Calendar year	
1975	
76	
77	
78	
79	
1980	
81	
82	
83	
84	
85	
86	
87	
Mean	47.5 days
CV	19.9%
Range	21 - 59

The variance of the annual precipitation is very large. Average precipitation figures only give a rough guide.

Table 5. Monthly Rainfall Probability (mm)in Percentiles and Quartiles.

San Francisco Javier 1975-1993. 19 years records.

Month

	J	F	M	A	M	J
L	0	1	1	0	0	0
25%	20	12	14	16	11	1
50%	32	27	22	34	31	5
75%	47	51	44	52	62	13
H	105	111	105	71	102	35

	J	A	S	O	N	D
L	0	0	0	2	1	3
25%	0	0	13	29	14	22
50%	0	5	25	65	36	35
75%	2	10	49	105	49	49
H	40	140	95	220	266	222

Fig.12a. Precipitation Ibiza and Formentera: 1988

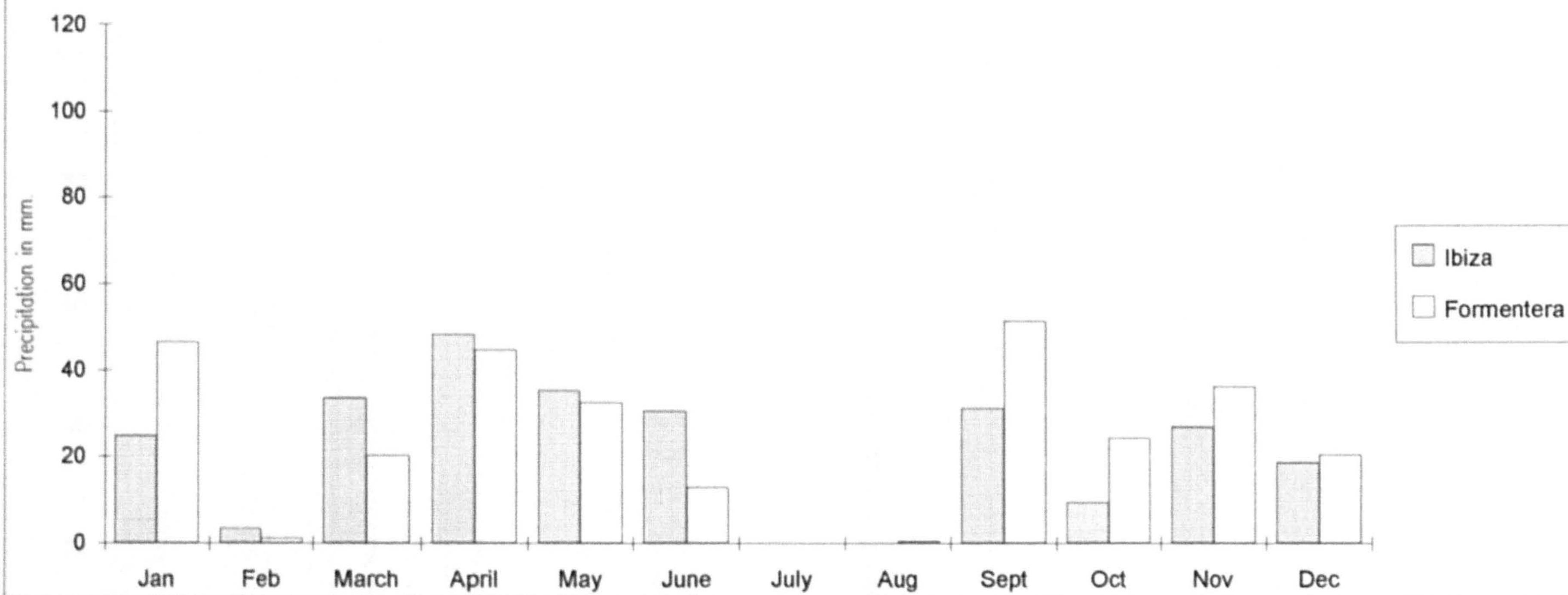


Fig. 12b. Precipitation Ibiza and Formentera: 1989

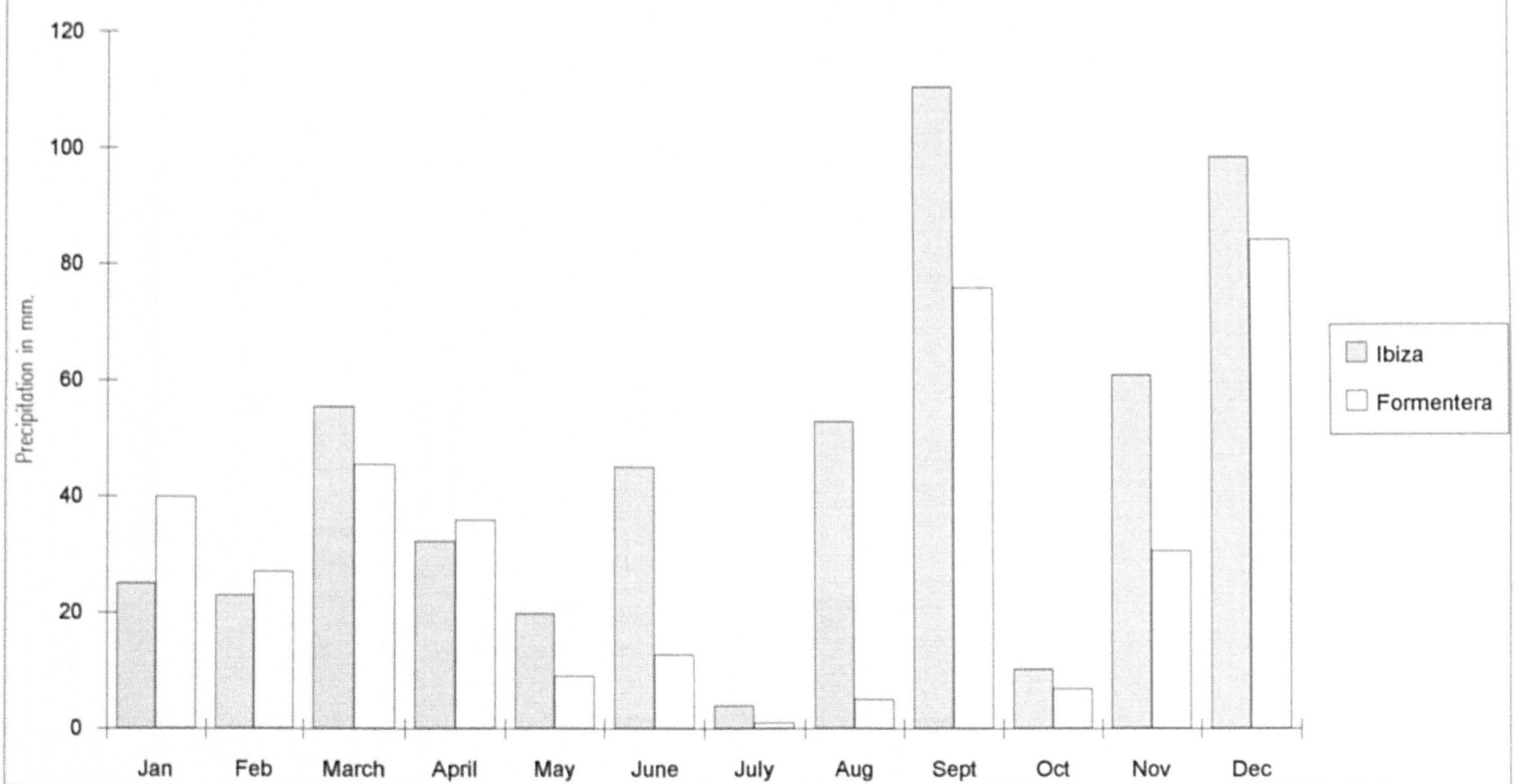
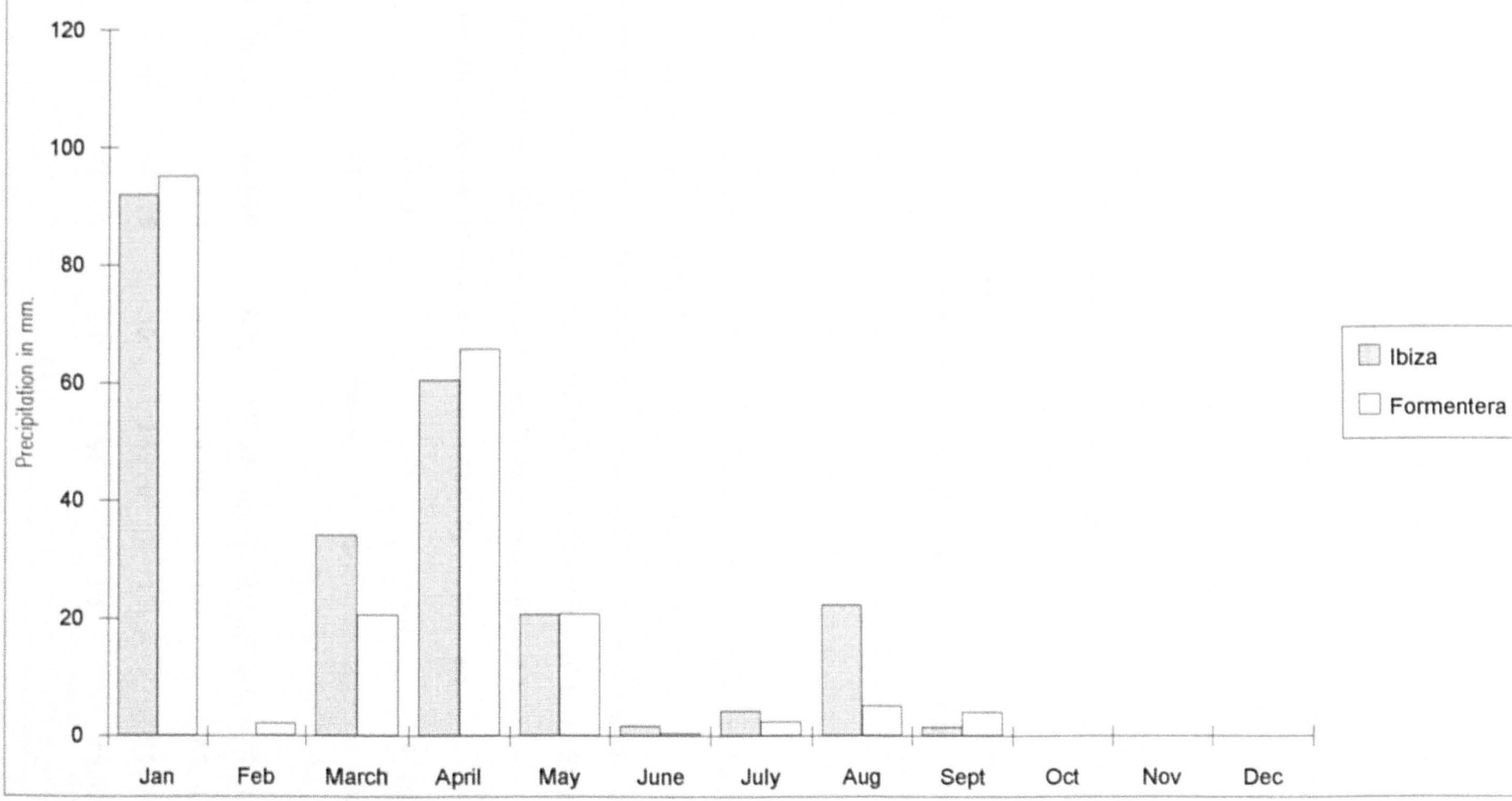


Fig 12c. Precipitation Ibiza and Formentera: 1990 (January-September)



4.8.ii. Concept of 'Effective' Precipitation.

Although in general the greater part of the rain falls in the winter months (October - March), there are often exceptional rains outside this season. During the period of the study, there were 'exceptional' rains which interfered with the irrigation regime in September 1989 and May 1991. Moreover, a large part of the rain falls in small amounts almost all of which evaporates from the soil surface rather than infiltrating and contributing to soil moisture reserves. This can be easily verified by scratching the soil immediately after a small rain. The soil will be quite dry a few millimetres under the surface.

For the period April 1986 to April 1991, the rainfall pattern has been analyzed to show 'effective rains'. Soil was examined after various amounts of rainfall and, for the purposes of this study, an 'effective' rain was deemed to be more than 10mm in 24 hours. See also Fig.13.

Table 6: Effective Precipitation (Eff.Ppt^n.)in mm.

	Total Ppt^n.	Rain days	Eff. Ppt^n.	Rain Days	% Ppt^n.
effective					
May 86-Apr87	400.8	49	284.0	10	70.85
87-88	303.4	50	192.4	11	63.41
88-89	326.5	50	169.0	11	51.76
89-90	408.9	54	256.2	14	62.65

90-91	400.5	47	285.4	12	71.26

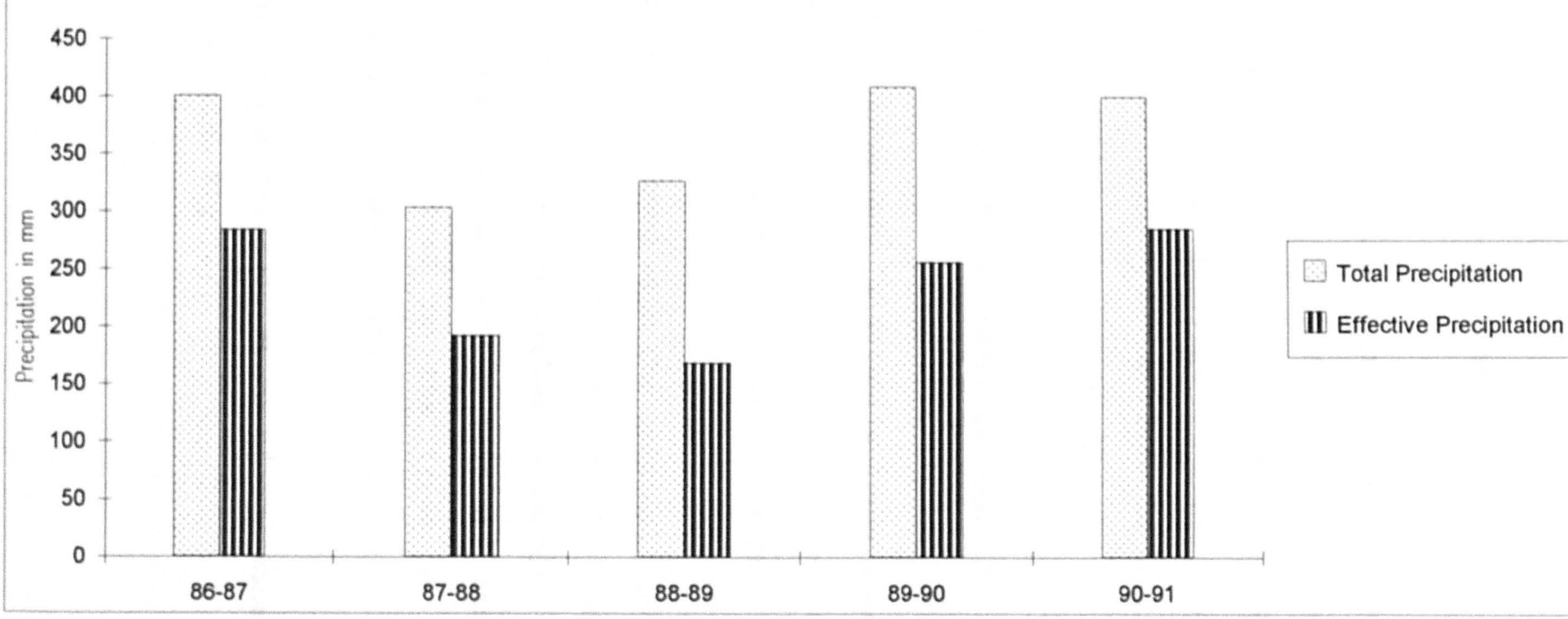
It should be noted that these figures are given for May-April. They are so given in order that the rainfall patterns before the two planting dates, Spring 1988 and 1991 can be examined.

4.8.iii. Pan Evaporation and the Calculation of Irrigation Requirement.

There are no consistent data for the water requirement of tree species in semi-arid zones (Usher 1978, Willens 1978, Armitage 1985). There are formulae for the estimation of water requirement of all crops, the most well known being that of Penman. However they all require a considerable amount of climatic data which in this case were not available. Reservations have already been expressed about the relevance of the Ibiza airport meteorological data. There were substantial differences, even during the period of study between the Ibiza data and the observations of pan, temperature and precipitation at the project sites.

Irrigation requirements are generally expressed as a multiple of Class A pan evaporation. The multiple used depends on the type of crop. These range from 0.6 for citrus to 1.95 for some grasses, lucerne and sugarcane (Usher 1978). The ratio often varies with different stages of growth.

Fig.13. Total and 'Effective'Precipitation 1987-1991



Since no data were available for eucalypts or acacias it was decided to follow the guidelines laid down by Usher in 1978, with some possible modifications.

Usher suggests that a Class A pan factor is estimated and water first administered on this basis. The soil moisture content in the root zone is monitored by tensiometers. Any loss or gain of moisture in the root zone is compensated by an increase or decrease in irrigation rate until the whole process of water application is in balance with the water use of the trees. Moore (1983) suggests irrigation when tensiometer readings reach 70 pascals, a point where research had shown that tip and marginal leaf tissue necrosis appeared. A slightly lower reading (50-60 pascals) was therefore decided on - the range to avoid any such effects and to allow for variations across the field.

This process was followed with the original rider that the rate would be modified should the irrigation rate calculated by this method exceed 300mm in the summer season. The mean annual winter rainfall and thus the amount of water received by the trees in excess of irrigation is approximately 300mm.

Pan evaporation for the five years of the experiment was as follows (see also Fig.14).

Table 7: Pan Evaporation.

Site 1	1988	1989	1990	1991	1992
	mm.	mm.	mm.	mm.	mm.
May	79.2	166.6	204.6	167.5	79.3
June	106.1	197.1	254.0	237.9	166.6
July	311.7	316.2	322.2	280.9	241.6
August	280.0	294.5	297.4	259.6	247.1
Sept	240.1	130.0	161.0	161.4	173.6
Total	1017.1	1104.4	1239.2	1107.3	908.2

Site 2

	1988	1989	1990	1991	1992
	mm.	mm.	mm.	mm.	mm.
May	84.1	171.4	181.9	162.1	67.2
June	101.6	225.0	242.0	188.3	158.4
July	308.0	268.7	338.4	293.5	242.6
August	288.2	215.1	272.2	250.9	237.4
Sept	219.3	128.0	159.0	154.3	171.4
Total	1001.2	1008.2	1193.5	1049.1	877.0

Six tensiometers were installed at each site - two in each of the three water treatment areas. From the start of the first irrigation season (May 1988) they were read at first daily and then twice weekly during the summer and the comparison with pan evaporation made at these intervals.

Fig. 14a. Pan Evaporation (mm). Site 1

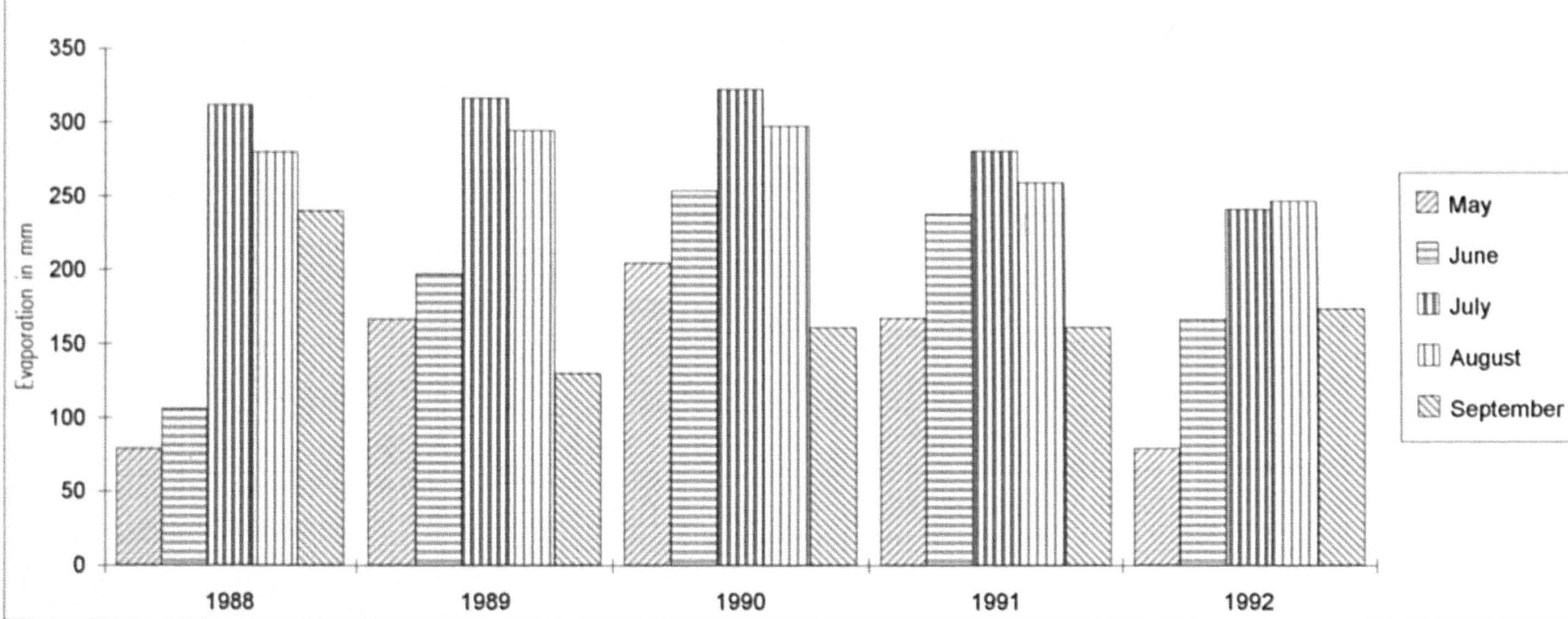
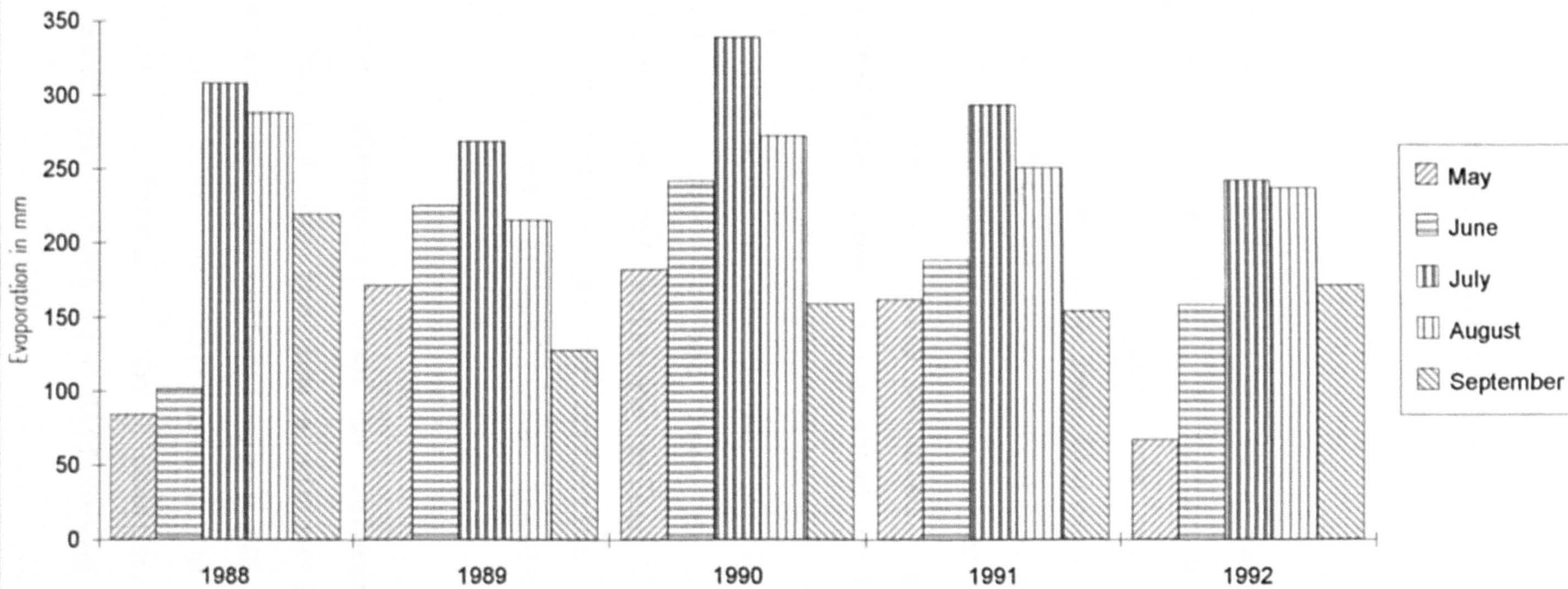


Fig. 14b. Pan Evaporation (mm). Site 2



During the summer irrigation period, no additional allowance was made for leaching. It was decided to test whether the winter rainfall (approximate mean 300mm in the winter) would be sufficient for leaching and to check this by soil analysis.

In the first summer, pan readings were taken at first daily and then twice a week. A factor was estimated (originally 0.4 of pan) and water was applied on that basis as litres/tree (making a pan factor of 0.135 over the whole area). For the first summer, when the trees were still small the figure was further divided by one third, as the site was not fully occupied, equating mm/m^2 with litres/tree (the trees were planted at 1.75 by 1.75 metres). Soil moisture was monitored by the tensiometers. Since one of the aims of the investigation was to use small amounts of water it had been decided that a relatively high level of moisture stress - 50 to 60 pascals - would be the trigger for irrigation. Should the trees show signs of stress, the levels would be reconsidered.

It was realised almost at once by reference to the tensiometers that 0.4 was too low a figure and the pan factor was altered to 0.5 (effectively 0.165 or for the first summer 0.055 over the whole area). At this level and irrigation interval, the tensiometers gave satisfactory readings. There were differences between the two sites, Site 1 usually but not always having higher evaporation than Site 2. The differences in 1988 and subsequently were not shown to be significant by paired t tests, so it was decided to take a mean of the readings at the two sites and apply water on that basis. The monitoring continued throughout the summer and the calculation indicated application for the first and subsequent years as follows:

Table 8: Irrigation Requirement.

	First year litres/tree	Subsequent years litres/tree
May	13.5	40.5
June	17.5	52.5
July	51.5	154.5
August	47.5	142.5
Sept	38	114

4.9. Water Application.

In the first year, the regime was adhered to in May, June and July.

In May, this resulted in three irrigations at ten day intervals of a total (for the three irrigations) of 13.5 litres per tree. In June, a total of 17.5 litres per tree was applied in four irrigations. In July, the rate increased considerably, with a total of 50 litres/tree applied in 5 irrigations.

Due to repeated generator failure in August, it proved impossible to apply water at the rate required by the pan/tensiometer readings. As a result, a total of only 18 litres/tree was applied in this month, instead of the indicated 47.5 litres. In spite of the deficit no trees died in the plots that should have received water. Some stress may have been caused but no colour change or wilting was observed.

Although the generator problems only applied to Site 1, the trees at Site 2 were irrigated as Site 1, to avoid unnecessary inter-site effects.

In September, a total of 64 litres/tree was applied in three irrigations. The pan/tensiometer figures indicated that only 38 litres/tree should be applied, but an attempt was made to compensate for the August deficit.
Thus a total for the season of 163 litres of water/tree was applied. It is considered legitimate to regard litres/tree figures as equivalent to mm rainfall in the first year, when root systems are small and do not cover the whole area planted (Morris 1984). Over the whole site, this would be the equivalent of 54 mm.

Extrapolating from the above figures this was equivalent to a total application of approximately 500 litres/tree

(166.6mm) for subsequent years.

The water application in the first year had thus proved to be 163 litres/tree, well under the 300mm cut off point. In subsequent years, this would translate into a total application of approximately 500 litres/tree (166.6mm). It was decided to vary the irrigation interval rather than the amount applied per irrigation. Water would be applied in thirty to thirty two irrigations of sixteen litres per tree, with three irrigations in May, three in June, ten in July, nine in August and five in September. The intervals would be varied should the pan readings in subsequent years be substantially different from the first year or should the trees show signs of wilting.

From 1988 onwards, the seasonal pan evaporation totals at Site 1 were always higher than those at Site 2. The monthly totals were not consistently higher. Paired t tests showed no significant difference in evaporation at the two sites. Therefore the practice of taking the mean of the readings at the two sites as the basis of the irrigation requirement for both continued.

The readings in 1989 were higher than those in 1988 but paired t tests showed no significant difference between the two years. The previous year's plan was therefore implemented, with the difference that the irrigation interval was shorter in May and June as the pan readings were higher. However, irrigation was stopped sooner than in the previous year, due to early rain in September. A total of 448 litres/tree (149mm) was applied in twenty eight irrigations.

In 1990, the pan readings were higher again than in the two previous years (and later proved to be the highest in the five years of the experiment). The figures indicated a requirement of approximately 600 litres/tree for the whole season. In fact 512 litres/tree (171mm) was applied in thirty two irrigations. The deficit fell in May. There had been a little late rain in May, which delayed the start of the irrigation. By the beginning of this third season, pan readings were taken only once a week. At the end of May, when the monthly figures were calculated, it was discovered that in spite of the precipitation, evaporation had been relatively high. However, it was decided not to compensate with increased irrigation in June, as had been done in August/September of the first year of the experiment.

In 1991, the seasonal total was down from the 1990 high and again there was late rain in May, delaying the start of the irrigation. The irrigation requirement indicated by the pan readings was 539 litres/tree (179.6mm). A total of 464 litres/tree (154mm) was applied in twenty nine irrigations.

The 1991 new plantings had been planted out on June 7th. The total seasonal requirement as indicated by the pan readings was 143.3mm. They received eighteen irrigations of eight litres each (144 litres/tree) in accordance with the first years' formula equating mm with litres/tree.

1992 was a low evaporation year. The 1991 plantings alone were irrigated, irrigation having been stopped altogether for the 1988 plantings. The pan indicated figure was 446 litres/tree. In this year, the irrigation interval and amount per irrigation were altered for logistical reasons and the trees received fifteen irrigations of thirty litres each (450 litres/tree or 150mm).

It had proved difficult to conform exactly to the pan indicated figures, partly due to the inevitable delay in the calculation and partly due to unexpected precipitation. However, for the first two years, both the 1988 and 1991 plantings had received amounts of irrigation very close to the indicated figures.

4.9.i. Pre-season Precipitation and Water Application.

The pre-season precipitation for the relevant years is as follows:

Table 9: Pre-season Precipitation in mm.

	Total Annual	.....of which..... Sept-April	May-Aug
May 87-Apr 88	303.4	236.4	67
88-89	326.5	280.6	45.9
89-90	408.9	381.2	27.7
90-91	400.5	371.7	28.8

In the September-April before the 1988 planting, there was a total of 236.4mm of which 165.9mm fell in 10 'effective' falls and the remainder, 70.5mm in smaller falls over 27 days. After planting, there was 24.5mm on May 11th and additional 'ineffective' May-August precipitation of 21.4mm in 9 days. The trees were planted on May 6 and received an assumed equivalent after planting of 163mm of irrigation throughout the season.

In the September-April before the 1991 planting, there was a total of 371.7mm of which 272.4mm fell in 11 'effective' days. 99.3mm fell in 28 other days. After planting, there was an effective rain on May 6th, of 13.0mm and a further 25.6mm in 8 'ineffective' days from May to August. Thus the later planting had received considerably more pre-season precipitation than the 1988 plantings. Trees were planted on June 7th and received the equivalent of

144mm. irrigation throughout the season. (See below Tables 10 and 11 and Calculation of Irrigation Requirement).

The first season irrigation quantities of 163mm. for the 1988 plantings and 144mm. for the 1991 did not reflect these differences. They were supposed to be equal and the difference of 19 mm was due to circumstances in the field. The differences in water storage from the pre-season effective precipitation between the two plantings is not readily quantifiable, but must be assumed to have had an effect on growth. The soil moisture deficit in 1988 was obviously greater than in 1991.

4.10. Effective Precipitation and Irrigation Quantity.

In spite of the close agreement between pan indicated figures and amounts of water applied to both sets of plantings, the precipitation pattern was substantially different, as has been mentioned above. To clarify these figures, the tables below (Tables 10 and 11) have been devised as a sort of 'calendar' to show the actual amounts of water received by the trees. They give an analysis of total effective precipitation and irrigation quantities for the relevant years.

Table 10: Effective Precipitation in mm. 1987 -1992.

	Annual Ppt^n.	Winter Ppt^n.	Eff Winter Ppt^n.	Eff Summer Ppt^n.	Total Eff Ppt^n.
May87-Apr88	303.4	236.4	165.9	34.2	200.1
88-89	326.5	280.6	169.0	24.5	193.5
89-90	408.9	381.2	256.2	0	256.2
90-91	400.5	371.7	272.4	13.0	285.4
91-92	423.2	384.5	264.0	13.0	277.0

Table 11: Irrigation, Effective Precipitation and Mean Pan Evaporation 1987-1992.

	No.of irr.	l.per irr.	Total irr. (l)	Total irr. (mm)	Eff annual ppt^n.+ irr(mm)	Mean pan evap (mm)
1988:	16	varying	163	54	254	1009
1989:	28	16	448	149	342	1056
1990*:	32	16	512	171	427	1216
1991*:	29	16	464	155	440	1078
1991N:	18	8	144	48	333	1078
1992N:	15	30	450	150	427	893

* = 2 blocks at each site irrigated

N = 1991 plantings

Thus although the irrigation rates for the newly planted trees were very similar in 1988 and 1991, the actual amounts of water received by the trees was substantially different due to the differences in precipitation.

4.11. Irrigation Systems and Practice.

Since the experiment was small in forestry terms and since one of the aims of the investigation was to see whether small amounts of water would effectively increase growth rates, large scale systems of flood and basin irrigation were inappropriate. Sprinkler systems were thought unsuitable for this experiment as these systems have not proved effective with highly saline water. There are often problems of leaf burn and salinization of soil surrounding the trees (Willens 1978, Armitage 1985). In an experimental situation, where the plots are small and the trees close together and receiving different waters, problems of overlapping also rendered this system inappropriate. A drip or trickle system might at first appear suitable, but many researchers, notably Usher (1978) and Wood (1987 personal communication), have encountered difficulties with these systems when there was insufficient water pressure. There can also be problems when using saline water, due to clogging of the emitters and precipitation of salts in the pipes.

It was decided that water should be delivered individually to each tree by means of a hosepipe. It should be emphasised that this choice was made because of the particular experimental situation with trees receiving different qualities of water. Should the experiments prove successful and the techniques be employed in other contexts, then other irrigation systems might be equally appropriate.

At the time of planting a polythene tube of approximately 10cm internal diameter by 60cm long was inserted to full depth where possible (it was sometimes impeded by stony ground) at each tree. The section of tubing was inserted at about 30 centimetres from the bole of the tree and slanted diagonally downwards towards it, to bring it into direct contact with the roots. Water was introduced through these tubes. This is a common practice observed in Spain in use by farmers (Kaul 1970). Advantages include reduced evaporation at the surface, thus minimising salinization of the soil and delivering more water directly to the tree. The farmers say that in this way the effective rate of irrigation can be significantly increased, when root systems are small and do not cover the whole field, as the water goes directly to the roots and does not evaporate on the surface soil. It is not known whether this system inhibits root development. The water was to be delivered to the trees by means of a

movable hosepipe which would be connected to fans of pipes divided into eight branches at its outlets, thus enabling each block of eight trees to be watered at one time.
Both the subsoil irrigation and multiple watering techniques were later discarded in view of experience in the field.

Techniques for mixing water proved satisfactory, but difficulties were encountered almost immediately with the system of watering eight trees at a time with branched pipes. This system had to be abandoned as insufficient pressure made it impossible to deliver an equal amount of water to each tree. The idea of watering through a section of tube inserted by the tree also had to be abandoned as the dimensions of the tubes did not allow sufficient water as indicated by the pan/tensiometer calculations to be delivered in the same irrigation. Instead, the slight depressions (small basins) around each tree were enlarged to a circle of approximately $1m^2$ and each tree was watered individually by hand held hosepipe.

For the 1988 irrigation, it should be emphasised that although the object was to achieve an irrigation regime using waters of the different salinities that was in balance with the pan evaporation and tensiometer readings, the main aim of irrigation in the first season was to establish the trees and to devise a suitable irrigation regime for the following year. Nevertheless the tensiometer findings were adhered to as strictly as possible.

4.12. Soil sampling.

Samples were taken at the beginning and end of each irrigation season. At each site, sampling points within each species and water treatment section were selected randomly for soil sampling (the same spots were used for tensiometer placement). Samples were taken at the surface and at 20cm depth below the surface, close to the six sample trees at each site (24 samples in all). This sampling density was increased at October 1990 to cover all combinations of treatments. Sampling spots were always selected randomly with dice within each treatment area.

At October 1995, 64 soil samples at two levels at Site 1 and 48 samples at two levels at Site 2 were taken, these being 4 samples at each level within each water treatment block where more than four trees survived (224 samples in all). Sampling spots were again selected randomly with dice. Some samples were also taken around the mixing tanks to compare salinity levels.

All samples were brought to London and analyzed in the laboratory. Exchangeable cations were extracted from all samples. These were subsequently examined by flame photometer for Na and K and by atomic absorbtion spectrometer for Ca and Mg. Exchangeable Sodium Percentage was then calculated for all samples. All topsoil samples were examined for organic matter by the Walkeley Black method (British Standards Institution 1967).

4.13. Litter sampling.

From April 1990, when the trees had been in the ground for two years, litter was to examined to see whether there was a build up which could be linked to nutrients to the soil. The four year irrigated trees and those which had been unirrigated from the beginning were used for this experiment. Ten litter traps were constructed for each site. This is a very much higher density of traps for the area covered than is suggested in the literature, but it was felt that because the area was small (for a forestry experiment) fewer traps would not adequately represent the sample. Since acacia and eucalypts were planted in close proximity to each other, it was felt that it would not be possible to classify the litter by species. In the event, acacia litter was often observed in traps under the eucalypts and vice versa.

Recommendations in the literature (Newbould 1967, Phillipson 1971 and Proctor 1983) cover various shapes and sizes of litter traps. The type of trap decided on conformed to the recommendations whilst making use of locally available material. The traps were made from wooden vegetable boxes lined with fine mesh net so that water, but not litter could escape at the bottom. Each trap was 37.5 by 28.5 centimetres.

Proctor (1983) recommends classifying litter according to size. In this study, all litter was of a fairly uniform size as the trees were still growing. There were no large pieces of branches or bark. The litter has therefore not been separated by size as this did not appear useful or possible.

Six traps were placed in the blocks that were to be continuously irrigated and four in the unirrigated blocks in the same spots at each site selected for soil sampling, to achieve proportionate coverage.

Attached to each box by a wire was a mosquito net bag approximately 20x20cm, mesh size 2mm, containing fresh litter of the tree under which it was sited. Each bag weighed 10 grams and the litter 20 grams at April 20th. This is a standard method of measuring decomposition rates mentioned by Medwecka-Kornas (in Phillipson 1971). Although it shows a satisfactory decline in weight it would seem that the decomposition process must be severely affected by the nets. On the one hand, the fact of the litter being enclosed in mesh must hamper the various agents of decomposition and may also be too small to allow the admission of some decomposers, for example beetles. On the other hand, being separated from the ground by the mesh, unlike the surrounding litter which is directly on the ground, must allow more air and therefore less moisture on the underside of the leaves. Moreover, as the litter breaks down and fragments, small pieces must be lost through the mesh.

In the first year, litter from the traps was collected and weighed at two month intervals, at the end of June, August, October, December 1990 and February and April 1991, to give a full year's sampling. After the first year, the traps were emptied six monthly. The bags were weighed at the same time, to calculate the rate of degradation. In the results, six monthly totals are given.

4.14. Fauna sampling.

From April 1991, soil fauna numbers were also measured. Soil samples were taken at 16 spots at each site, at the surface and at 20cm depth, to represent all combinations of species and water treatment. Three large trowels of earth were taken at each sampling point. They were well mixed, first examined by naked eye and any fauna discovered listed. A Tulgren funnel system was then set up and approximately 250 grams of each sample put in the funnels. After four days, the animals in the killing liquid were examined under the microscope and counted. A

Bayermann system was also set up. (Since this resulted in no animals at all emerging, it was discontinued). Fauna were examined three times a year, in April/May, August/September 1991 and December 1991/January 1992.

4.15. Experimental timetable.

Sept-Dec 87: Seed obtained and planted in pots. Practical work of preparing sites. Installation of evaporation pans, raingauges,etc. Soil and water sampling at both sites.

Apr-May 88: Trees planted out at both sites. Measurements of trees' height and diameter.

May-Oct 88: Irrigation requirement calculated by pan/tensiometer method and irrigated throughout the summer. Meteorological instruments checked at each watering.

Oct 88: Tree measurements taken as before. Soil samples taken for analyses.

Winter 88-89: Samples analyzed in laboratory.

Apr 89: Tree measurements taken. Soil samples taken for analyses. Second season of irrigation and meteorological reading as before.

Oct 89: Tree measurements and soil samples.

Winter 89-90: Soil samples analyzed as before.

Apr 90: Tree measurements taken. Soil samples taken for analyses. Continued irrigation of half existing trees and irrigation withdrawn from the other half. Litter traps and bags set up at both sites.

Oct 90: Tree measurements taken. Soil samples taken for analyses.

Winter 90-91: Samples analyzed as before. Seed of local provenance planted in pots, November and January.

Apr 91: Tree measurements, soil and litter samples. Samples of soil fauna taken and examined by Tulgren method. New trees planted and irrigated through the season. Fourth and last season of irrigation for half the 1988 planted trees.

Oct 91: Measurement and sampling of all variables.

Winter 91-92: Laboratory and statistical analyses of all variables.

Apr 92: Tree measurement and soil sampling. Second season of irrigation for trees of local provenance.

Oct 92: Tree measurement and soil sampling.

Oct 95: Tree measurement and acacia branching index. Intensive soil sampling. Laboratory and statistical analysis.

CHAPTER 5. HEIGHT GROWTH AND SURVIVAL RESULTS.

Height and diameter of all trees were measured from the beginning of the experiment. They proved to be very strongly correlated:

	r	df.	P
October 1988:	.8044	248	<.001
October 1989:	.8382	237	<.001

It was therefore decided to use the height measurements as the main indicators of growth.

5.1. Height Growth.

Height growth results will be reported in three stages. First, the two seasons to October 1989 will be discussed in terms of differences in growth pattern attributable to water quality, site, species and soil depth. Survival rates will then be examined. The second phase, to October 1991, during which irrigation was withdrawn from half the previously irrigated trees will then be examined on the same basis, particularly looking at any differences in growth pattern due to irrigation duration. The overall survival rate will then be examined at greater length and the effect of irrigation on adjacent rows of unirrigated trees will be considered. Finally, height growth at October 1995, three years after the end of the experiment, will be examined.

5.2. Height Growth in the First Phase (April 1988 - October 1989).

Heights of trees in all irrigation classes from planting in the spring of 1988 till the end of the second season in the autumn of 1989, are shown in Table 12 and Figs.15 a,b,c and d.

Table 12: Acacia and Eucalypt Mean Heights at Sites 1 and 2 from April 1988 to October 1989. Height and (standard deviations) in cm.

Site 1 Acacia

	Apr-88 (at planting)	Oct-88	Apr-89	Oct-89
No water	12.5 (3.2)	63.5(29.2)	88.0(36.1)	99.0(44.8)
10dS	12.5 (3.2)	101.5(23.5)	119.5(33.4)	146.0(41.4)
5dS	13.0 (3.6)	98.0(36.5)	124.0(43.8)	145.0(48.7)
<1dS	12.0 (3.6)	92.0(27.7)	124.5(39.7)	154.5(48.7)

Site 2 Acacia

	Apr-88	Oct-88	Apr-89	Oct-89
No water	11.0 (2.0)	30.0(10.0)	43.0(14.5)	54.5(16.7)
10dS	12.0 (3.1)	85.0(28.5)	108.5(34.0)	160.0(58.1)
5dS	15.5 (5.7)	82.0(28.8)	100.5(34.6)	157.0(47.9)
<1dS	14.0 (4.6)	62.0(24.0)	73.5(30.2)	103.0(59.6)

Site 1 Eucalypt

	Apr-88	Oct-88	Apr-89	Oct-89
No water	24.0(12.9)	59.0(16.3)	77.5(22.1)	92.0(29.5)
10dS	23.0(13.3)	79.0(14.9)	105.0(25.5)	159.0(31.2)
5dS	24.5(12.6)	94.5(17.4)	119.5(20.1)	180.5(33.8)
<1dS	23.5(12.9)	83.0(15.5)	114.5(25.7)	168.0(37.9)

Site 2 Eucalypt

	Apr-88	Oct-88	Apr-89	Oct-89
No water	24.0(12.9)	35.5(13.1)	40.5(12.6)	51.0(20.1)
10dS	24.5(12.6)	71.0(17.5)	91.0(21.9)	141.0(28.7)
5dS	25.0(11.7)	65.0(11.1)	92.0(19.0)	152.0(37.4)
<1dS	25.0(11.1)	59.0(16.7)	77.0(21.3)	122.0(27.9)

By the end of the second season (October 1989), it was clear that the establishment and vigorous early growth of the trees had been satisfactorily achieved. Trees in the irrigated sections were approximately one and a half metres tall at this date. There were very marked differences between irrigated and unirrigated trees. The standard deviations, as would be expected, increased with increased growth of the trees.

5.3. Water Quality Effects.

There had been major responses to irrigation. Whilst there were no significant differences between the classes at planting (April 1988), when Table 12 and Figs.15 a,b,c and d are examined, it will be seen that differences were quite large at all subsequent dates when all four classes are considered. The three irrigated classes grew substantially taller than the unirrigated trees. When the three irrigated classes are examined without the unirrigated trees, major differences do not appear, in spite of the apparently poorer growth of those trees irrigated with BAW (<1dS) visible in Figures 15b. The cause was unknown but it was thought that it might be related to soil depth (See below Sections 5.12 and 5.14.v).

5.4. Site Effects.

5.4.i. Site Differences.

For these first two years, trees at Site 1 did consistently better than those at Site 2. Although there was no significant difference in the size of trees at planting, there were significant differences favouring Site 1 at all subsequent dates until October 1989 when acacias at both sites ceased to show differences (Table 13). The cause of these differences was not known.

Table 13: Tests of Height Differences between Sites. All Trees from Planting to October 1989. Mann-Whitney U Tests.

	Acacia		Eucalypt	
	U	N	U	N
April 1988 (at planting)	1927.0	128	1854.0	128
October 1988	1249.5*	128	886.5*	122
April 1989	1164.5*	127	870.5*	115
October 1989	1634.5	126	1148.5*	113

* = significant at $p < .025$

(Site 1 > Site 2 in all significant cases)

5.4.ii. Site and Water Quality Effects.

To examine the site differences mentioned above more clearly, differences in relation to water quality at each site were examined. There were considerable variations (Tables 14 and 15).

Fig. 15a. Site 1 Mean Acacia Heights in all Irrigation Classes. 1988-1989.

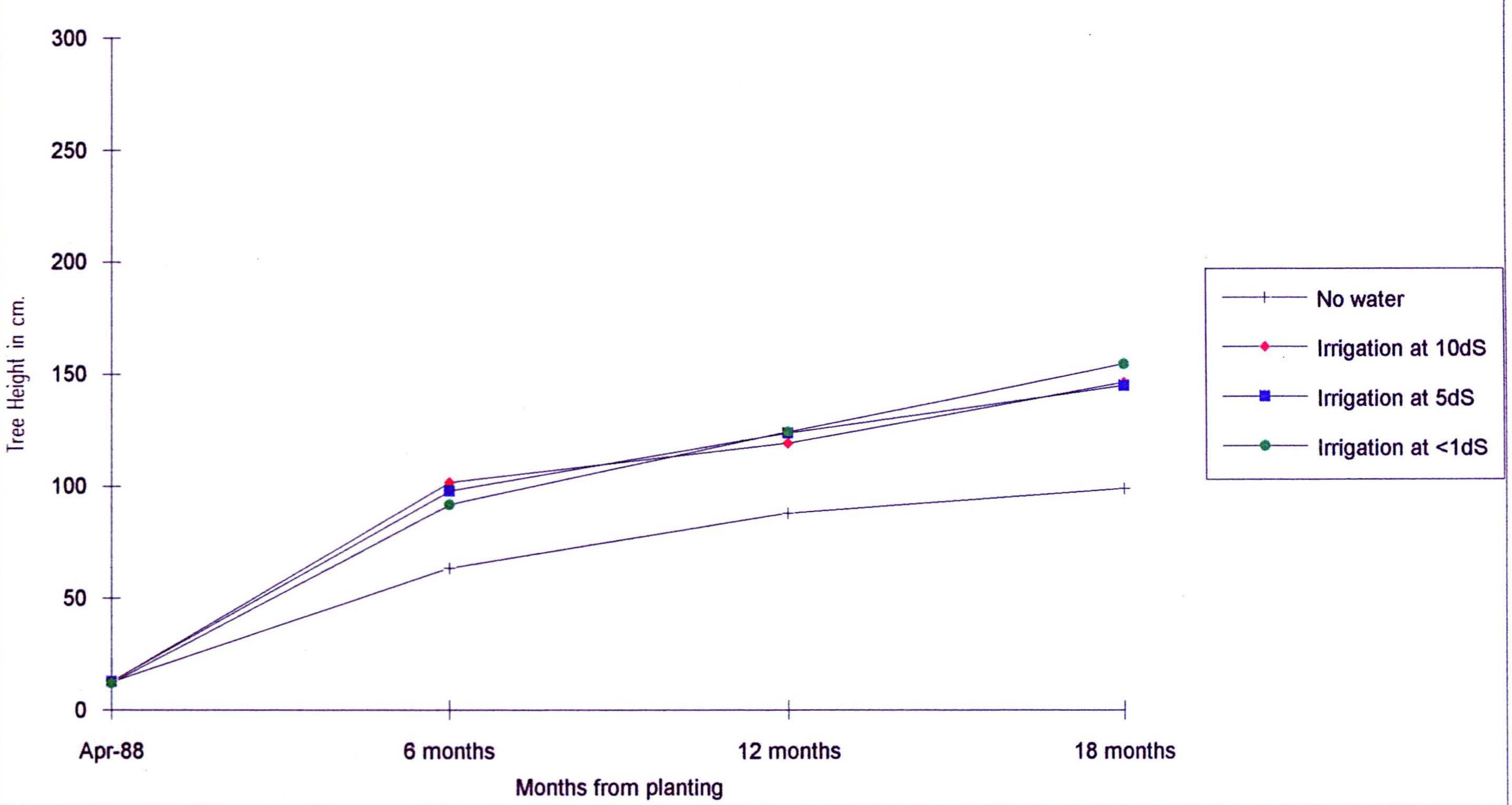


Fig.15b. Site 2 Mean Acacia Heights in all Irrigation Classes. 1988-1989.

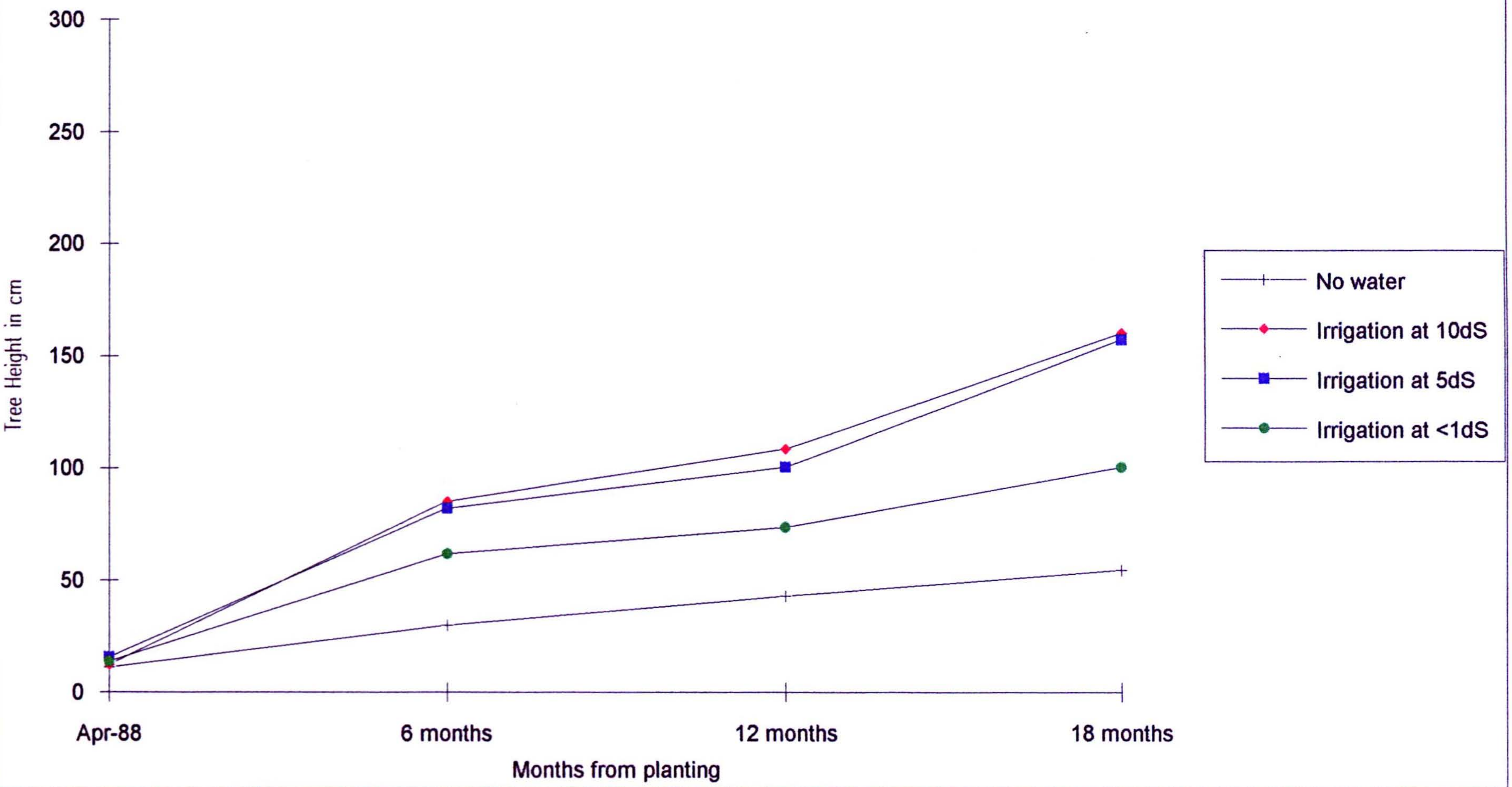


Fig.15c. Site 1 Mean Eucalypt Heights in all Irrigation Classes.1988-1989.

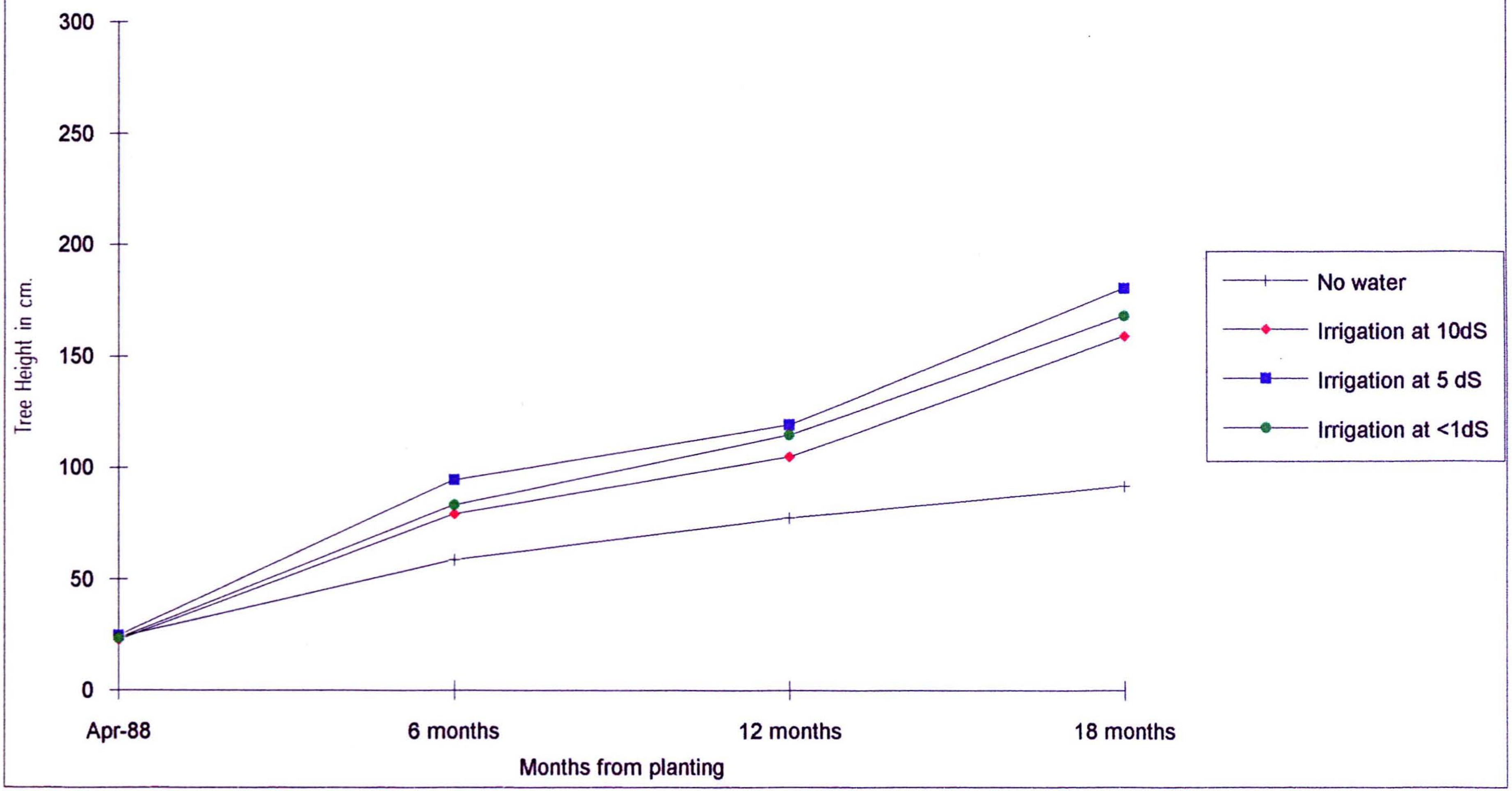


Fig.15d. Site 2 Mean Eucalypt Heights in all Irrigation Classes. 1988-1989.

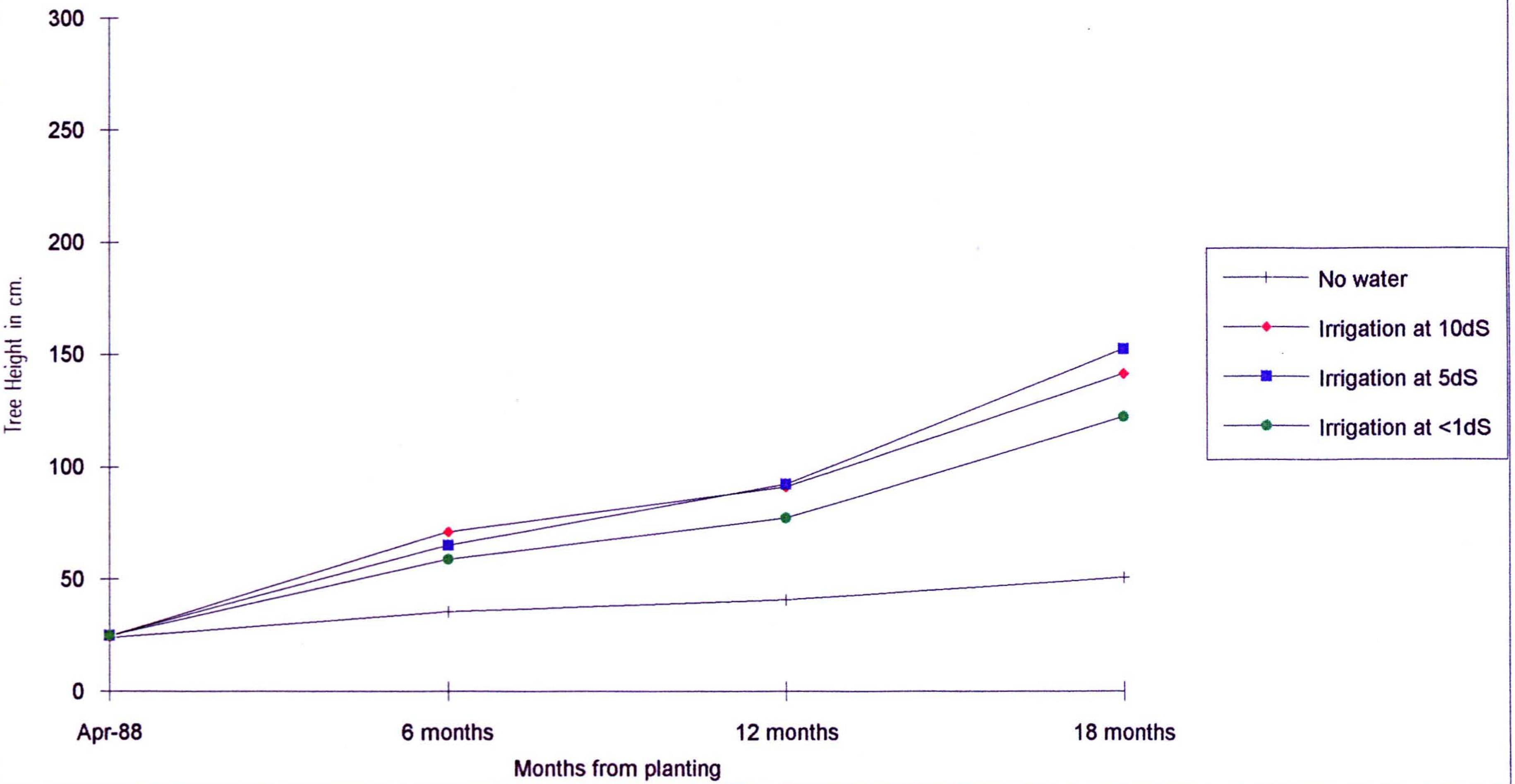


Table 14: Tests of Height Differences between Sites for each Water Class: Acacia. Mann-Whitney U Tests.

Water 1: No water	U	N	Water 2: Irrigated at 10dS U	N
April 1988	94.5	32	120.5	32
October 1988	40.5*	32	88.0	32
April 1989	34.0*	32	111.5	32
October 1989	40.5*	31	109.0	32

Water 3: Irrigated at 5dS	U	N	Water 4: Irrigated at <1dS U	N
April 1988	91.0	32	97.0	32
October 1988	96.0	32	56.5*	32
April 1989	87.0	32	36.5*	31
October 1989	110.0	32	60.0*	31

* = significant at p <.025

(Site 1 > Site 2 in all significant cases)

Table 15: Tests of Height Differences between Sites for each Water Class: Eucalypts. Mann-Whitney U Tests.

	Water 1: No water		Water 2: Irrigated at 10dS	
	U	N	U	N
April 1988	128.0	32	107.0	32
October 1988	23.5*	27	88.5	31
April 1989	10.0*	24	85.5	31
October 1989	12.5*	22	86.0	31

	Water 3: Irrigated at 5dS		Water 4: Irrigated at <1dS	
	U	N	U	N
April 1988	123.5	32	104.5	32
October 1988	20.5*	32	32.0*	32
April 1989	38.0*	30	26.5*	30
October 1989	60.0	30	36.0*	30

* = significant at p <.025

(Site 1 > Site 2 in all significant cases)

Unirrigated trees and those irrigated at <1dS of both species show differences in height growth between sites throughout the period. Trees irrigated at 10dS show no significant differences between sites. Acacias irrigated at 5dS show no differences between sites, whilst eucalypts irrigated at this level show differences at October 1988 and April 1989 but none at October 1989.

The unirrigated trees grew significantly better at Site 1 than at Site 2 throughout the experiment. Of the <1dS irrigated trees, it is interesting to note that although it is clear from Figures 15a and b that the acacias grew better at Site 1 than at Site 2, this difference is not so noticeable from the Figures for eucalypts (Figs.15c and d) but was nonetheless significant when analyzed by Mann-Whitney U. The differences between the two sites for eucalypts irrigated at 5dS at October 1988 and April 1989, again favoured Site 1.

Although pointing to the groups of greatest difference, the examination by water quality did little to explain the initial better performance of trees at Site 1. In the second two years of the experiment Site 2 trees caught up and overtook those at Site 1. (Tables 24 and 25 and Figs.16a,b,c and d).

5.5. Species Effects.

The acacias initially grew faster than the eucalypts, but in the second season the eucalypts caught up and overtook the acacias. Since they are a larger tree when fully grown, this was only to be expected.
(Table 12).

5.6. Soil Depth and Height Growth.

The soil depth survey was not undertaken until 1992 (See above Section 4.6). To see whether soil depth was a factor in height growth, soil depth in relation to height growth was examined by correlation and no significance at any date was shown (Tables 16 and 28). No relationship could be found between soil depth and tree height (see also Figs.17a,b,c and d), though soil depth appeared to have a large influence on survival (See below Section 5.14.v).

Table 16: Correlation of Height with Soil Depth.

	r	df.
April 1988	.02995	254
October 1988	.13639	248
April 1989	.12291	240
October 1989	.06462	235

All correlations non significant.

5.7. Survival: First Phase (to April 1990).

Thus far, results to October 1989 have been reported to identify water and site effects at the end of the second irrigation season. Survival is here reported for the full two years, to the following spring (April 1990).

5.7.i. Site 1.

At Site 1 there was only one death in the first two years of the experiment. One eucalypt, irrigated at 10dS died in the second winter (1989-1990). The death did not appear to be linked to the quality of the irrigation water, as surrounding trees continued to thrive and grow. However the cause of death is unknown.

5.7.ii. Site 2.

At Site 2, 20 trees died in the first two years. One of these was trampled by a workman. Of the other nineteen deaths, unirrigated trees died at a far higher rate than those which were irrigated, as Table 17 shows, but quality of irrigation water did not appear to be a major factor.

Table 17: Site 2. No. of Tree Deaths in Relation to Water Quality (April 1988-April 1990).

	Acacias				Eucalypts			
	No water	10dS	5dS	<1dS	No water	10dS	5dS	<1dS
6 months to:								
October 1988					5	(1)		
April 1989				1	3		2	2
October 1989	1				2			
April 1990	1			1			1	
Total	2			2	10	(1)	3	2

() = trampled.

Total 19 (excluding trampled tree).

Two acacias and ten eucalypts died in the unirrigated sections. Apart from the trampled tree, only seven other trees died, four of them (two eucalypts and two acacias) in the <1dS sections. The remaining three deaths were eucalypts irrigated at 5dS. Thus far, there was no evidence that deaths were associated with water quality as distinct from presence or absence of irrigation.

5.7.iii. Soil Depth and Survival.

As has been mentioned above, the soil depth survey was not undertaken until considerably later, but when it was, the results tended to reinforce the initial suspicions of the author, that soil depth was a major factor in tree death. Table 18 shows that of the nineteen deaths, 11 trees (58% of deaths) were in the 0-10cm depth class. The frequency of the 0-10cm soil depth class was 27% of the whole site.

When the seven deaths in the irrigated sections were examined individually, it was seen that three were in the 0-10cm class, one in the 10-20cm class and three in the 20-30cm (See below Fig.19b).

Table 18: Site 2 Tree Deaths in relation to Soil Depth (April 1988-April 1990).

(excluding trampled tree).

Site 2.

Soil depth class in cm.	0-10	10-20	20-30	30-40	40-50	50-60	60-70
Soil depth frequency %	26.6	26.6	27.3	10.2	3.9	2.3	3.1
Deaths(19)	11	2	6	0	0	0	0
%Deaths	57.89	10.53	31.58	0	0	0	0

Thus by April 1990, there had been one death at Site 1. At Site 2 there had been 12 deaths in the unirrigated section, and seven deaths in the irrigated sections. Deaths did not appear to be related to the quality of the irrigation water. The large difference between the sites indicated that a site factor was involved. Soil depth was a factor that appeared to have a close relationship with survival.**5.8. Height Growth in the Second Phase (April 1990 - October 1992).**

From April 1990, half the previously irrigated trees continued to be watered as before and half received no further irrigation.

Height and diameter continued to be strongly correlated. From October 1990 to October 1992, correlations were as follows:

	r	df.	P	
October 1990:	.8828	230	<.001	
October 1991:	.9317	264	<.001	(inc 1991 plantings)
October 1992:	.8862	242	<.001	

5.8.i. **Height Growth from October 1989 to October 1992.**

Growth from October 1989 is shown in Table 19 and in Figs 16 a,b,c and d.

Table 19: Acacia and Eucalypt Mean Heights at Sites 1 and 2 with 4 Year and 2 Year Irrigation from October 1989 to October 1992. Height and (standard deviations) in cm.

Site 1 Acacia

	Oct89	Apr90	Oct90	Apr91	Oct91	Apr92	Oct92
No water	99 (44.8)	104 (47.4)	108 (51.3)	119 (60.6)	125 (66.4)	127 (68.7)	150 (73.5)
4 yr:dS10	149 (41.9)	151 (45.5)	154 (50.1)	164 (58.3)	167 (62.0)	171 (62.9)	198 (79.2)
2 yr:dS10	144 (43.7)	146 (41.4)	146 (41.4)	159 (43.9)	164 (43.7)	182 (49.8)	195 (51.0)
4 yr:dS5	122 (46.5)	126 (47.2)	135 (54.0)	137 (52.3)	137 (52.3)	137 (52.3)	154 (45.0)
2 yr:dS5	167 (42.0)	170 (41.7)	175 (47.8)	180 (46.6)	180 (46.6)	189 (56.2)	209 (59.3)
4 yr:dS<1	140 (39.6)	141 (41.9)	154 (42.7)	160 (43.8)	166 (43.7)	179 (56.9)	220 (51.0)
2 yr:ds<1	169 (55.1)	171 (54.1)	171 (54.1)	187 (64.3)	190 (65.2)	192 (65.2)	216 (53.5)

Site 2 Acacia

	Oct89	Apr90	Oct90	Apr91	Oct91	Apr92	Oct92
No water	55 (16.7)	72 (29.9)	83 (39.1)	103 (53.8)	119 (54.9)	140 (54.3)	153 (59.3)
4 yr:dS10	177 (61.8)	186 (63.8)	222 (79.4)	230 (76.5)	237 (71.1)	242 (67.8)	246 (65.0)
2 yr:dS10	142 (52.0)	157 (45.3)	162 (47.1)	189 (59.1)	206 (62.3)	212 (54.7)	234 (63.2)
4 yr:dS5	136 (52.3)	149 (48.8)	169 (39.4)	182 (41.7)	197 (27.1)	207 (30.1)	226 (34.1)
2 yr:dS5	178 (34.4)	202 (35.7)	204 (33.8)	214 (45.0)	224 (42.8)	234 (33.6)	246 (28.2)
4 yr:dS<1	61 (34.7)	68 (34.3)	90 (46.9)	125 (35.3)	140 (42.4)	145 (35.3)	170 (.000)
2 yr:dS<1	140 (52.4)	155 (54.5)	164 (51.6)	179 (55.8)	181 (56.4)	187 (52.5)	187 (52.5)

Site 1 Eucalypts

	Oct89	Apr90	Oct90	Apr91	Oct91	Apr92	Oct92
No water	92	116	133	150	165	176	197
	(29.5)	(33.0)	(43.0)	(48.3)	(56.6)	(55.8)	(63.7)
4 yr:dS10	166	192	228	234	259	261	282
	(38.1)	(39.5)	(51.1)	(55.3)	(57.4)	(55.9)	(63.0)
2 yr:dS10	151	169	174	194	228	254	288
	(22.3)	(17.7)	(20.7)	(18.0)	(40.2)	(37.2)	(53.1)
4 yr:dS5	202	222	261	272	301	308	334
	(22.7)	(13.9)	(25.3)	(20.9)	(11.2)	(14.4)	(19.0)
2 yr:dS5	159	185	195	208	224	246	267
	(29.5)	(26.7)	(27.2)	(28.1)	(34.6)	(30.7)	(35.7)
4 yr:dS<1	179	195	227	235	276	283	319
	(38.9)	(36.2)	(42.0)	(45.6)	(67.8)	(63.3)	(90.8)
2 yr:dS<1	156	176	184	206	219	248	276
	(35.4)	(38.0)	(37.0)	(47.2)	(47.6)	(51.0)	(59.3)

Site 2 Eucalypts

	Oct89	Apr90	Oct90	Apr91	Oct91	Apr92	Oct92
No water	51	73	80	106	120	132	180
	(20.1)	(19.7)	(26.1)	(47.1)	(54.8)	(70.0)	(99.0)
4 yr:dS10	140	162	204	229	296	305	350
	(31.6)	(42.0)	(54.7)	(56.2)	(50.9)	(54.6)	(84.4)
2 yr:dS10	142	169	172	192	222	257	310
	(28.1)	(32.7)	(33.3)	(59.1)	(69.5)	(82.1)	(106.8)
4 yr:dS5	162	168	210	242	333	345	408
	(37.1)	(35.6)	(40.0)	(44.4)	(63.8)	(43.0)	(77.9)
2 yr:dS5	144	190	202	253	290	323	410
	(38.2)	(57.6)	(61.3)	(28.9)	(65.6)	(45.4)	(85.4)
4 yr:dS<1	125	162	188	210	267	277	322
	(38.1)	(32.5)	(38.7)	(52.5)	(74.4)	(69.8)	(108.7)
2 yr:dS<1	119	166	183	202	226	254	306
	(29.6)	(53.2)	(46.1)	(63.8)	(80.5)	(78.9)	(97.9)

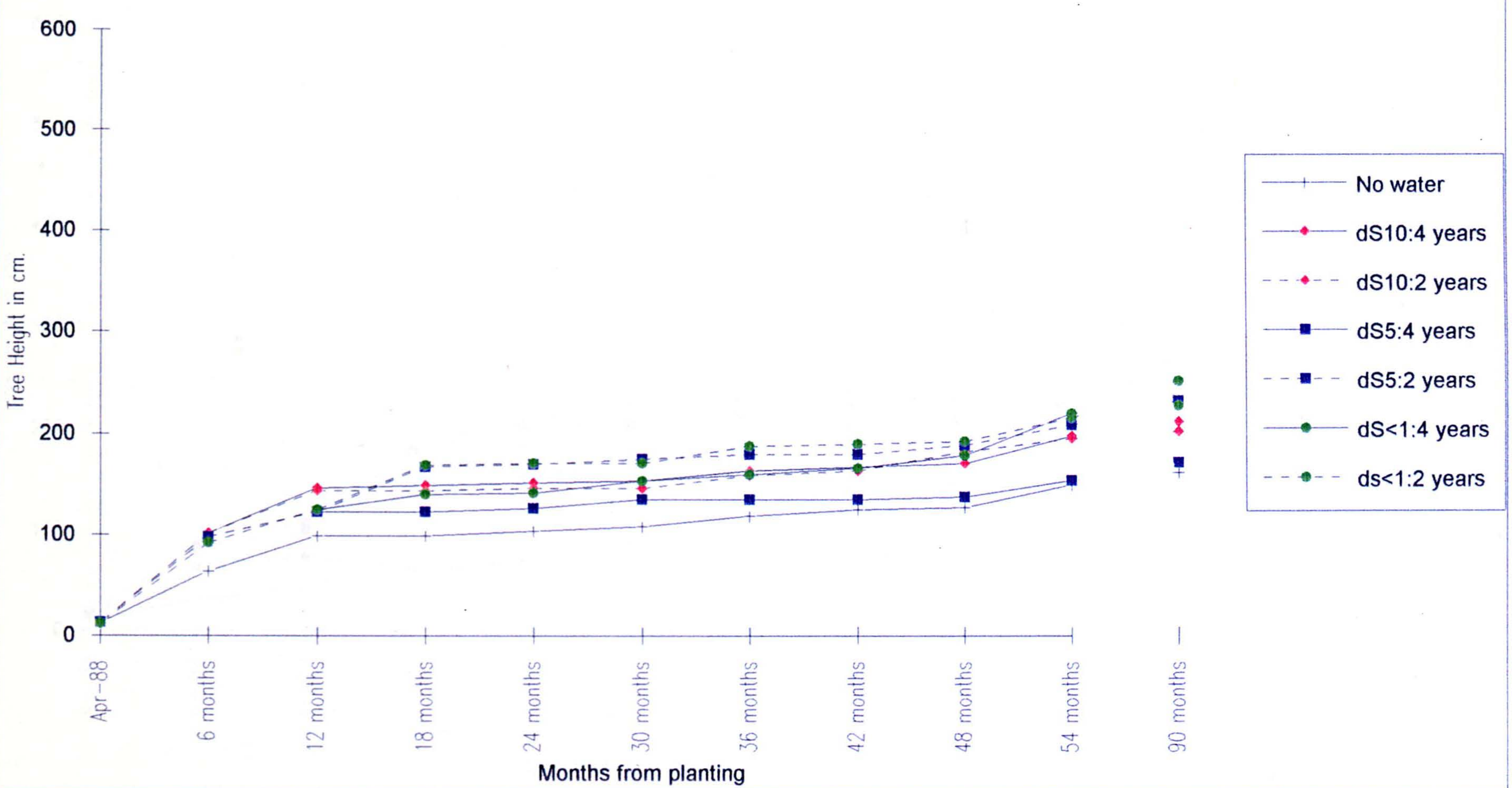
Heights in all irrigated classes tended to reflect base heights (October 1989) rather than to respond to the extra irrigation. By October 1991, in the 10dS group acacias at both sites, the 4 year irrigated trees were taller than the 2 year irrigated, as they had been in 1989. In both the 5dS and <1dS group acacias, the two year irrigated trees were taller than the four year, again reflecting October 1989 differences. The eucalypts at Site 1 showed higher means in the four year irrigated trees in all three water groups as they did in 1989. Only among the eucalypts at Site 2 was this pattern broken, with the four year irrigated trees in the 10dS group overtaking the two year irrigated trees in mean height. The 5dS and <1dS eucalypts at this site showed higher mean heights for the four year irrigated trees, as at October 1989.

At October 1992, a year after irrigation had been stopped for all trees, there were differences in mean heights between the irrigation duration groups. Whilst all Site 2 acacias and those at Site 1 in the 5 and 10dS groups followed the previous pattern, in the acacias at Site 1 irrigated at <1dS the trees irrigated for four years finally overtook those with only two years irrigation.

However the pattern is reversed with the eucalypts at Site 1 where, in the 10dS group the two year irrigated trees overtook those with four years irrigation. The other two groups of eucalypts at this site (5 and <1dS) followed the previous pattern. At Site 2 the four year irrigated trees continued to be taller than the two year trees in the 10dS and <1dS groups. In the 5dS group the two year irrigated trees slightly overtook the four year.

Standard deviations, as before, generally increased as the trees grew, the largest deviations being among the

Fig.16a. Site 1 Mean Acacia Heights in all Irrigation Classes. 1988-1995.



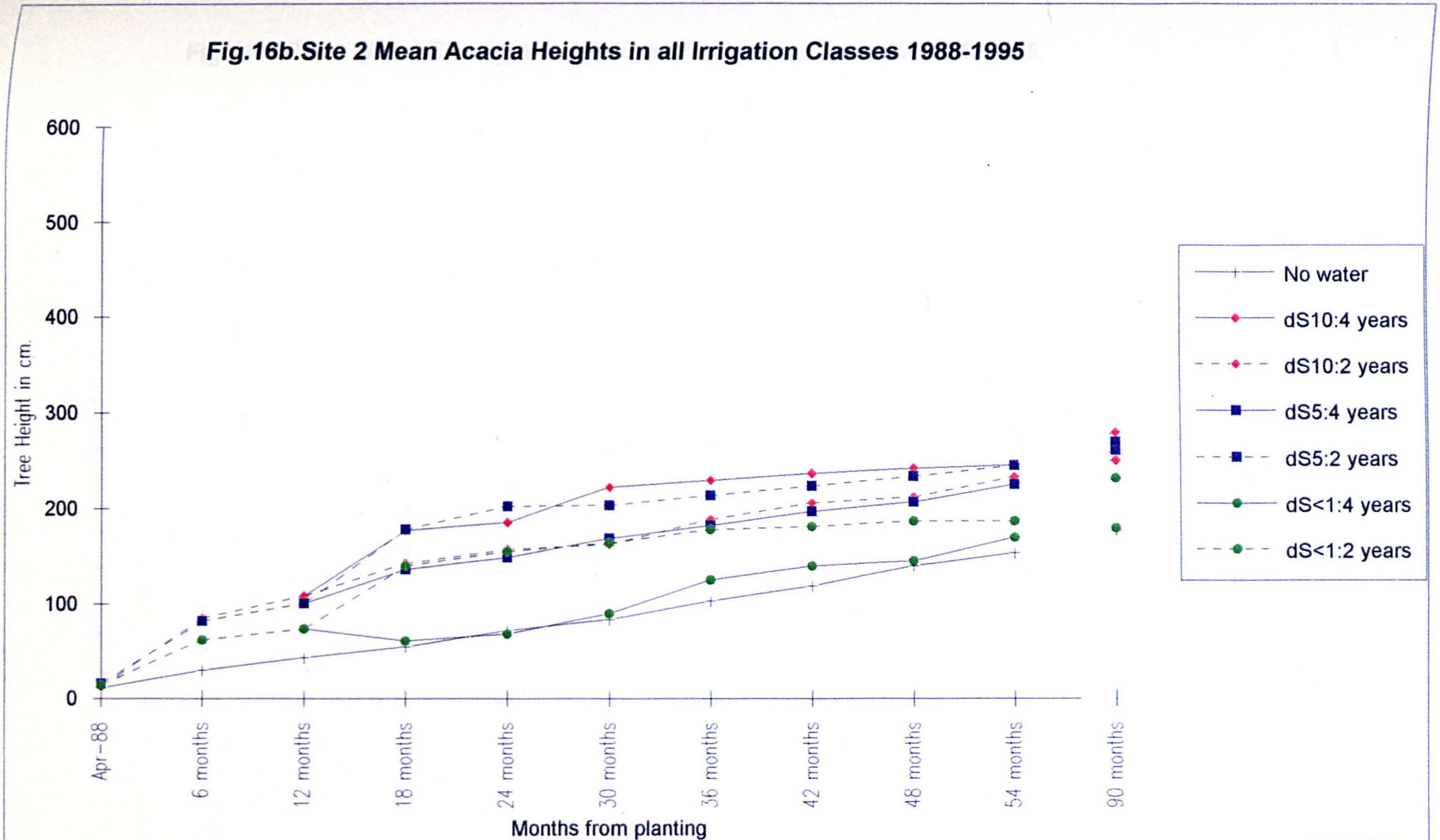
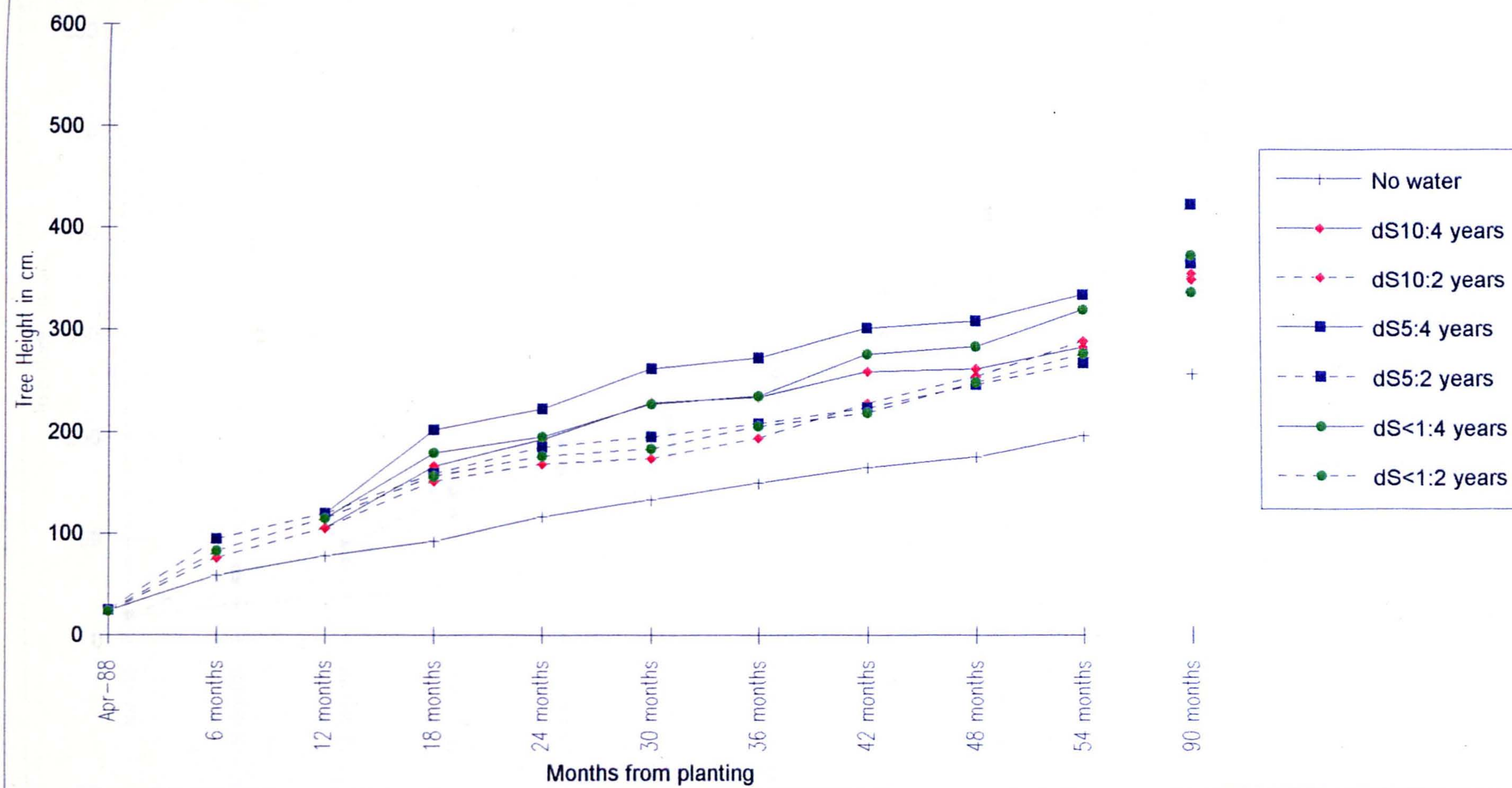


Fig.16b.Site 2 Mean Acacia Heights in all Irrigation Classes 1988-1995
600
500
400
300
200
100
0
Tree Height in cm.
Apr-88
6 months
12 months
18 months
24 months
30 months
36 months
42 months
48 months
54 months
90 months
Months from planting
No water
dS10:4 years
dS10:2 years
dS5:4 years
dS5:2 years
dS<1:4 years
dS<1:2 years

Fig.16c. Site 1 Mean Eucalypt Heights in all Irrigation Classes. 1988-1995.



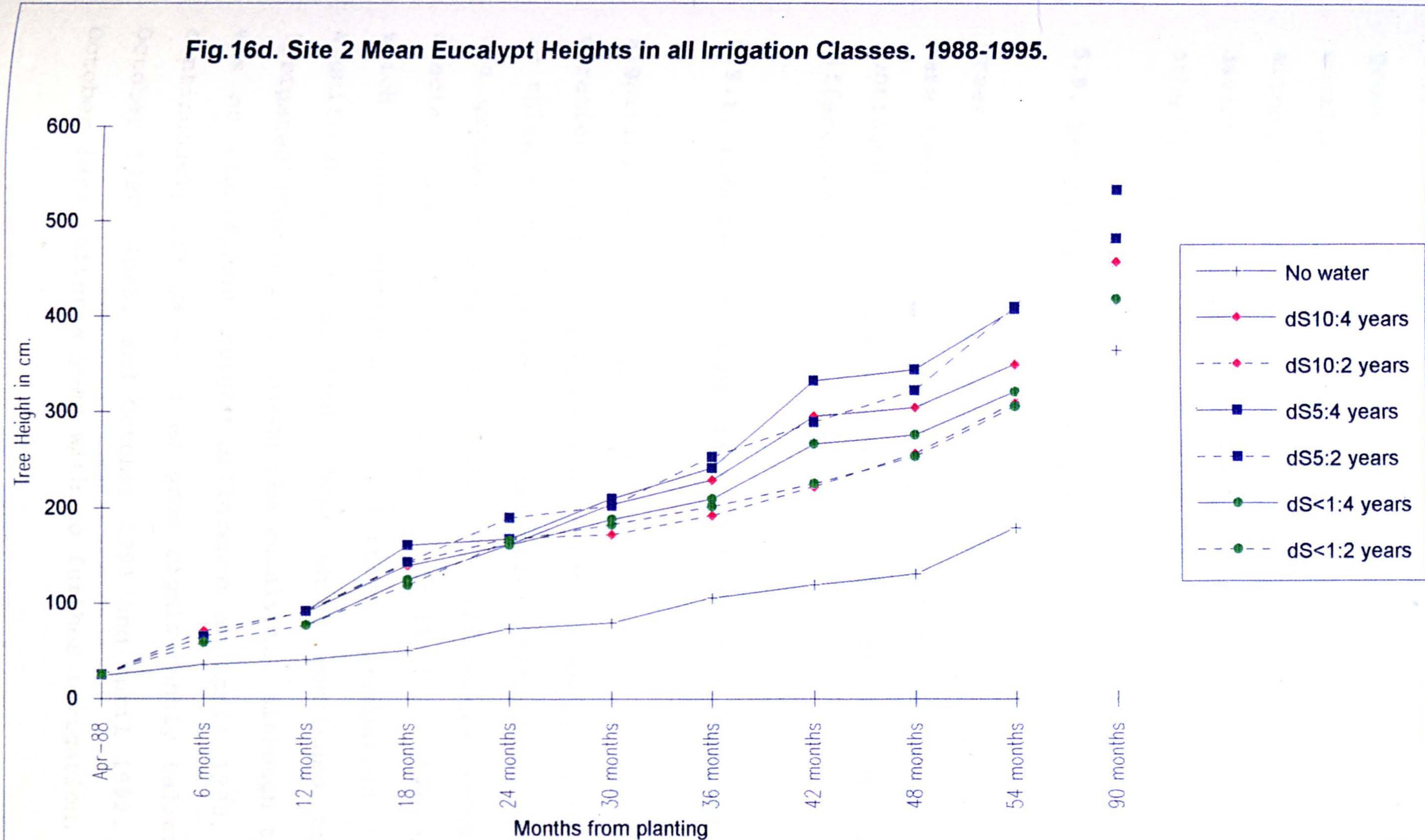


Fig.16d. Site 2 Mean Eucalypt Heights in all Irrigation Classes. 1988-1995.
600
500
400
300
200
100
0
Tree Height in cm.
Apr-88
6 months
12 months
18 months
24 months
30 months
36 months
42 months
48 months
54 months
90 months
Months from planting
No water
dS10:4 years
dS10:2 years
dS5:4 years
dS5:2 years
dS<1:4 years
dS<1:2 years

eucalypts at Site 2, which also exhibited the greatest growth. The exception to this trend was among the eucalypts at Site 1 irrigated for four years at 5dS where, although height growth increased steadily, standard deviations fluctuated but remained low in comparison to other groups.

5.9. Irrigation Duration Effects.

Trees in the blocks where irrigation had been withdrawn were tested with Mann-Whitney tests against those which continued to receive irrigation. The erratic pattern of differences is discussed below.

5.9.i. Tree Height in Relation to Irrigation Duration.

Significance levels of height in relation to irrigation duration for both species are shown in Tables 20 and 21. In spite of the apparently substantial differences between the groups displayed by Table 19, differences among the acacias were only significant at April 1990 when trees which were receiving no further irrigation were significantly taller than those which continued to be irrigated (Table 20). Among the eucalypts, although there was no significant height difference at April 1990, the continuously irrigated trees grew significantly taller at October 1990, April and October 1991 and April 1992. By October 1992, after a year with no further irrigation, the gap was closing and there was no significant difference between the four year and the two year irrigation.

Table 20: Tests of Height Differences in relation to Irrigation Duration for Acacia. Trees in all Irrigated Classes. April 1990 - October 1992. Mann-Whitney U Tests.

	U	N
April 1990	770.5*	94
October 1990	850.5	91
April 1991	778.5	88
October 1991	814.0	88
April 1992	804.0	88
October 1992	663.5	75

* = significant at p <.025

(2 year > 4 year in significant case)

Table 21: Tests of Height Differences in relation to Irrigation Duration for Eucalypts. Trees in all Irrigated Classes. April 1990 - October 1992. Mann-Whitney U Tests.

	U	N
April 1990	847.5	89
October 1990	536.0*	88
April 1991	436.5*	76
October 1991	335.5*	76
April 1992	445.0*	75
October 1992	526.5	75

* = significant at p <.025

(4 year > 2 year in all significant cases)

5.9.ii. Tree Height in relation to Irrigation Duration, Site and Water Quality.

To identify the specific differences seen above, Mann-Whitney U analysis was performed by site and water class on the groups in which differences had been significant.

Table 22: Tests of Height Differences in relation to Irrigation Duration, for each Site and Water Quality Class for Acacias at October 1990. Mann-Whitney U Tests.

	Site 1		Site 2	
	U	N	U	N
Acacia 10dS	31.0	16	26.0	16
5dS	13.0	16	11.5	16
<1dS	20.0	16	3.5*	14

* = significant at p <.025

(2 year > 4 year in significant case)

The table shows that the significant difference shown in Table 20 only applied to acacias in the <1dS class at Site 2. After October 1990 differences ceased to be significant among acacias.

Table 21 had shown significant differences between irrigation duration groups for eucalypts at October 1990, April and October 1991 and April 1992. These differences were examined by site and water quality class in the same way as those for acacia above. As there were more significant differences among the eucalypts, figures for April 1990 and October 1992 were also examined.

Table 23. Tests of Height Differences in relation to Irrigation Duration, for each Site and Water Quality Class for Eucalypts. April 1990 to October 1992. Mann-Whitney U Tests.

	Site 1 U	N	Site 2 U	N
Apr 1990:10dS	17.0	15	24.5	15
5dS	5.5*	16	12.5	13
<1dS	24.0	16	22.0	14
Oct 1990:10dS	8.0*	15	19.0	15
5dS	1.5*	16	18.0	13
<1dS	12.5	16	21.0	13
Apr 1991:10dS	13.0	14	10.5	11
5dS	3.0*	16	7.0	8
<1dS	18.0	16	14.5	11
Oct 1991:10dS	15.5	14	6.0	11
5dS	3.5*	16	3.0	8
<1dS	15.5	16	7.5	11
Apr 1992:10dS	23.5	14	22.0	10
5dS	2.0*	16	5.0	8
<1dS	22.0	16	11.0	11
Oct 1992:10dS	22.0	14	9.0	10
5dS	4.5*	16	7.5	8
<1dS	24.0	16	12.5	11

* = significant at p <.025.

(4 year > 2 year in all significant cases)

The analysis shows that of the significant differences by irrigation duration for eucalypts shown in Table 21, the differences at October 1990 were in the 5dS and 10dS blocks at Site 1. Thereafter they only occurred in the 5dS blocks at Site 1 as they had at October 1989. Although Table 21 shows no differences at April 1990 or October 1992, Table 23 shows that there were differences in 5dS eucalypts at Site 1 at those dates. It is assumed that when all water classes were analyzed together (Table 21) the differences were subsumed in the larger picture.

Thus, the only class in which 4 year irrigated trees grew consistently taller than those irrigated for two years, were the 5dS eucalypts at Site 1. Stepwise linear regression was performed for this group in an attempt to examine growth patterns more closely. The variables examined were original height, irrigation duration and soil depth. Irrigation duration ($R = .849$ $SE = 25.739$) was the only variable admitted. The probability associated with original height and soil depth did not reach the required level ($p <.05$). The same analysis was performed for all trees. No trees in this group (Site 1 eucalypts irrigated at 5dS) were among the residuals. Residuals were examined, but no clear pattern emerged. No significant differences were shown between the four and two year irrigated trees in any of the other classes.

5.10. Water Quality Effects.

As for the first two years, differences were examined, between all four water classes and between the three irrigated classes only.

5.10.i. All Four Water Classes.

As in the first two years, differences by water quality are substantial in both species when all four water classes are examined. (Table 19 and Figs.16 a,b,c and d and 21 and 22 a-h). The unirrigated trees were considerably less tall than any of the three irrigated classes.

5.10.ii. Three Irrigated Classes Only.

Again, as Figs. 16a,b,c and d and Figs 21 and 22 a-h show, when only the irrigated and formerly irrigated classes are considered, the differences between them are not substantial. Figures 21 a-h particularly show the considerable overlapping in height between the three irrigated classes. As before, high responses to irrigation were demonstrated with no large differences between the three irrigated classes.

5.11. Site Effects.

In the first two years, growth had been better at Site 1 than at Site 2. To see whether this effect had persisted, height differences between sites were analyzed by Mann-Whitney U tests.

Table 24: Tests of Height Differences between Sites for Acacia from April 1990 to October 1992. Mann Whitney U Tests.

	U	N
April 1990	1838.5	124
October 1990	1656.5	120
April 1991	1403.0	117
October 1991	1204.5*	114
April 1992	1167.0*	114
October 1992	960.0	97

* = significant at p <.025

(Site 2 > Site 1 in significant cases)

Table 25: Tests of Height Differences between Sites for Eucalypts from April 1990 to October 1992. Mann Whitney U Tests.

	U	N
April 1990	1317.5	111
October 1990	1343.5	110
April 1991	1006.5	96
October 1991	831.0	96
April 1992	692.0*	94
October 1992	563.5*	93

* = significant at p <.025

(Site 2 > Site 1 in significant cases)

5.11.i. Height Differences between Sites.

Tables 24 and 25 show that the better performance of the Site 1 trees in the first two years, shown in Tables 13, 14 and 15, did not persist. From April 1990, the tests showed significant differences in height between sites for acacia at October 1991 and April 1992 and for eucalypts at April and October 1992, all favouring Site 2. There was no consistent pattern. The differences appeared erratic and can be more closely examined in Table 19 above and Tables 26 and 27 below.

5.11.ii. Height Differences between Sites in relation to Water Quality.

To examine the apparently erratic pattern of Tables 24 and 25 more closely, differences by water quality were also analyzed by Mann-Whitney U tests. The results are shown in Tables 26 and 27.

Table 26: Tests of Height Differences between Sites at each Water Quality for Acacia. Mann-Whitney U Tests.

	Water 1: No water		Water 2: Irrigated at 10dS	
	U	N	U	N
April 1990	58.0*	30	96.0	32
October 1990	62.5	29	81.5	32
April 1991	78.0	29	73.0	32
October 1991	75.5	26	62.5*	32
April 1992	76.0	26	72.5	32
October 1992	59.0	22	66.5	29

	Water 3: Irrigated at 5dS		Water 4: Irrigated at<1dS	
	U	N	U	N
April 1990	87.0	32	72.5	30
October 1990	84.0	32	69.0	30
April 1991	67.5	31	69.5	25
October 1991	48.5*	31	67.5	25
April 1992	50.0*	31	65.5	25
October 1992	33.5*	26	33.0	20

* = significant at p <.025 (Site 1 > Site 2 at April 1990. Site 2 > Site 1 in all other significant cases)

Table 27: Tests of Height Differences between Sites at each Water Quality for Eucalypts. Mann-Whitney U Tests.

	Water 1: No water		Water 2: Irrigated at 10dS	
	U	N	U	N
April 1990	14.0*	22	92.5	30
October 1990	15.0*	22	95.0	30
April 1991	14.0	20	73.0	25
October 1991	19.0	20	55.0	25
April 1992	13.5	19	48.0	24
October 1992	14.5	18	46.0	24

	Water 3: Irrigated at 5dS		Water 4: Irrigated at <1dS	
	U	N	U	N
April 1990	78.0	29	84.5	30
October 1990	86.0	29	82.0	29
April 1991	58.5	24	83.0	27
October 1991	29.0	24	82.5	27
April 1992	19.0*	24	80.0	27
October 1992	15.0*	24	72.5	27

* = significant at p <.025

(Site 1 > Site 2 at April and October 1990. Site 2 > Site 1 at April and October 1992)

Again, no clear pattern emerges for all classes. Differences which appeared to be diminishing at October 1989 re-emerge at different dates in different water classes. For acacias, the greater height at Site 2 was in the 5 and 10 dS classes. For eucalypts it was in the 5dS class. Unirrigated trees did better at Site 1. Thus there were significant differences in height between the unirrigated classes at the two sites at April 1990 for acacias and at April and October 1990 for eucalypts favouring Site 1. Unirrigated eucalypts had always done badly at Site 2. The results for this class at Site 2 should be regarded with caution, owing to the large number of deaths (10 out of sixteen trees in the first two years). In the 10dS class, acacias showed significant differences between the sites at October 1991 favouring Site 2 (eucalypts in this class showed no significant differences). At 5dS, acacias showed significant differences at October 1991 and at April and October 1992. 5dS eucalypts were also significantly different by Site at April and October 1992. All these differences favoured Site 2. At <1dS, differences between sites were not shown to be significant in either species.

No particular explantation can be offered for these differences beyond the general observation of greater growth at Site 2 in the second part of the experiment.

5.12. Soil Depth Effects.

Figs. 17 a,b,c and d show the relation of soil depth to height growth. There did not appear to be any pattern of increasing growth with deeper soils. Correlation was performed on the height growth figures with soil depth (Table 28). Again no relationship appeared.

Table 28: Correlation between Height and Soil Depth.

	r.	df.
April 1990	.00504	233
October 1990	.06505	228
April 1991	.05608	211
October 1991	.03773	208
April 1992	.04499	206
October 1992	.00855	188

None of the correlations were significant.

5.13. Species Effects.

There were, as expected, obvious differences in height between species.

5.14. Survival: Second Phase (from April 1990).

Although tree growth had, in the second two years of the experiment, reversed the previous pattern between sites -

the Site 2 trees catching up with those at Site 1, the survival pattern remained the same as before. There was again a very high survival rate at Site 1 and a larger number of deaths at Site 2.

5.14.i. Site 1.

At Site 1, there were only three further deaths during these two years, in spite of the withdrawal of irrigation from half the trees. The first to die was the neighbour to the one that had died previously (eucalypt irrigated at 10dS for two years) and although it was in a block where irrigation had been withdrawn, death was not thought to be due to this cause. The tree died in the winter of 1990-1991 but had shown symptoms of ill-health (poor and uneven growth, yellowing of leaves) before withdrawal of irrigation.

Two unirrigated acacias also died at this site in the summer of 1991. These two trees had been unirrigated from the start of the experiment and were on a mean soil depth for that block of 25.62cm. They were adjacent to a section that had been irrigated for two years and it was thought that they had previously 'stolen' water from the adjacent irrigated trees (See below Section 5.15).

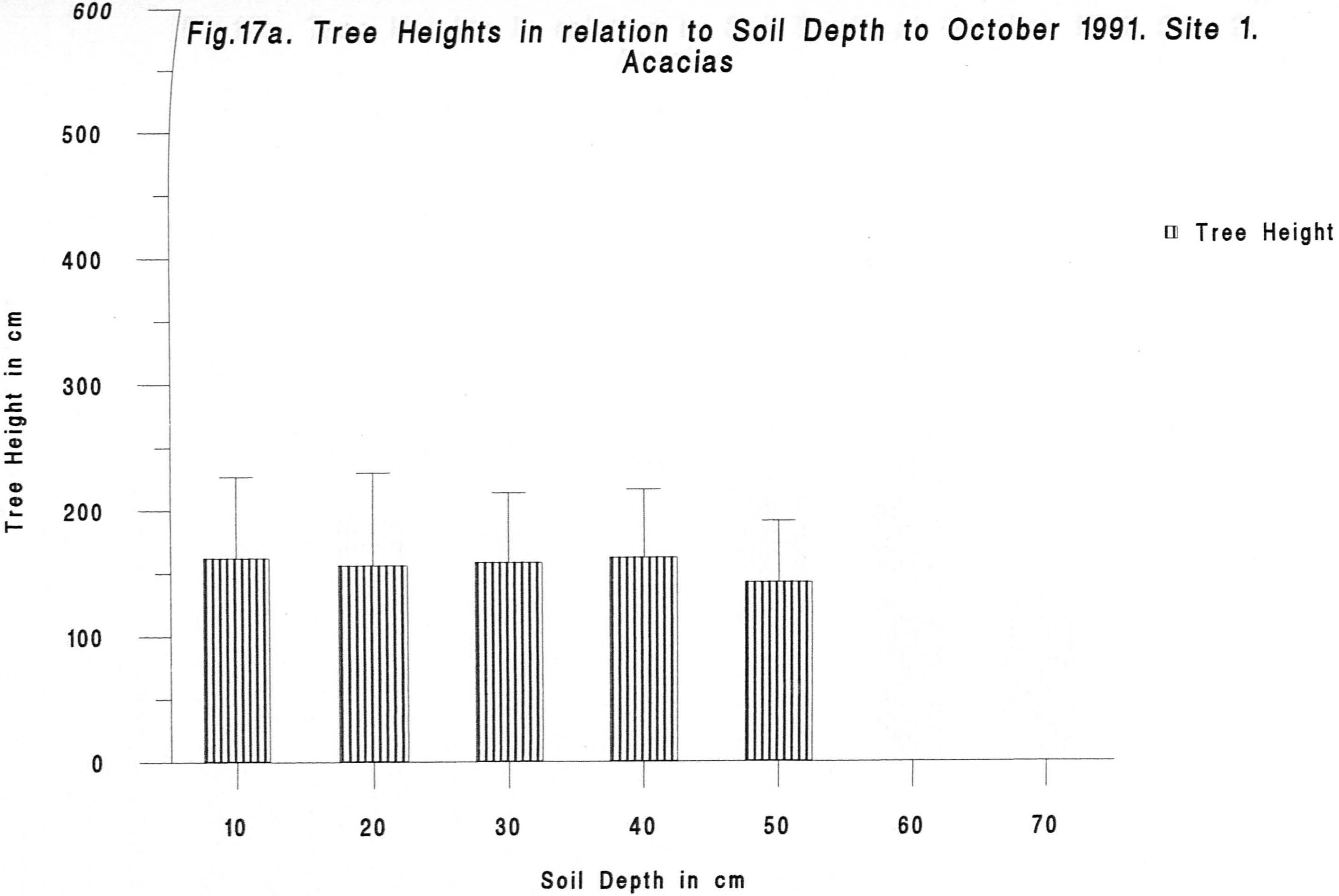
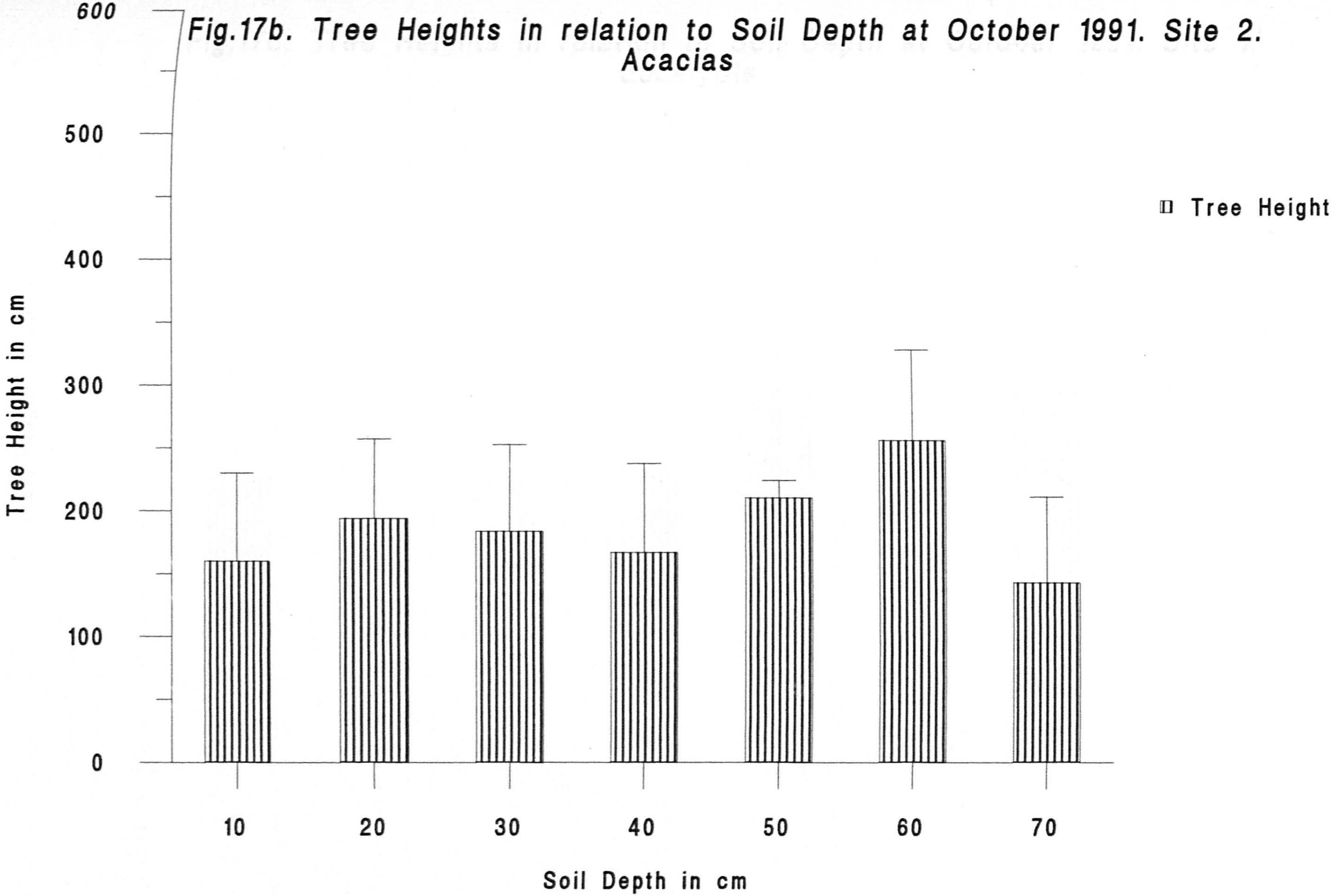


Fig.17a. Tree Heights in relation to Soil Depth to October 1991. Site 1. Acacias

Fig.17b. Tree Heights in relation to Soil Depth at October 1991. Site 2. Acacias



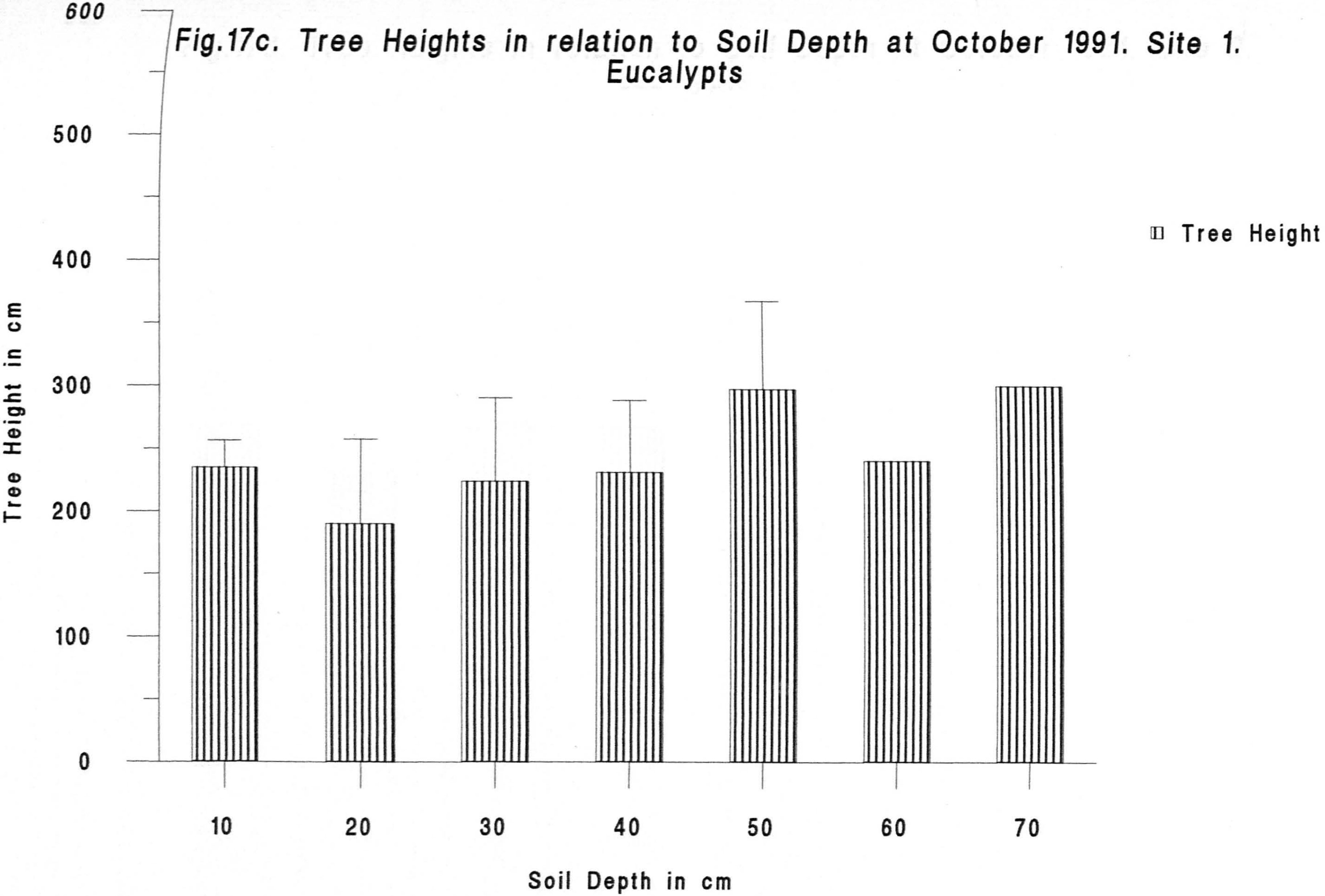


Fig.17c. Tree Heights in relation to Soil Depth at October 1991. Site 1. Eucalypts

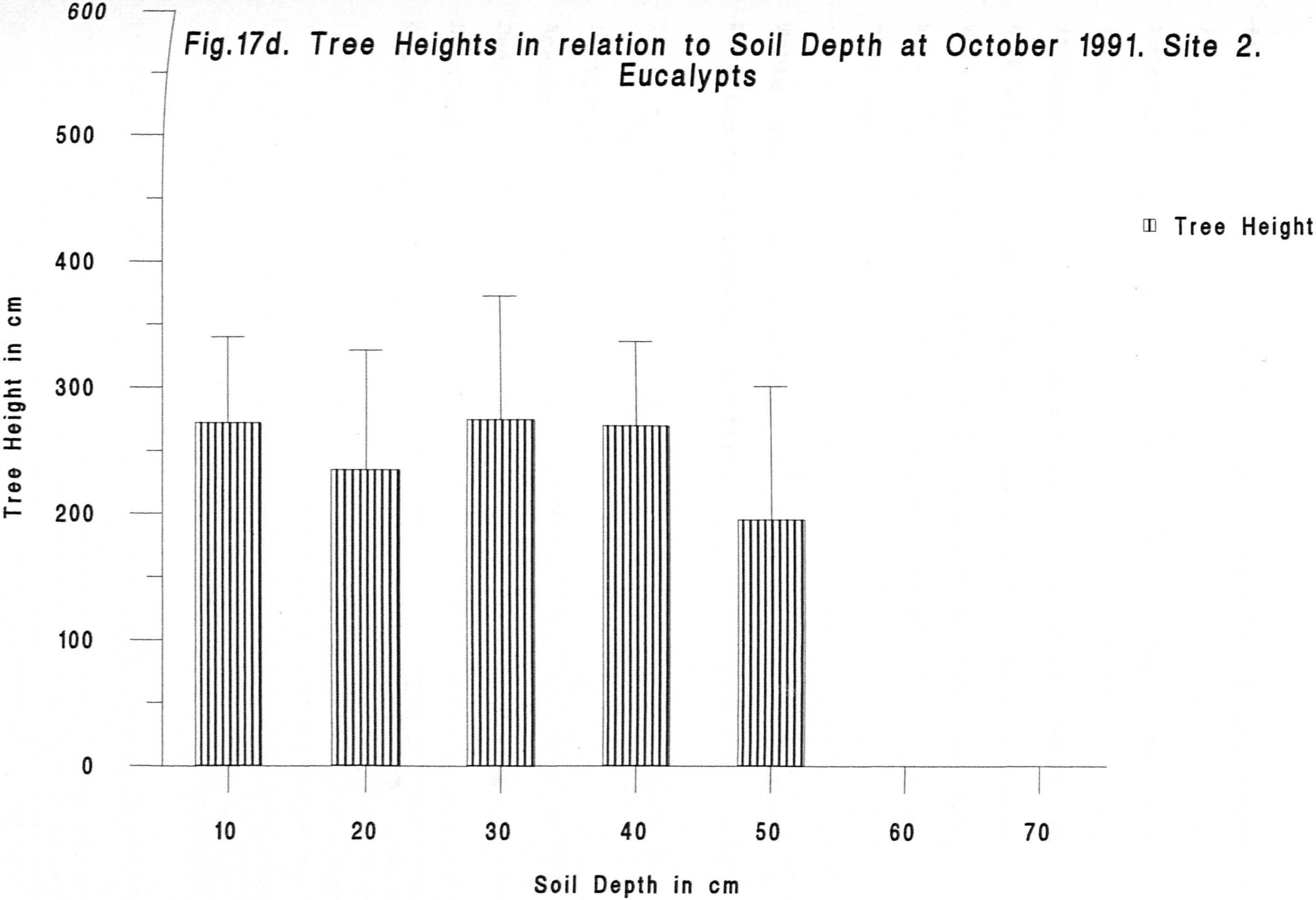


Fig.17d. Tree Heights in relation to Soil Depth at October 1991. Site 2. Eucalypts

5.14.ii. Site 2.

At Site 2, a further twenty two trees died during these two years. Of the twenty two deaths, four trees had never received any irrigation, four were in the four year irrigated acacia blocks and fourteen in the blocks where irrigation had been withdrawn after two years (Tables 29 and 30). Of these fourteen, two were acacias and twelve were eucalypts. It thus at first appeared that eucalypts were less able to withstand the withdrawal of irrigation than acacias.

Table 29: Site 2. Deaths in relation to Irrigation Duration April 1990-October 1991.

	No water	2 year irrigation	4 year irrigation	
Acacia				
Deaths	2	2	4	Total: 8
Eucalypt				
Deaths	2	12	0	Total:14
				Overall Total:22

Table 30: Site 2. Deaths in relation to Water Quality and Irrigation Duration (April 1990 - October 1991).

4 year Irrigation.

	Acacia				Eucalypt			
	No water	10dS	5dS	<1dS	No water	10dS	5dS	<1ds
October 1990	1			2				
April 1991				2	2			
October 1991	1							
Total		2			4		2	

2 year Irrigation.

	Acacia				Eucalypt			
	No water	10dS	5dS	<1dS	No water	10dS	5dS	<1ds
October 1990				1			1	
April 1991			1			4	5	2
Total			1	1		4	5	3

Overall total: 22

5.14.iii. Site 2 Deaths in relation to Irrigation Duration and Water Quality.

This pattern is shown in Table 30. Again, there seemed to be no evidence that death was linked to water quality as opposed to presence or absence of irrigation. The death rate in the unirrigated sections was, as before and as expected, proportionately higher than in those receiving irrigation. Ten of the 16 eucalypts in the unirrigated class at Site 1 had died in the first two years and two had died in the second two years, leaving only four.

5.14.iv. Site 2 Deaths in relation to Irrigation Duration.

Irrigation duration in relation to Site 2 deaths in the second phase is shown in Table 29. Irrigation duration did appear to be linked to survival, especially for eucalypts (See above Section 5.14.ii). However, when soil depth (See below Section 5.14.v) is taken into account, it seems doubtful whether the apparent irrigation duration effect was as influential as it at first appeared.

5.14.v. Soil Depth.

Soil depth again seemed to be a major factor in tree death. The relationship is shown in Table 31. Once more there was a strong relationship between shallow soil and deaths. The four acacia deaths in the blocks irrigated with BAW (<1dS) for four years proved to have been in the 0-10cm soil depth class (See below Fig.19b). Many of the deaths in the blocks where irrigation had been withdrawn, particularly among the eucalypts, also appeared to fall on very shallow soil. The supposition that eucalypts did not survive the withdrawal of irrigation as well as acacias needed to be reappraised in view of the soil depth figures.

Table 31: Site 2. Deaths in relation to Soil Depth (April 1990 - October 1991).

Site 2.

Soil depth class in cm.	0-10	10-20	20-30	30-40	40-50	50-60	60-70	
Soil depth frequency %	26.6	26.6	27.3	10.2	3.9	2.3	3.1	
Deaths	13	3	5	0	1	0	0	(22)
%Deaths	59.1	13.6	22.7	0	4.5	0	0	

5.14.vi. Soil Depth in relation to Total Deaths.

The much higher death rate at Site 2 may be partially explained by the soil depth figures. The 13 deaths (nearly 60% of all deaths at this site) in the 0-10cm soil depth class, where the frequency of this depth was only 27%, would seem indicative. Mann-Whitney tests on soil depths between the two sites showed very significant differences overall, although some of the differences were less significant when analyzed by species and irrigation status blocks. The results of these tests are shown in Table 32.

Table 32: Tests of Difference in Soil Depth between the two Sites. Mann Whitney U Tests.

	U	N
Entire sites	5385.0*	256
Acacia blocks:		
No water	76.0	32
4 year irrigation	263.0	48
2 year irrigation	160.5*	48
Eucalypt blocks:		
No water	28.0*	32
4 year irrigation	82.5*	48
2 year irrigation	183.0*	48

* = significant at p <.025

Thus there were more significant differences among the eucalypt blocks than among the acacias. In only one case, the unirrigated acacias, was soil depth less at Site 1 than at Site 2, and it was in this block that six of the eight Site 1 deaths occurred. The difference in depth was not significant, however, when tested by Mann-Whitney U.

The mean depth of the soils at each site was:

Site 1: 32.3cm.

Site 2: 25.8cm.

Although the difference is not great, when the depth in the individual blocks is examined with the total deaths, it shows a distinct pattern.

Table 33: Mean Soil Depth (cm) and Number of Deaths. 1988 to 1992.

	No water		4 yr irrigation		2 yr irrigation		
	Acacia	Eucalypt	Acacia	Eucalypt	Acacia	Eucalypt	
Site 1.							
Depth	25.62	33.12	30.83	39.58	33.33	29.16	
Deaths	6	0	0	0	0	2	(8)
Site 2.							
Depth	38.75	16.25	29.17	22.92	26.25	22.50	
Deaths	4	13	6	5	4	12	(44)

Table 33 shows that at mean depths of 30cm and over, no irrigated trees died. When the blocks where the death rate was high are examined, the soil depth figures appear related. Even the unirrigated trees survived better on deeper soils. In the unirrigated eucalypt blocks at Site 1 there is a mean soil depth of 33.1cm. No trees died in this block. In the same blocks at Site 2 there is a mean soil depth of only 16.2cm. Thirteen out of sixteen trees died.

In the eucalypt 2 year irrigation block at Site 1 mean soil depth is 29.2cm. Two trees died (although it should be noted that these two deaths were not thought to be irrigation related). In the same block at Site 2, where soil depth is 22.5cm twelve trees died. Mann-Whitney tests on the differences in soil depth between the eucalypt 2 year irrigation blocks at each site gave U = 183, P = .0248, a significant difference. It does appear that where soils are generally less than 25cm. deep, there will be a substantial increase in the death rate when irrigation is withdrawn. (See also Fig.18a and b).

When deaths and survivals are examined in the unirrigated blocks at Site 2 which suffered a substantial number of deaths (Table 34) the figures seem to confirm the likelihood of soil depth as a major factor in survival. This block (thirty two trees of which one was cut down) suffered sixteen deaths out of the remaining thirty one trees to October 1992. Soil depth for survivors and for dead trees are shown in Table 34, which again demonstrates the disproportionate number of deaths on the shallowest soils.

Fig18a. Site 2. Frequency Distribution of Tree Deaths with Soil Depth.

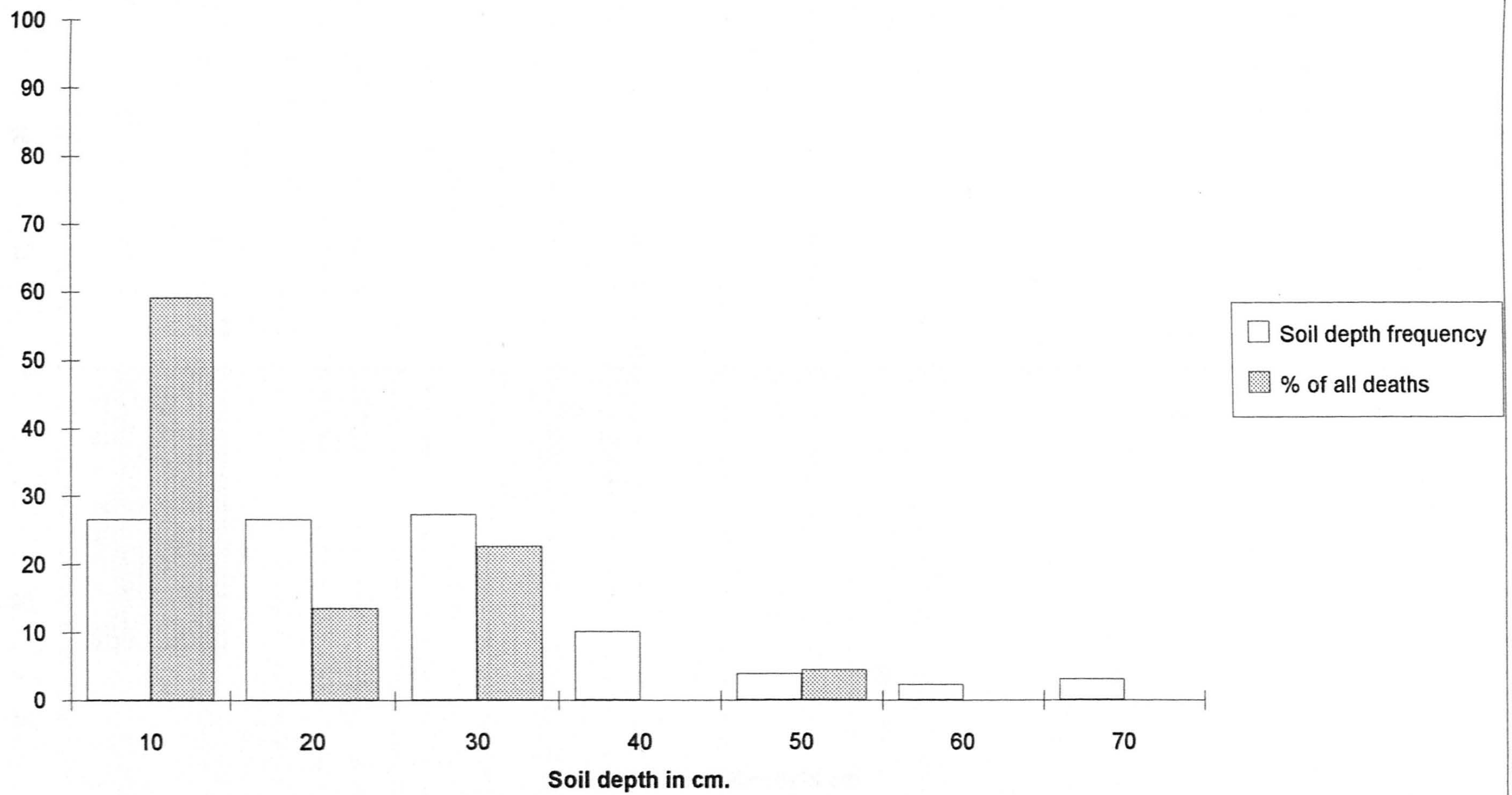


Fig 18b. Site 2. Numbers of Dead and Surviving Trees in each Soil Depth Class

Table 34: Dead and Surviving Trees in Unirrigated Blocks at Site 2 with Soil Depth.

Soil depth class in cm.	0-10	10-20	20-30	30-40	40-50	50-60	60-70	
Soil depth frequency % (in this block)	31.3	18.8	31.3	3.1	3.1	3.1	9.4	
Survivors:								
Acacia	0	3	5	1	0	1	2	(12)
Eucalypt	1	1	1	0	0	0	0	(3)
% Survivors	6.6	26.6	40	6.6	0	6.6	13.3	
Deaths:								
Acacia	0	1	1	0	1	0	1	(4)
Eucalypt	8	1	3	0	0	0	0	(12)
% of Deaths	50	12.5	25	0	6.25	0	6.25	

It is difficult to establish the critical depth. A large percentage of the unirrigated trees died at all soil depths. Of the irrigated trees, the percentage of deaths with mean soil depth is shown in Table 35. The very large percentage of deaths (33.3%) at the 29.17cm. depth in the four year irrigation appears to be an anomaly. While mean depth for the whole block is 29.17cm., when the individual depths at the actual spots where the trees died are examined in Figure 19b, it will be seen that the deaths were all at the shallow edge of this block.

Table 35: Percentage of all Irrigated Tree Deaths with Mean Soil Depth in cm.

2 year irrigation:

		Soil depth	% Deaths
Site 2	Eucalypts	22.5	50
	Acacias	26.25	8.3
Site 1	Eucalypts	29.16	8.3
	Acacias	33.33	0
4 year irrigation:			
Site 2	Eucalypts	22.92	20.83
	Acacias	29.17	33.3
Site 1	Acacias	30.83	0
	Eucalypts	39.58	0

Survival and Soil Depth for Site 2 are shown graphically in Figs.18b. and 19b. where it can be seen that in the lowest soil depth class, deaths far outnumbered survivals. Fig.11b. is here reprinted for ease of reference.

5.14.vii. October 1991 - October 1992.

Although no further irrigation of the 1988 planted trees took place after October 1991, measurements continued in 1992. There were seven deaths in the year following withdrawal of all irrigation. No trees died during the winter, but in the summer of 1992, four Acacias which had received no irrigation from the start of the experiment died at Site 1. At Site 2, one eucalypt which had never been irrigated and two Acacias which had been irrigated for four years at 10dS died.

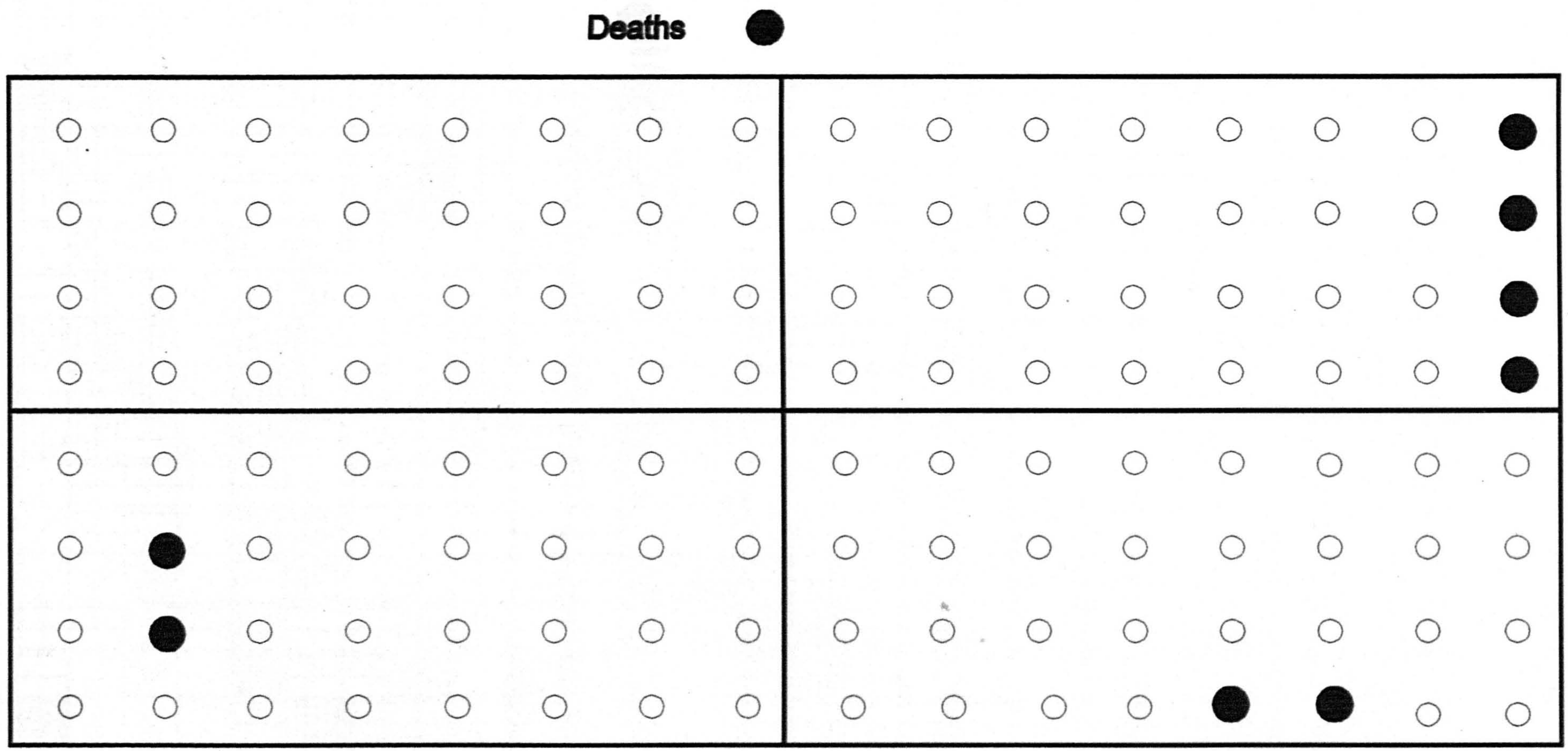
In the autumn of 1992, eleven trees at Site 1 and two trees at Site 2 were cut down for reasons unconnected with the experiment. Thus, to sum up, at Site 1 in the four and a half years from planting, a total of eight trees had died:

First two years:	1 x irrigated eucalypt
Second two years:	1 x irrigated eucalypt
	2 x unirrigated acacias
Fifth year:	4 x unirrigated acacias

At Site 2, forty four trees had died (not counting the tree trampled in the first year):

First two years:	5 x irrigated eucalypts
	2 x irrigated acacias
	10 x unirrigated eucalypts
	2 x unirrigated acacias
Second two years:	12 x 2 year irrigated eucalypts
	2 x 2 year irrigated acacias
	4 x 4 year irrigated acacias
	2 x unirrigated eucalypts
	2 x unirrigated acacias
Fifth year:	2 x 4 year irrigated acacias
	1 x unirrigated eucalypt

Fig 19a. Tree Layout Overlay With Deaths Site 1



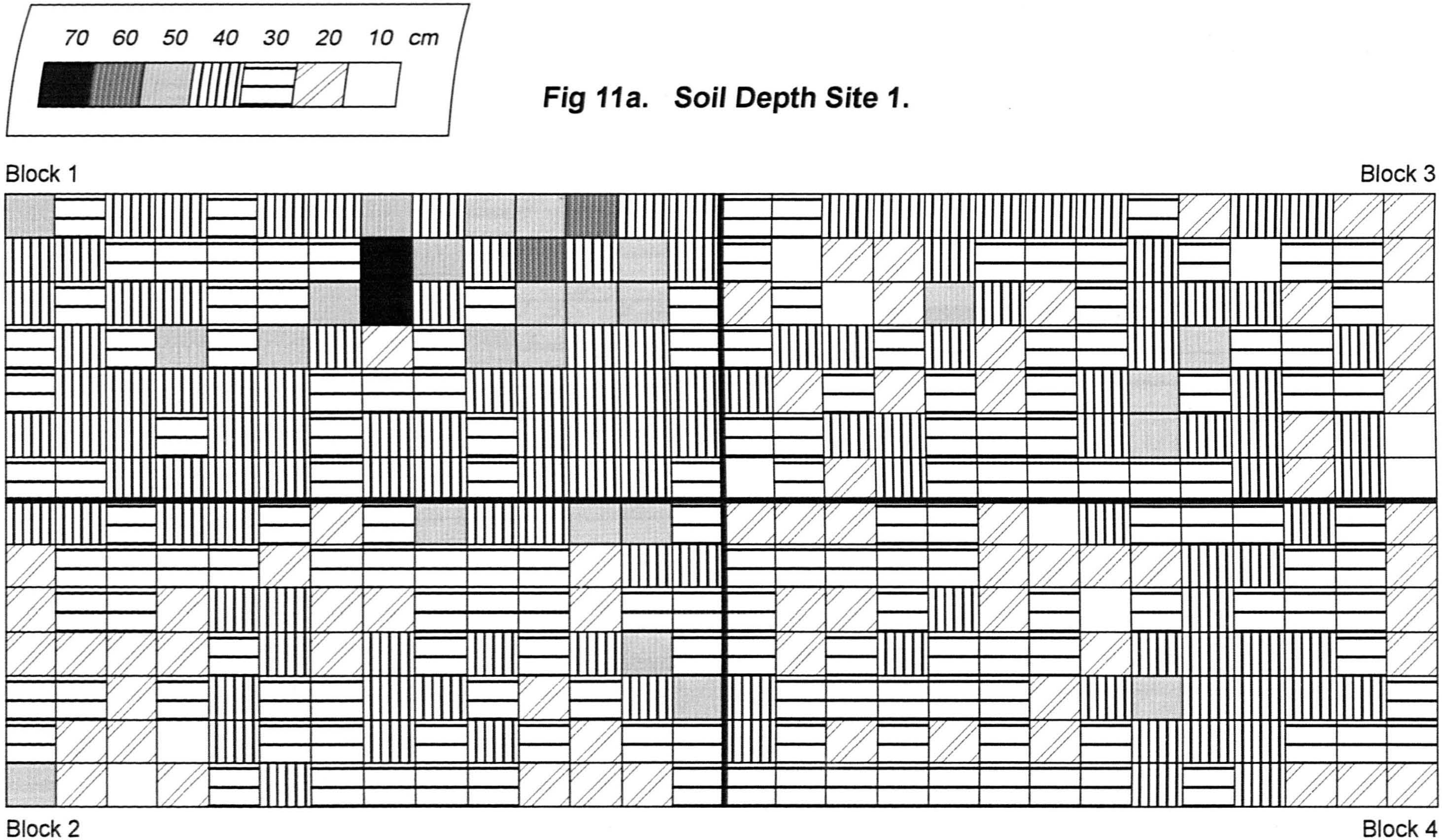


Fig 11a. Soil Depth Site 1.

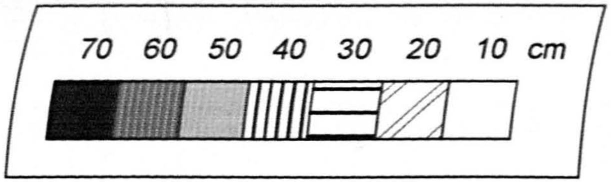
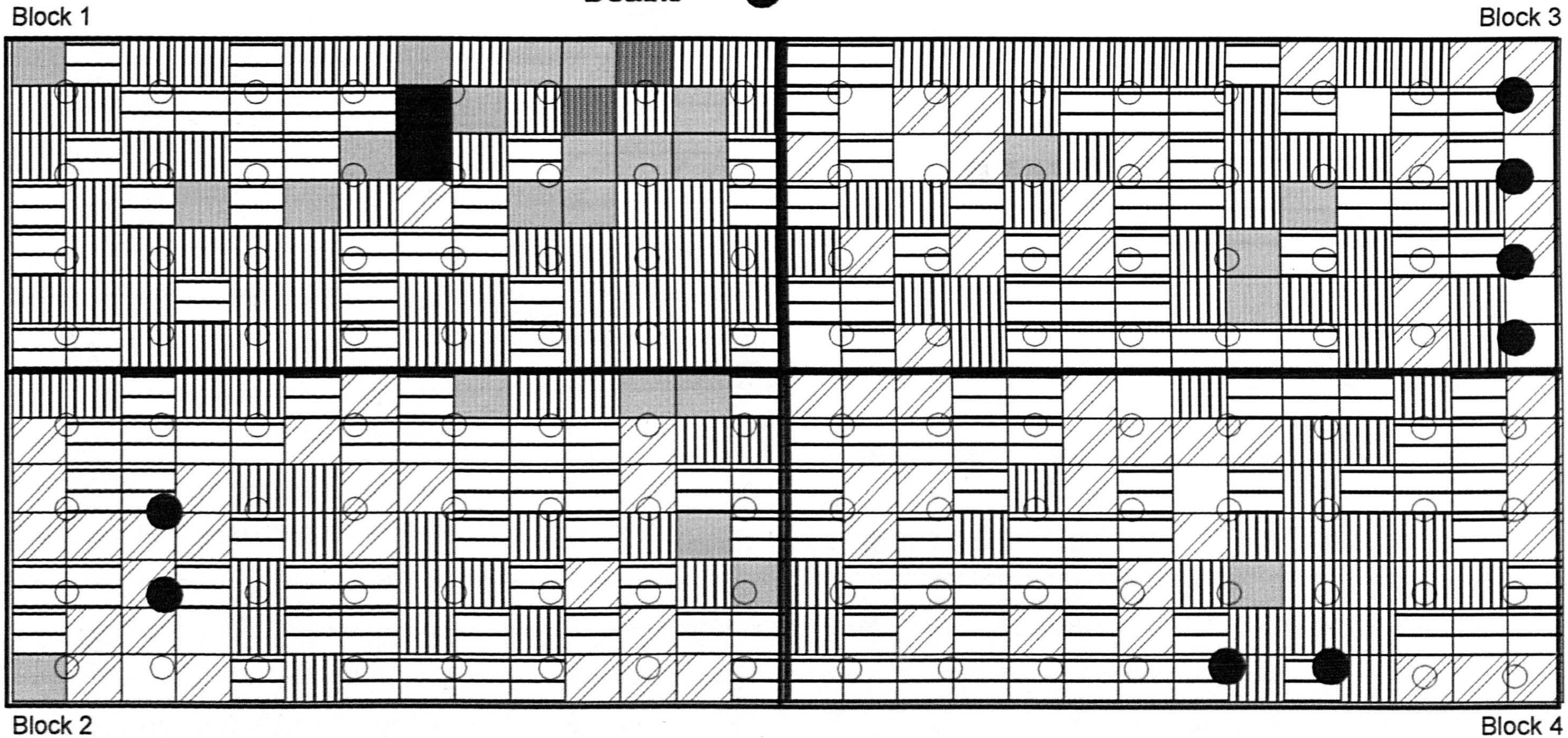


Fig 19a. Tree Layout Overlay With Deaths Site 1

Fig 11a. Soil Depth Site 1.

Deaths



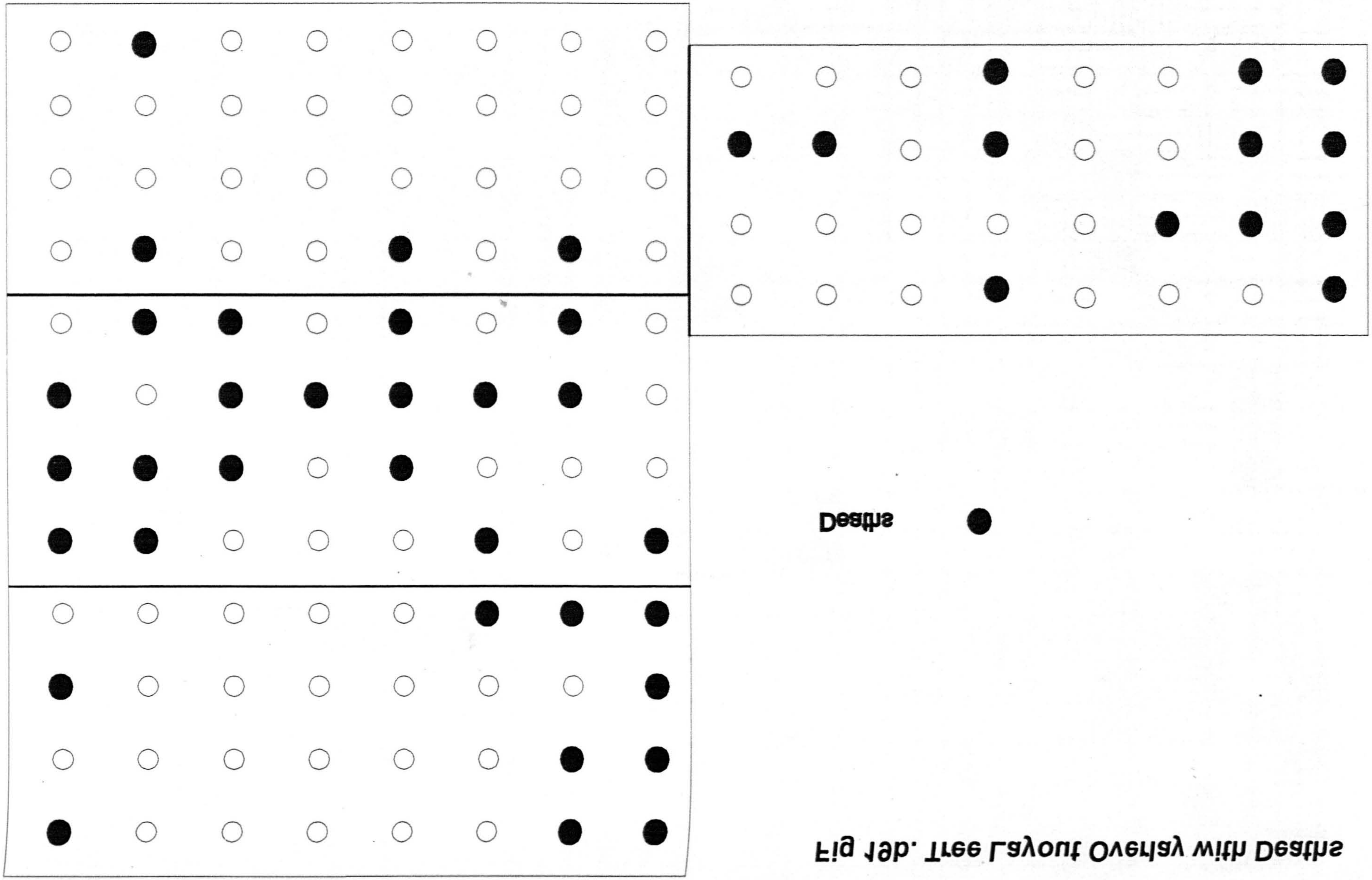


Fig 19b. Tree Layout Overlay with Deaths

Fig 11b. Soil Depth Site 2.

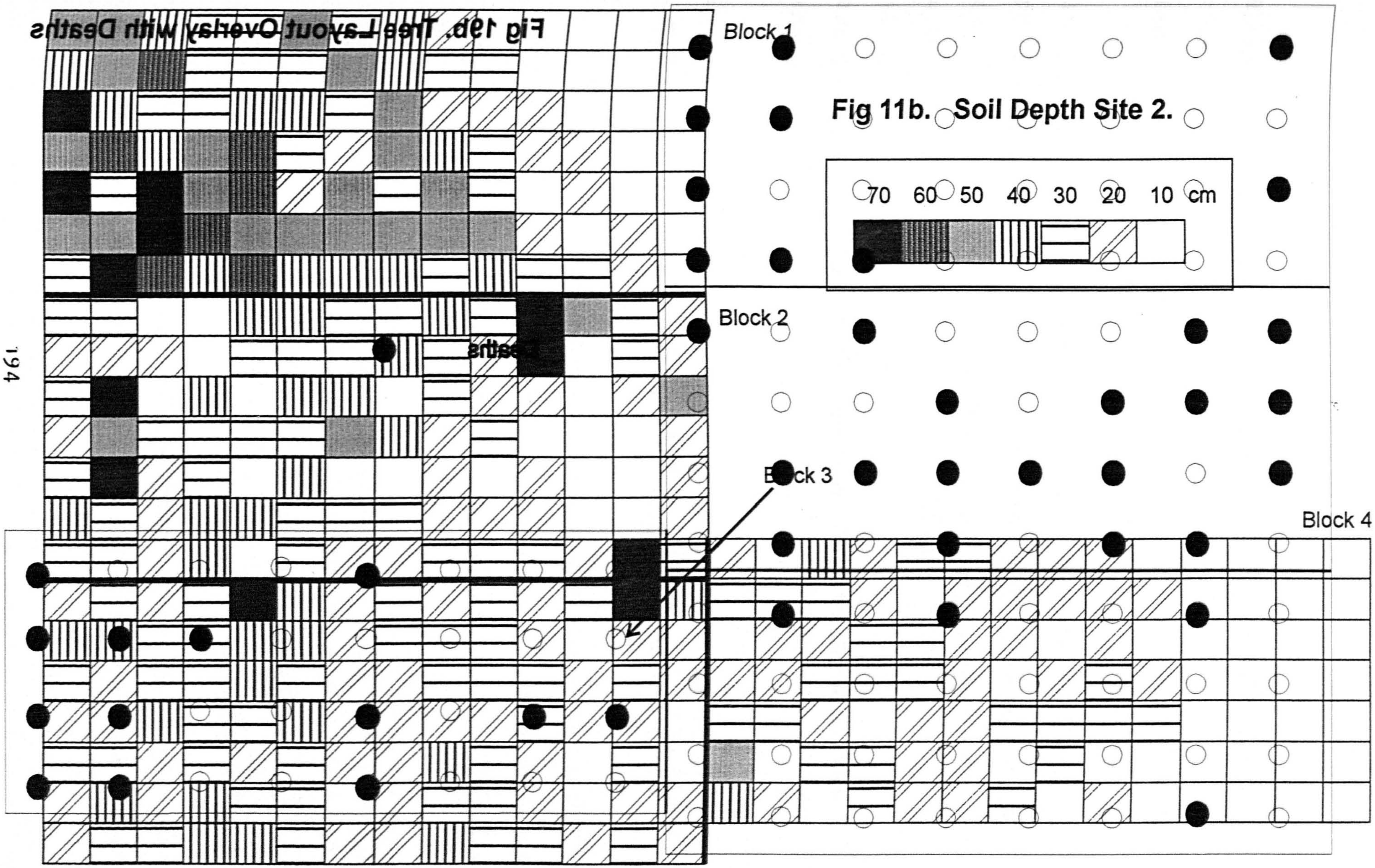


Fig 11b. Soil Depth Site 2.

5.15. Lateral Overlap.

There were four unirrigated double rows at each Site. All these rows were on the outside edges of the respective blocks (Figs 8a and b).

It was clear from the beginning that it was impossible to prevent all lateral flow from the irrigation. An examination of the height growth for the inside and outside rows of these unirrigated trees shows that, in almost all cases, the inside row trees (those adjacent to the irrigated classes) made considerably more growth than the outside rows.

Heights in cm. of outside and inside rows of unirrigated trees are as shown in Table 36: (see also Figs.20a,b,c and d).

Table 36: Mean Heights (cm) of Outside and Inside Row Unirrigated Trees

Site 1 Acacias:	Block 2		Block 3	
	Out	In	Out	In
Apr-88	11.25	13.75	12.5	12.5
Oct-88	67.5	90	32.5	63.75
Apr-89	92.5	115	61.25	82.5
Oct-89	117.5	125	61.25	92.5
Apr-90	122.5	125	67.5	100
Oct-90	130	127.5	67.5	107.5
Apr-91	140	145	77.5	112.5
Oct-91	147.5	200	77.5	112.5

Site 1 Eucalypts:	Block 1		Block 4	
	Out	In	Out	In
Apr-88	27.5	18.75	22.5	27.5
Oct-88	62.5	68.75	45	66.25
Apr-89	77.5	85	62.5	102.25
Oct-89	92.5	107.5	65	125
Apr-90	110	125	90	162.5
Oct-90	132.5	147.5	95	175
Apr-91	146.25	158.75	110	195
Oct-91	163.75	180	112.5	212.5

Site 2 Acacias:	Block 1		Block 3	
	Out	In	Out	In
Apr-88	10	12.5	10	11.25
Oct-88	30	35	31.25	23.75
Apr-89	45	47.5	45	37.5
Oct-89	51.2	66.25	50	50
Apr-90	59.5	90	73.75	60
Oct-90	66.6	112.5	78.75	60
Apr-91	73.3	142.5	103.75	67.5
Oct-91	90	147.5	125	77.5

Site 2 Eucalypts:	Block 2		Block 4	
	Out	In	Out	In
Apr-88	27.5	22.5	20	26.25
Oct-88	40	28.3	25	30
Apr-89	40	36.6	35	50
Oct-89	45	41.6	0	90
Apr-90	65	65	0	110
Oct-90	70	70	0	130
Apr-91	60	97.5	0	170
Oct-91	60	120	0	180

t tests showed significantly greater tree heights in the inside rows, compared to the outside rows in all blocks at Site 1 and the eucalypt blocks at Site 2. In the Site 2

Fig.20a1. Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Acacias Site 1 Block 2.

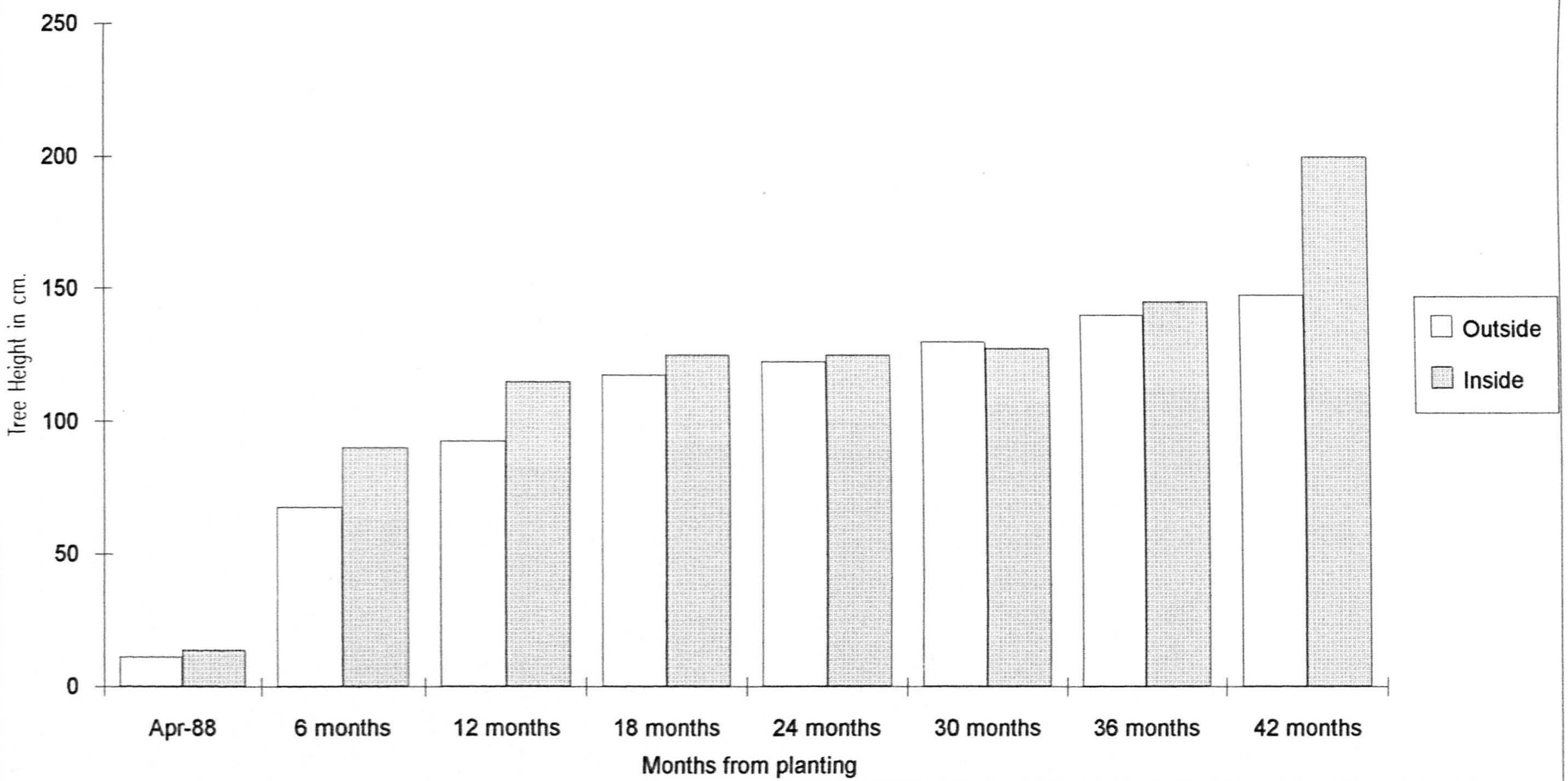


Fig.20a2. Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Acacias Site 1 Block 3.

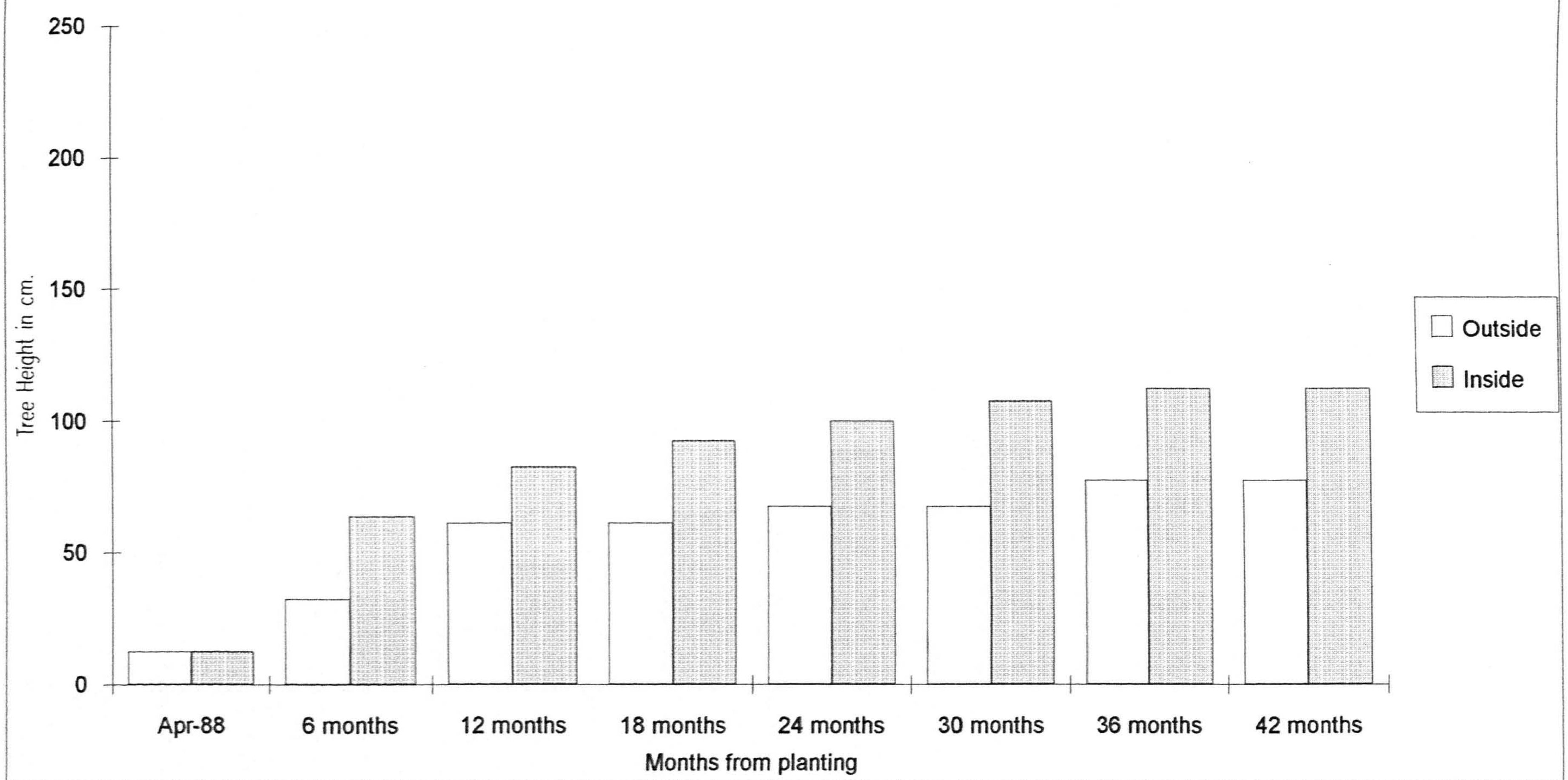


Fig.20b1.Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Acacias Site 2 Block 1

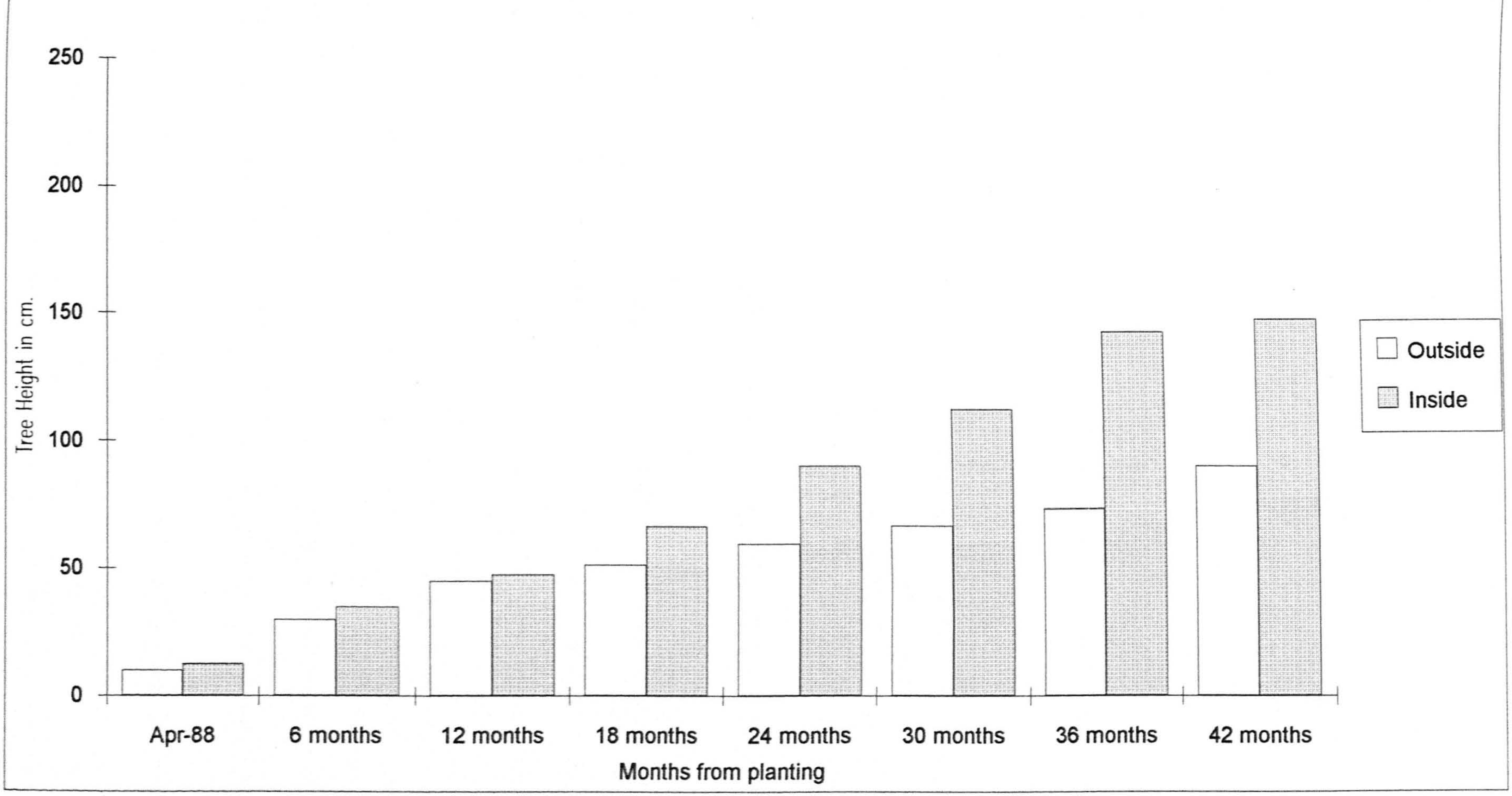


Fig.20b2. Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Acacias Site 2 Block 3.

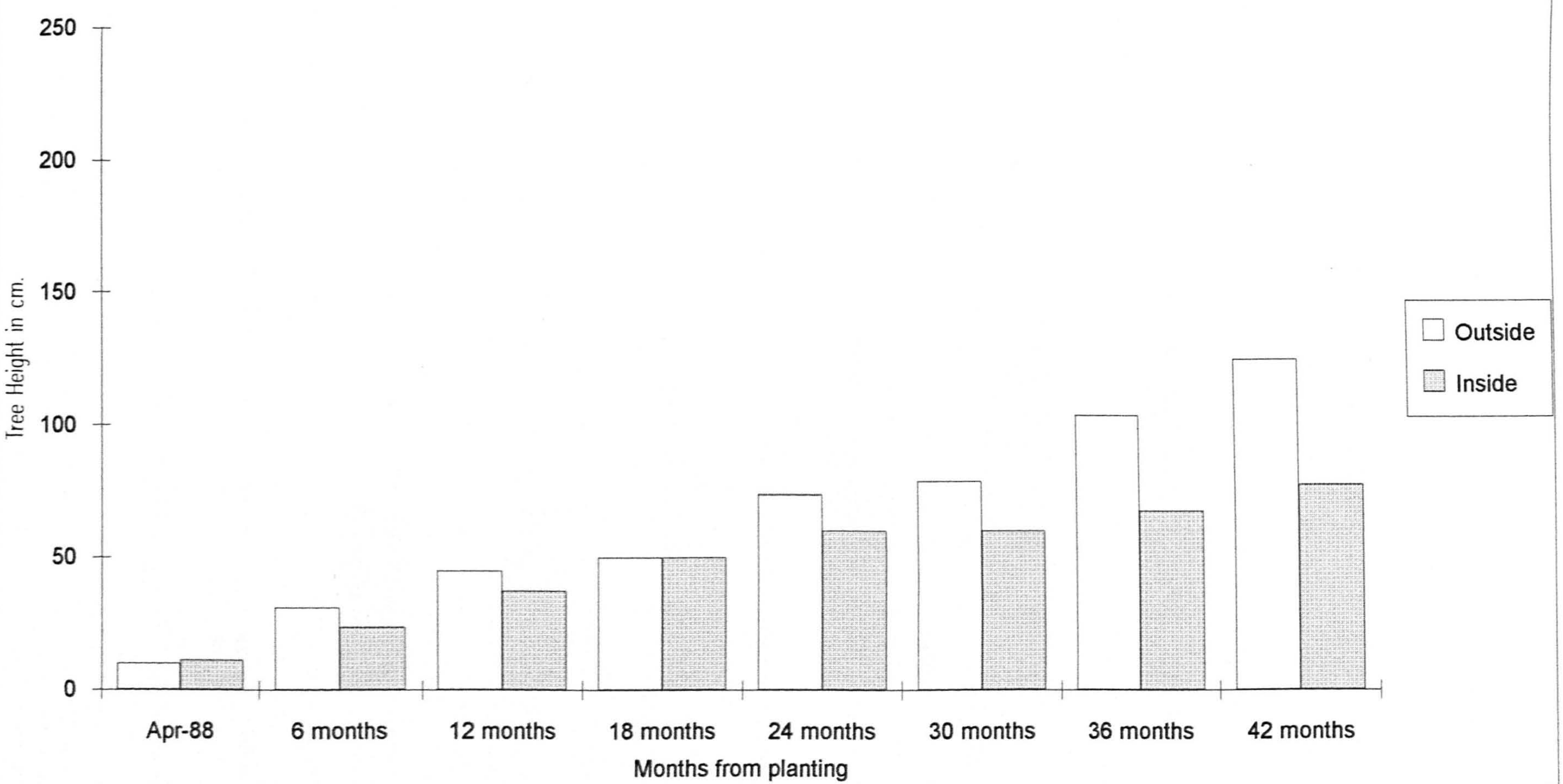


Fig. 20c1. Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Eucalypts Site 1 Block 1

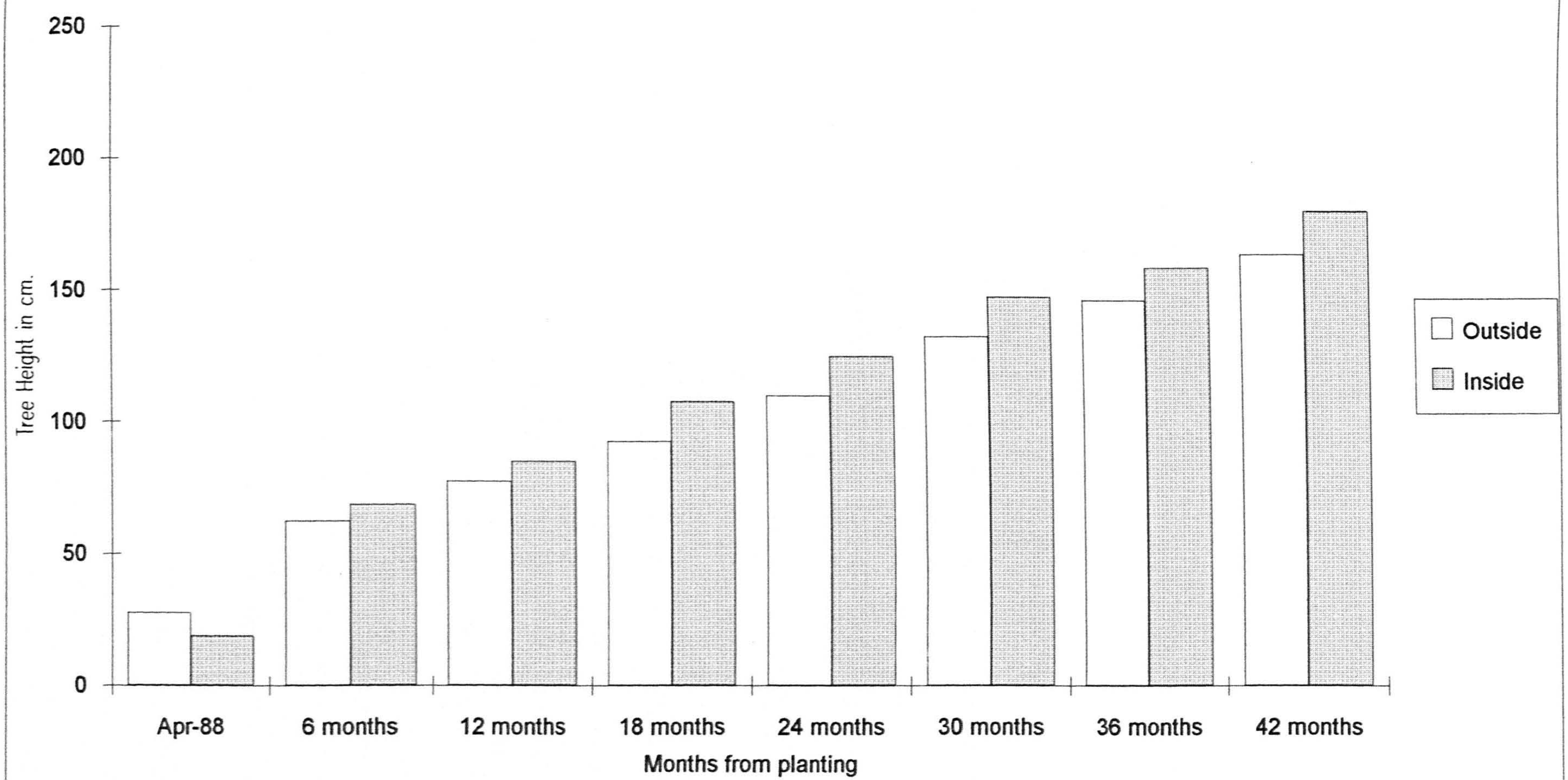


Fig. 20c2. Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Eucalypts Site 1 Block 4

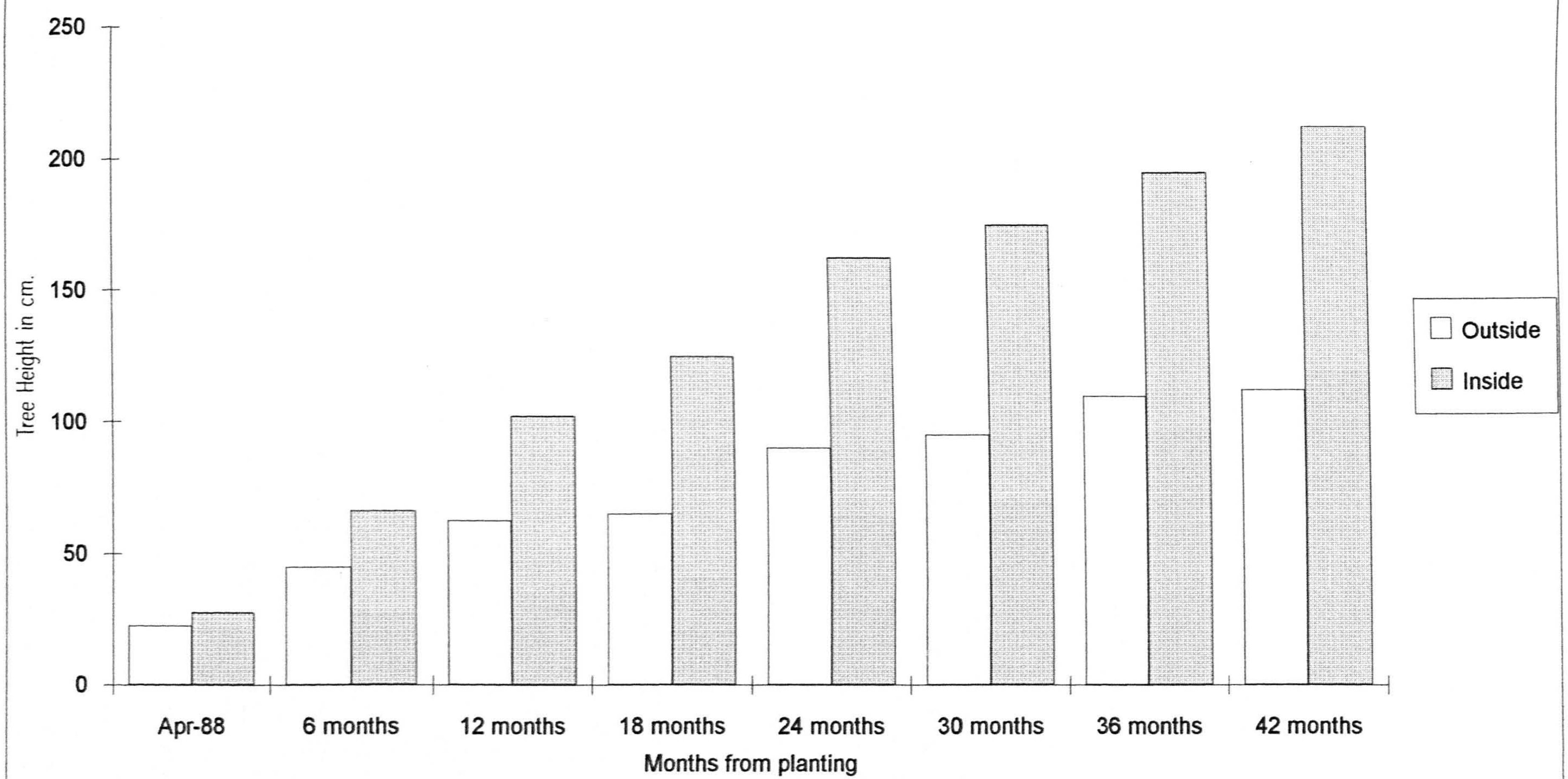


Fig.20d1. Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Eucalypts Site 2 Block 2

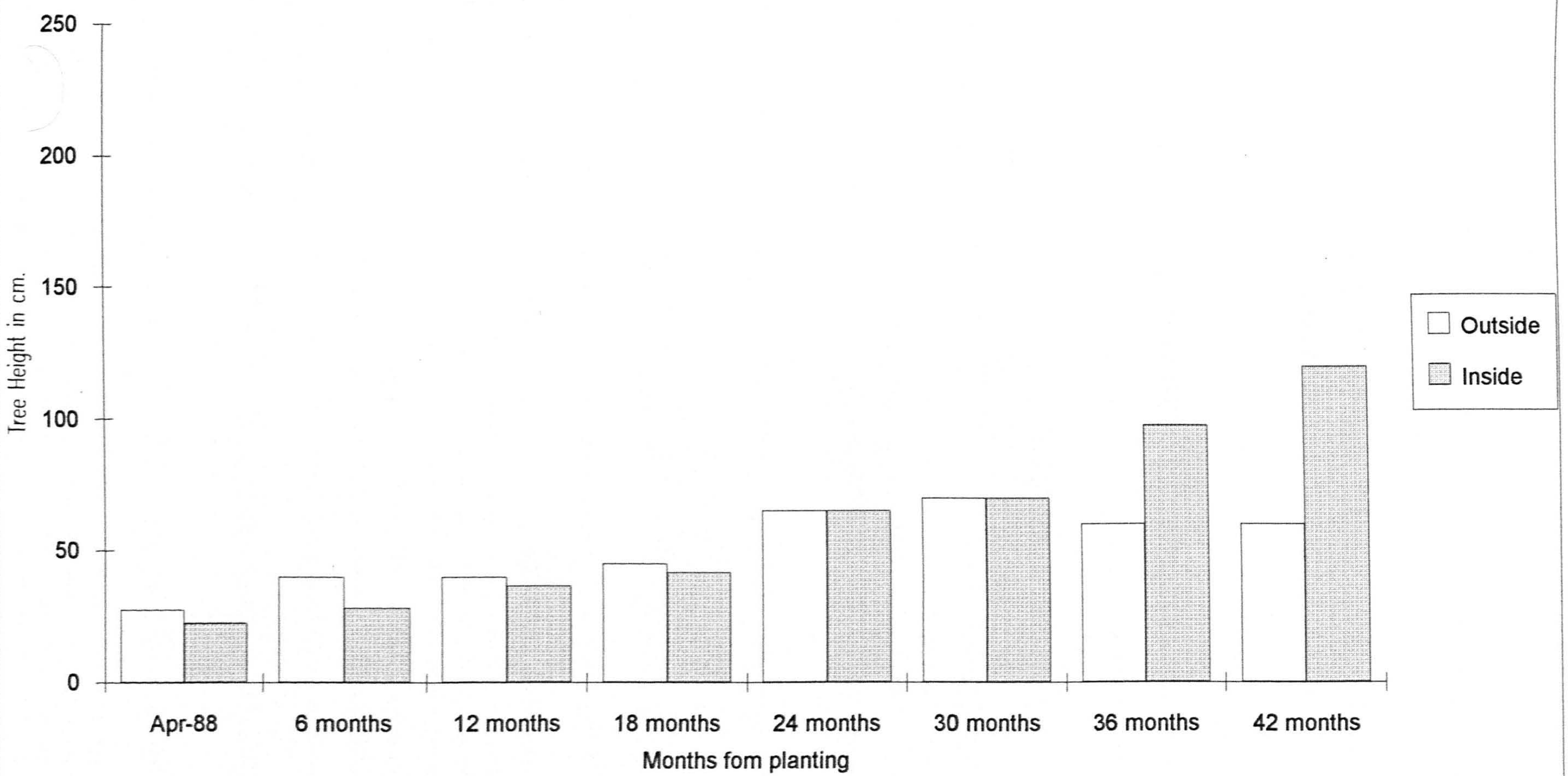
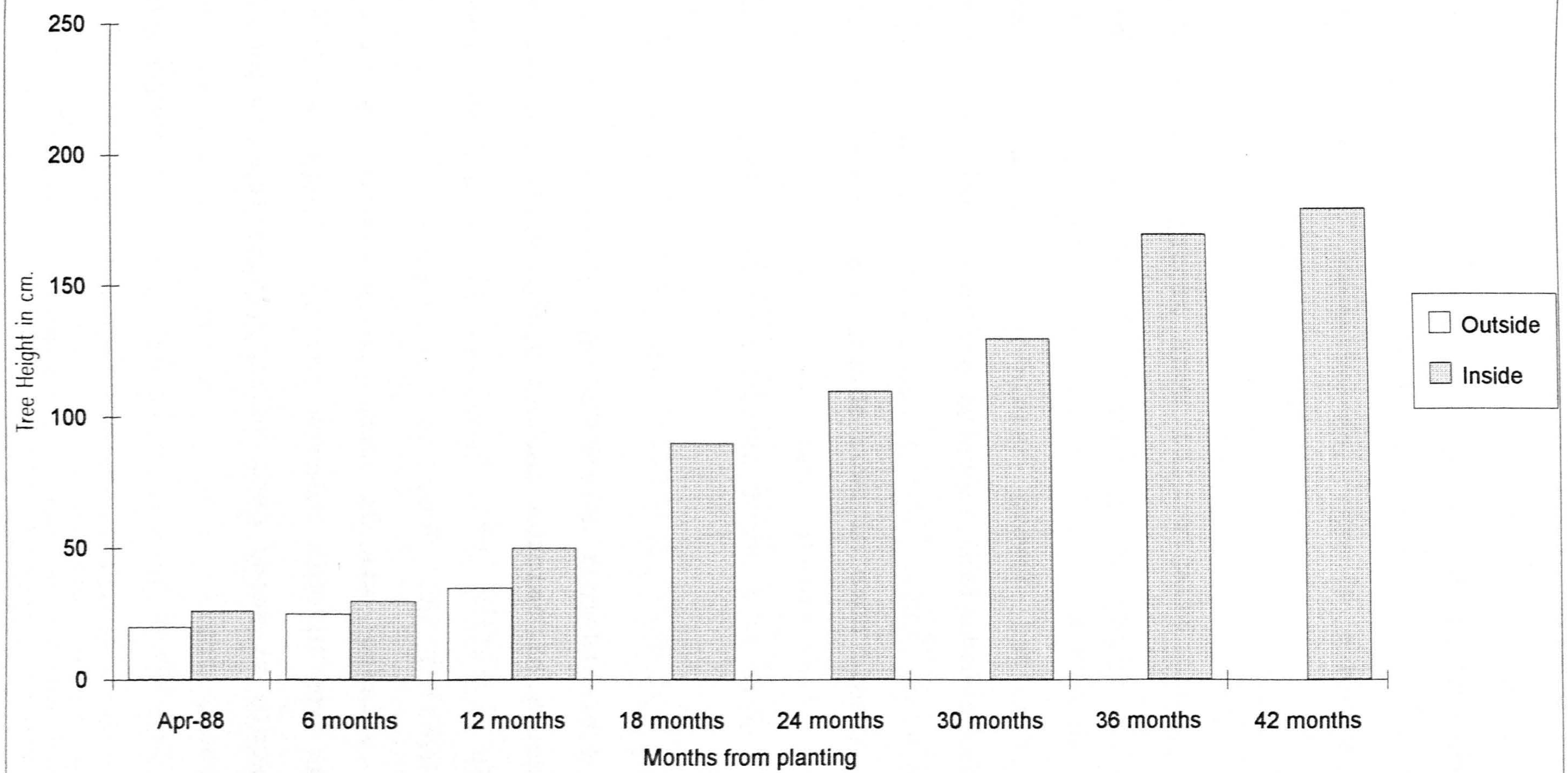


Fig.20d2. Comparison of Outside-Inside Rows. Mean Heights of Unirrigated Eucalypts Site 2 Block 4



acacias, Block 1 showed the same effect of greater growth in the inside row, but in Block 3 there was no significant difference between the rows. In this block, the inside row trees were quite small and one outside row tree grew exceptionally tall. Nevertheless, Figs.20 a,b,c and d show the general trend.

The inside rows (adjacent rows to irrigated trees) did consistently better than the outside rows (except for the aforementioned Block 3 at Site 2). Although not consistent in their summer/winter growth patterns (if there is lateral flow from the adjacent irrigated trees to the 'inside' rows one would expect the 'extra' growth to be greater in summer), all inside rows in each block, with the one exception, were taller than outside rows, until irrigation was withdrawn from Blocks 2 and 4 at Site 1 and 2 and 3 at Site 2.

At Site 1, when irrigation was withdrawn from Blocks 2 and 4, there was a marked effect on the acacias in Block 2, with growth falling off in the inside row, whilst in Block 3, where adjacent irrigation continued, the pattern of inside row growth exceeding that of the outside row continued. The acacias on the eastern side of the field (Block 2) were consistently taller than those in Block 3. This may be accounted for by a very slight gradient across the field.

The effect on the eucalypts at this site was not so marked. The same basic pattern of inside rows being taller than outside rows was quite clear, and there was a much larger height difference between the two rows in Block 4 than in Block 1. This again may possibly be accounted for by the very slight west-east gradient across the field. There was not the same falling off effect on the inside rows of Block 4 when irrigation was withdrawn from the adjacent block. The trees in this section continued to thrive and grow.

Soil depth may also have been a contributing cause of the falling off of growth in the unirrigated acacias. From Table 33 it can be seen that mean soil depth under unirrigated acacias at Site 1 was 25.6cm. whereas under the unirrigated eucalypts it was 33.1cm.

At Site 2, the pattern is less clear because of the greater number of deaths in the unirrigated rows. In Block 1 (acacias), adjacent irrigation continued and the inside/outside row effect was extremely marked. In Blocks 2 (eucalypts) and 3 (acacias) both with adjacent irrigation withdrawn, there did appear to be a falling off effect on the inside rows, but the number of deaths in these two sets of inside rows together with the freak growth of the aforementioned tree in the outside row of Block 3 combined to confuse the picture. In Block 4 (eucalypts), seven of the eight unirrigated trees died in the first two years.

The remaining tree, an inside row tree, certainly received some water laterally.

The two deaths of unirrigated trees at Site 1 to 1991 were in inside rows adjacent to rows from which irrigation had been withdrawn and it seems likely that this was a contributing cause of death. The greater number of deaths at Site 2 make it more difficult to attribute cause.

Overall, it was clear that the growth of the inside row trees exceeded that of the outside rows. It seems evident that these inside row trees had received water laterally.

5.16. Height Trends in the Different Water Classes.

In the graphs (Figs 21 a-h and 22 a-h) and Table 37, tree height is shown by replicate. Replicates 1 and 2 are at Site 1 and Replicates 3 and 4 at Site 2.

Table 37. Height Growth from Planting at April 1988 to October 1992. Regression Analysis.

		R^2	Linear Regression Equation
Acacia.			
No Water:			
Replicate	1:	0.199	y = 38.243 + 1.501x
	2:	0.404	y = 56.753 + 2.330x
	3:	0.564	y = 12.198 + 2.720x
	4:	0.694	y = 8.857 + 2.483x
10dS:			
Replicate	1:	0.409	y = 69.657 + 2.546x
	2:	0.466	y = 72.280 + 2.405x
	3:	0.541	y = 70.159 + 3.957x
	4:	0.636	y = 49.579 + 3.624x
5dS:			
Replicate	1:	0.376	y = 56.149 + 2.108x
	2:	0.346	y = 93.793 + 2.120x
	3:	0.727	y = 46.490 + 3.617x
	4:	0.711	y = 70.357 + 3.809x
<1dS:			
Replicate	1:	0.540	y = 58.508 + 2.895x
	2:	0.443	y = 74.845 + 2.871x
	3:	0.662	y = 18.221 + 2.631x
	4:	0.500	y = 60.765 + 2.901x
Eucalypts.			
No Water			
Replicate	1:	0.809	y = 41.834 + 2.982x
	2:	0.504	y = 34.051 + 2.969x
	3:	0.637	y = 15.563 + 2.240x
	4:	0.906	y = 17.253 + 3.809x
10dS:			
Replicate	1:	0.729	y = 63.237 + 4.467x
	2:	0.884	y = 44.024 + 4.459x
	3:	0.758	y = 39.103 + 4.738x
	4:	0.849	y = 23.477 + 5.990x
5dS:			
Replicate	1:	0.901	y = 74.584 + 5.217x
	2:	0.840	y = 59.841 + 4.038x
	3:	0.859	y = 20.584 + 6.599x
	4:	0.904	y = 20.152 + 6.899x
<1dS:			
Replicate	1:	0.751	y = 58.977 + 4.971x
	2:	0.763	y = 56.330 + 4.105x
	3:	0.746	y = 28.467 + 4.967x
	4:	0.800	y = 22.864 + 5.491x

The slope of the regression lines are less for the unirrigated trees than for any of the irrigated classes. Differences are further examined below.

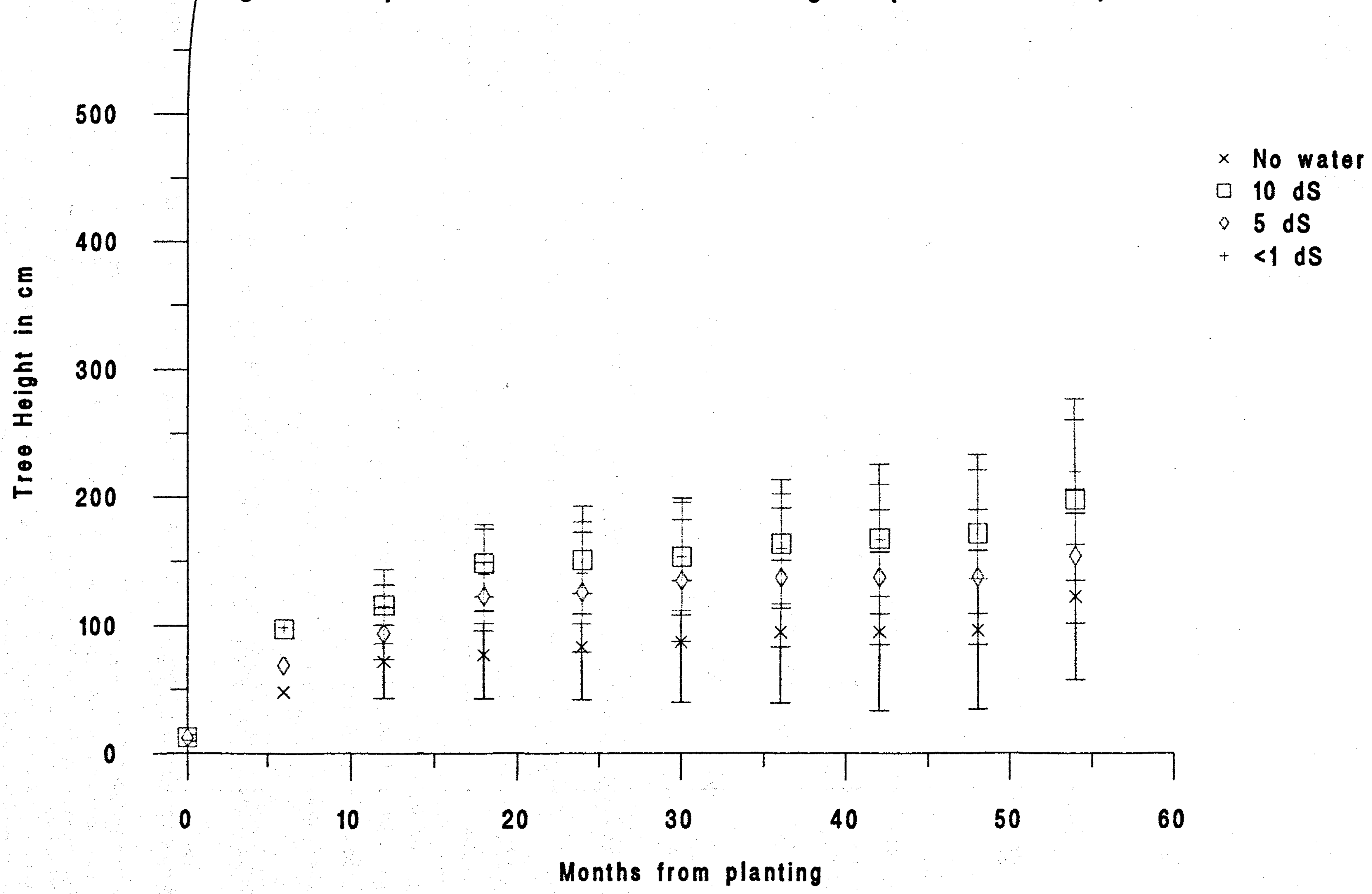
Acacias.

Figs.21 a,b,c,d show the mean heights of the trees in the four water classes with error bars showing standard deviations. The error, as would be expected, increases with growth. There is considerable overlapping between the irrigated classes. The unirrigated trees overlap with the other classes, but are always in the lowest range. The error grows with the height of the trees, as would be expected, but there is no substantial difference in the magnitude of variation between treatments.

In Replicates 1 and 2 (Site 1), the overlapping is quite tight and the errors small. Replicate 3 (Site 2) shows the 10dS trees to be the tallest, and have the largest error. In Replicate 4, also at Site 2,the errors at the higher levels again overlap, but the errors are larger than in Replicates 1 and 2.

In Figs.22 a,b,c and d, the trees are shown individually with linear regression lines. The lines are not a very good fit, particularly in the predicted starting heights. In reality, there were no significant differences between the classes at the starting date and growth was initially non-linear, whereas the figures given by these regressions show very large differences. However they do again demonstrate in almost all cases that the unirrigated trees have not achieved the growth of the three irrigated classes. In each acacia replicate, there is one very tall

Fig.21a. Replicate 1. Acacia Mean Heights (Error Bars +/- 1 Std. Deviation)



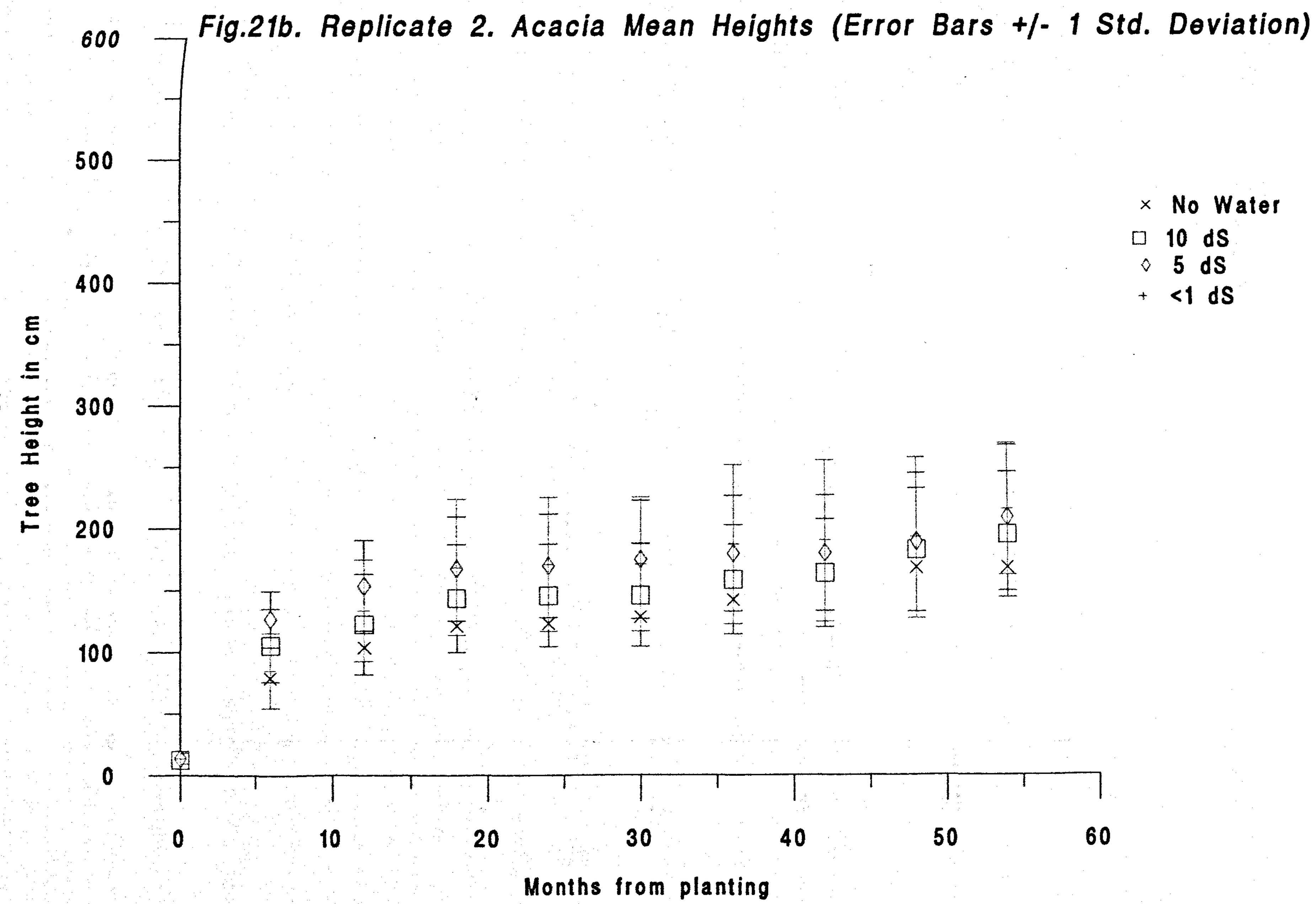


Fig.21b. Replicate 2. Acacia Mean Heights (Error Bars +/- 1 Std. Deviation)
Tree Height in cm
600
500
400
300
200
100
0
10
20
30
40
50
60
Months from planting
No Water
10 dS
5 dS
<1 dS

Fig.21c. Repicate 3. Acacia Mean Heights (Error Bars +/- 1 Std. Deviation)

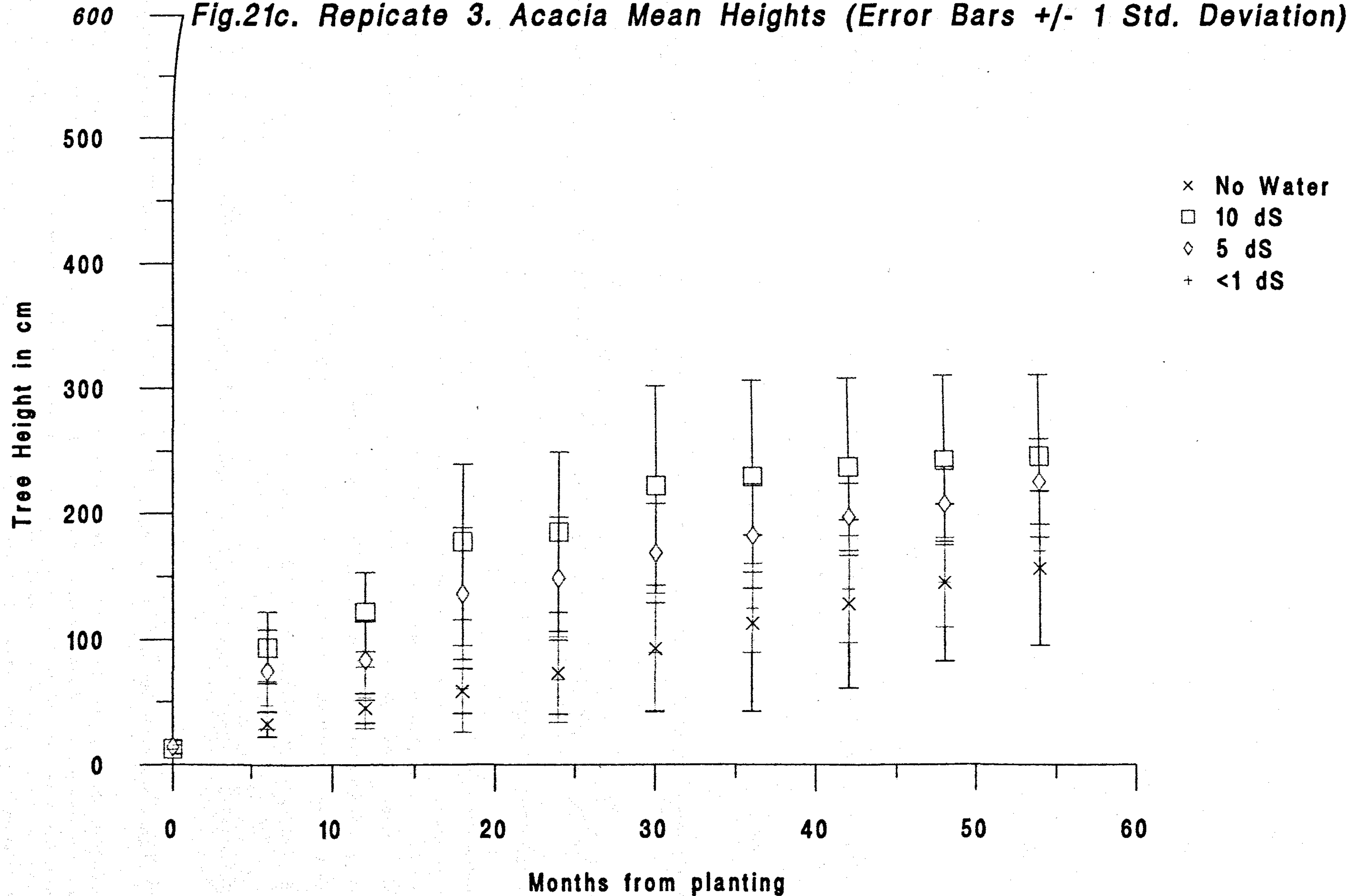
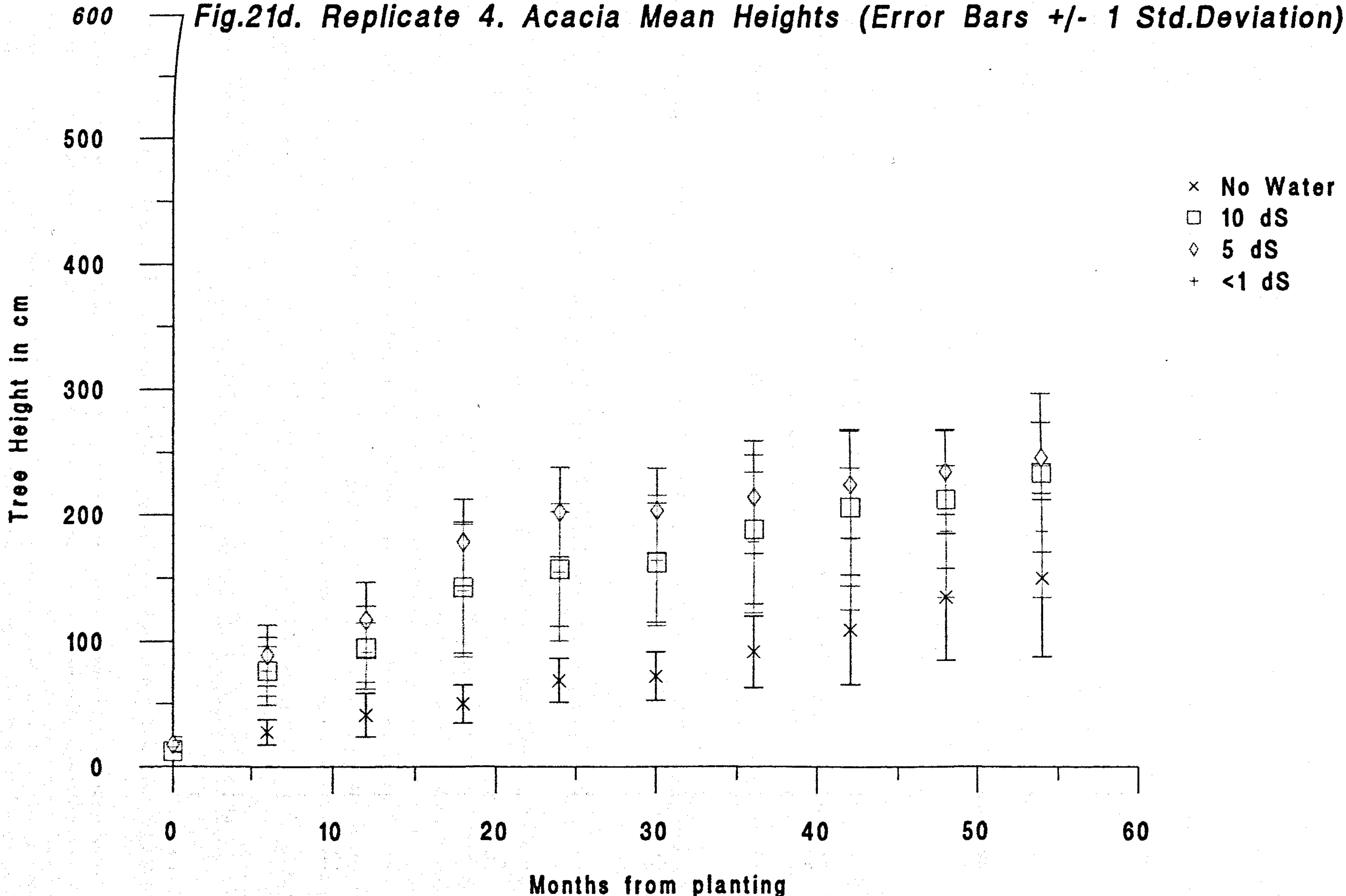


Fig.21d. Replicate 4. Acacia Mean Heights (Error Bars +/- 1 Std.Deviation)



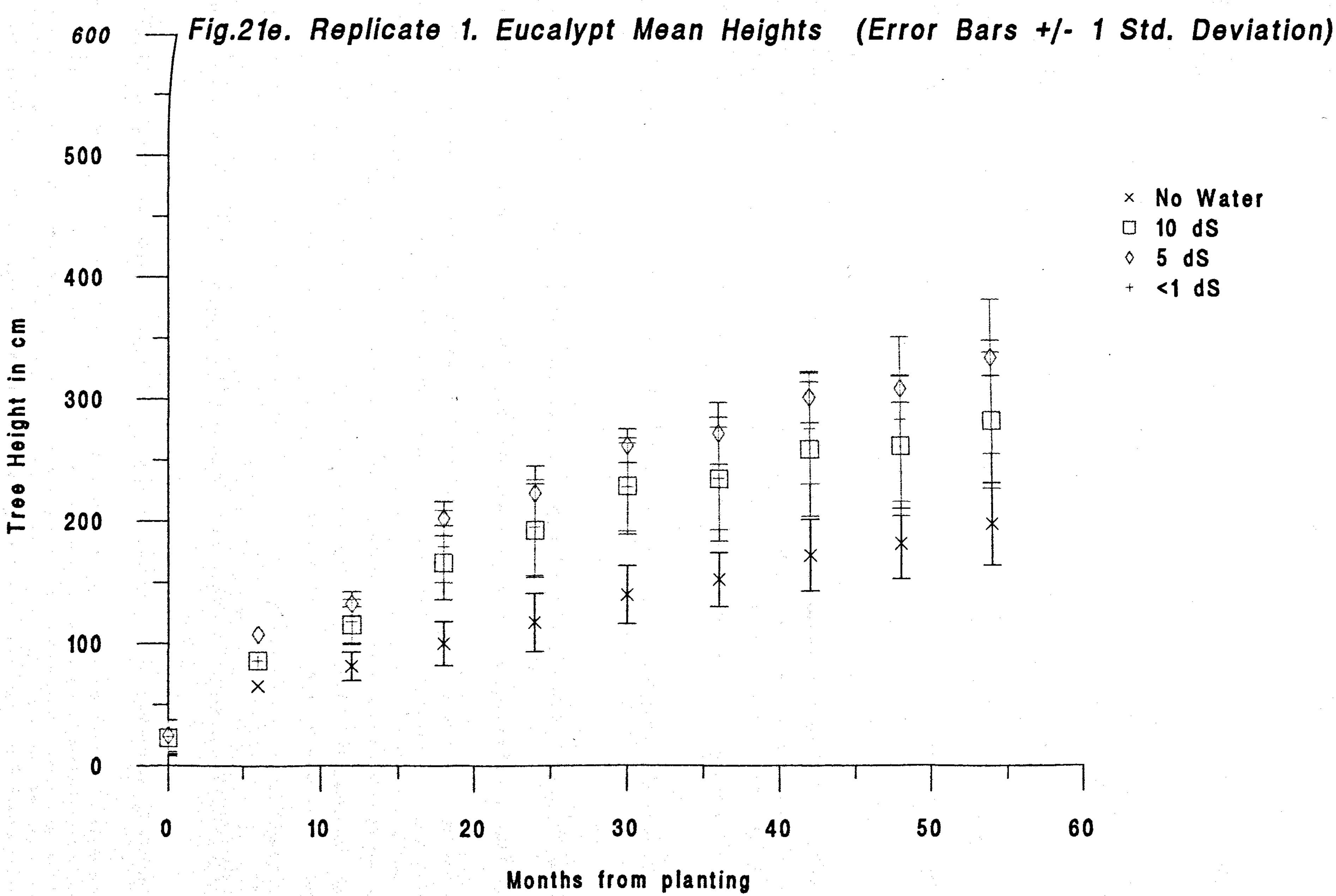
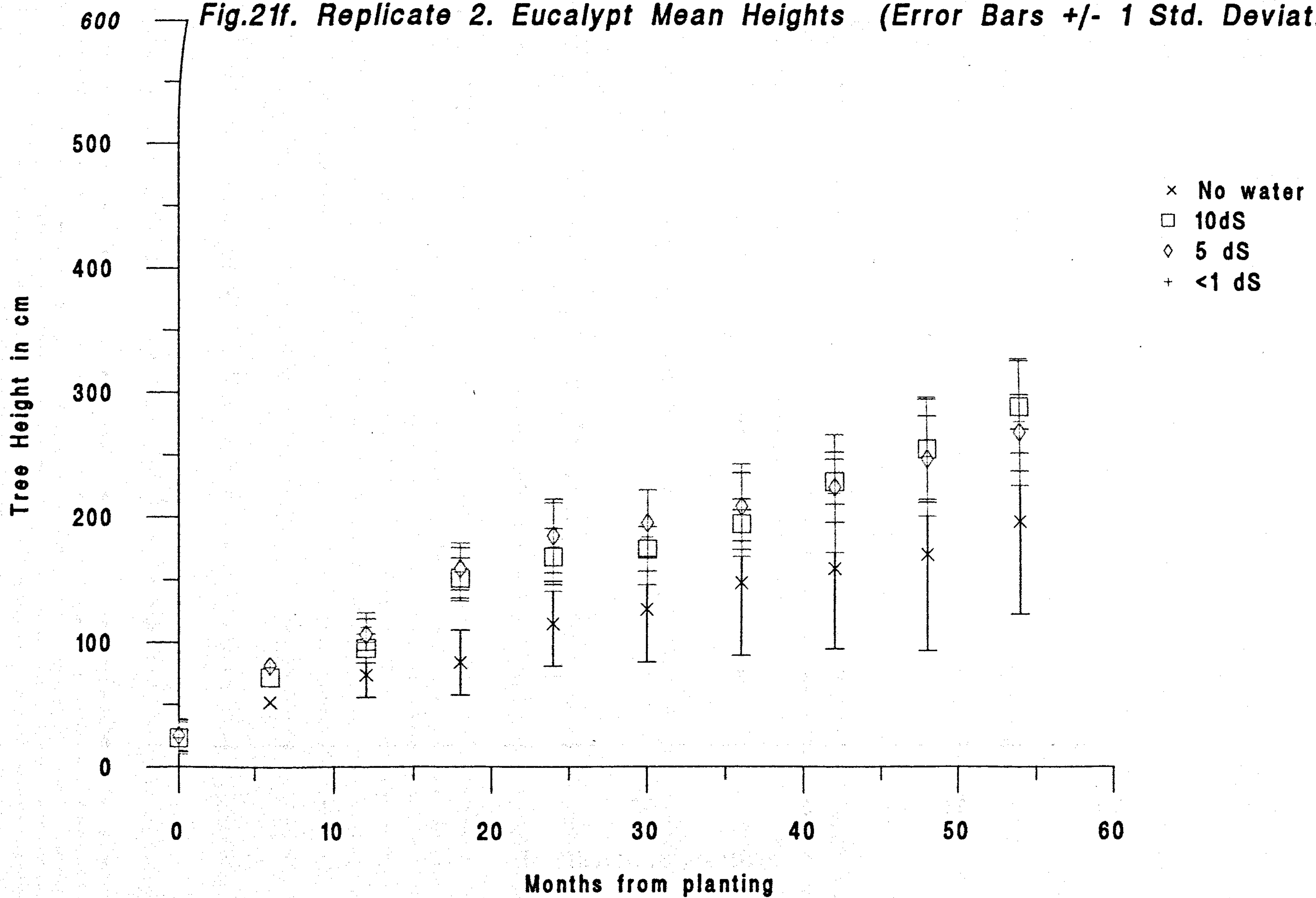


Fig.21e. Replicate 1. Eucalypt Mean Heights (Error Bars +/- 1 Std. Deviation)
Tree Height in cm
600
500
400
300
200
100
0
0
10
20
30
40
50
60
Months from planting
× No Water
□ 10 dS
◊ 5 dS
+ <1 dS

Fig.21f. Replicate 2. Eucalypt Mean Heights (Error Bars +/- 1 Std. Deviation)



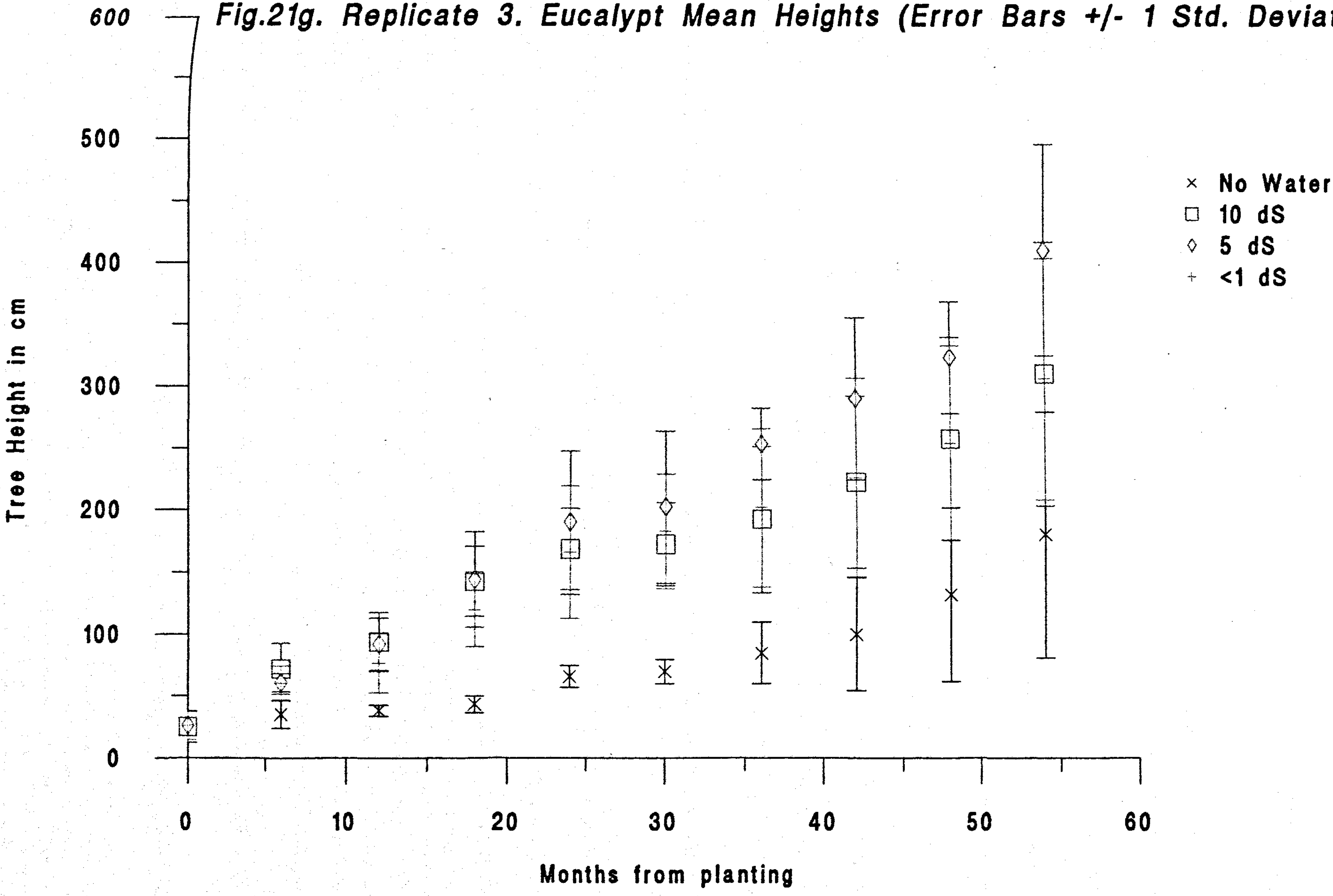


Fig.21g. Replicate 3. Eucalypt Mean Heights (Error Bars +/- 1 Std. Deviation)

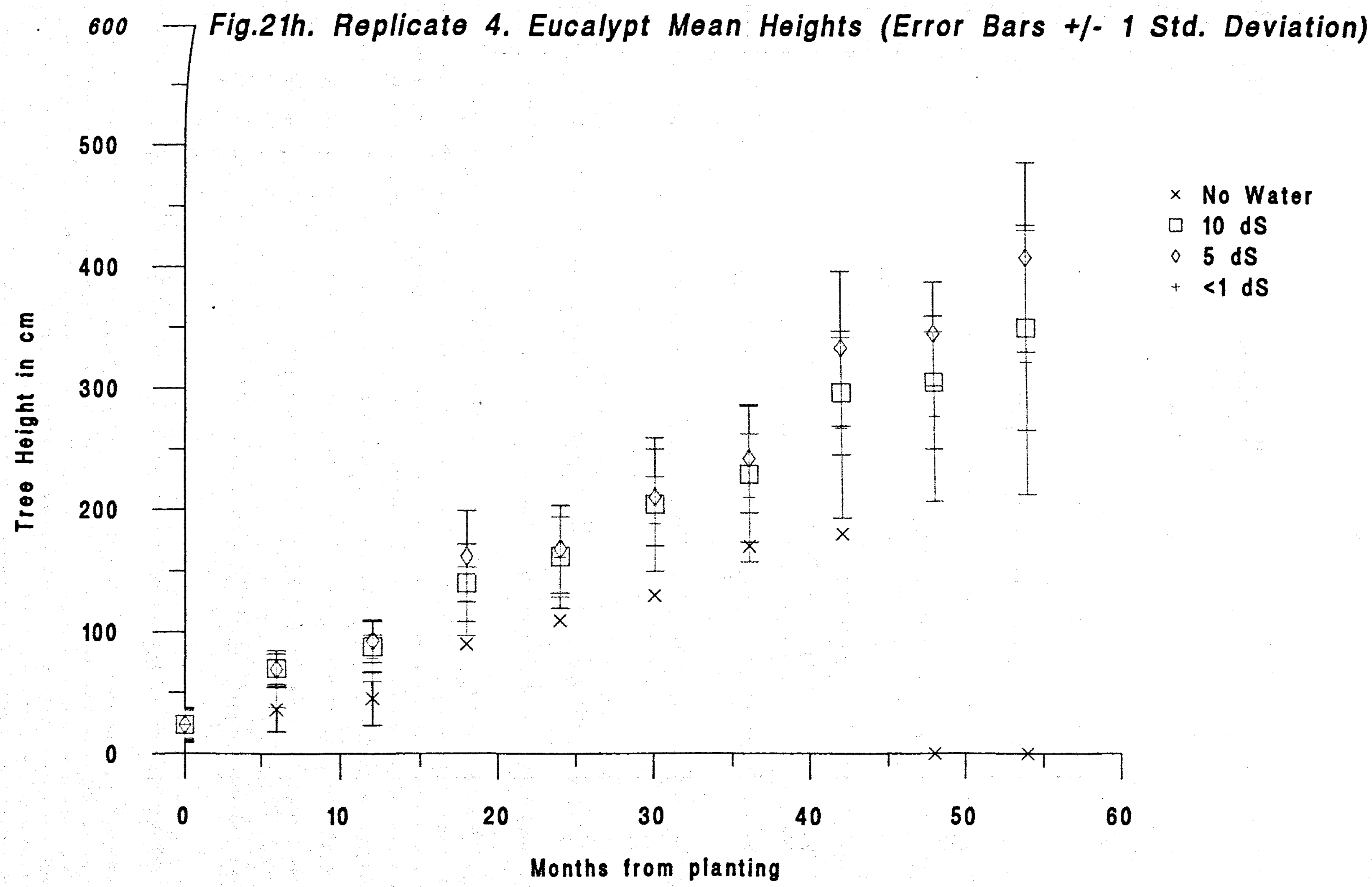


Fig.21h. Replicate 4. Eucalypt Mean Heights (Error Bars +/- 1 Std. Deviation)
Tree Height in cm
600
500
400
300
200
100
0
0
10
20
30
40
50
60
Months from planting
No Water
10 dS
5 dS
<1 dS

Fig.22a. Replicate 1. Individual Acacia Height Growth to 1992 with Regression Lines in all Irrigation Classes

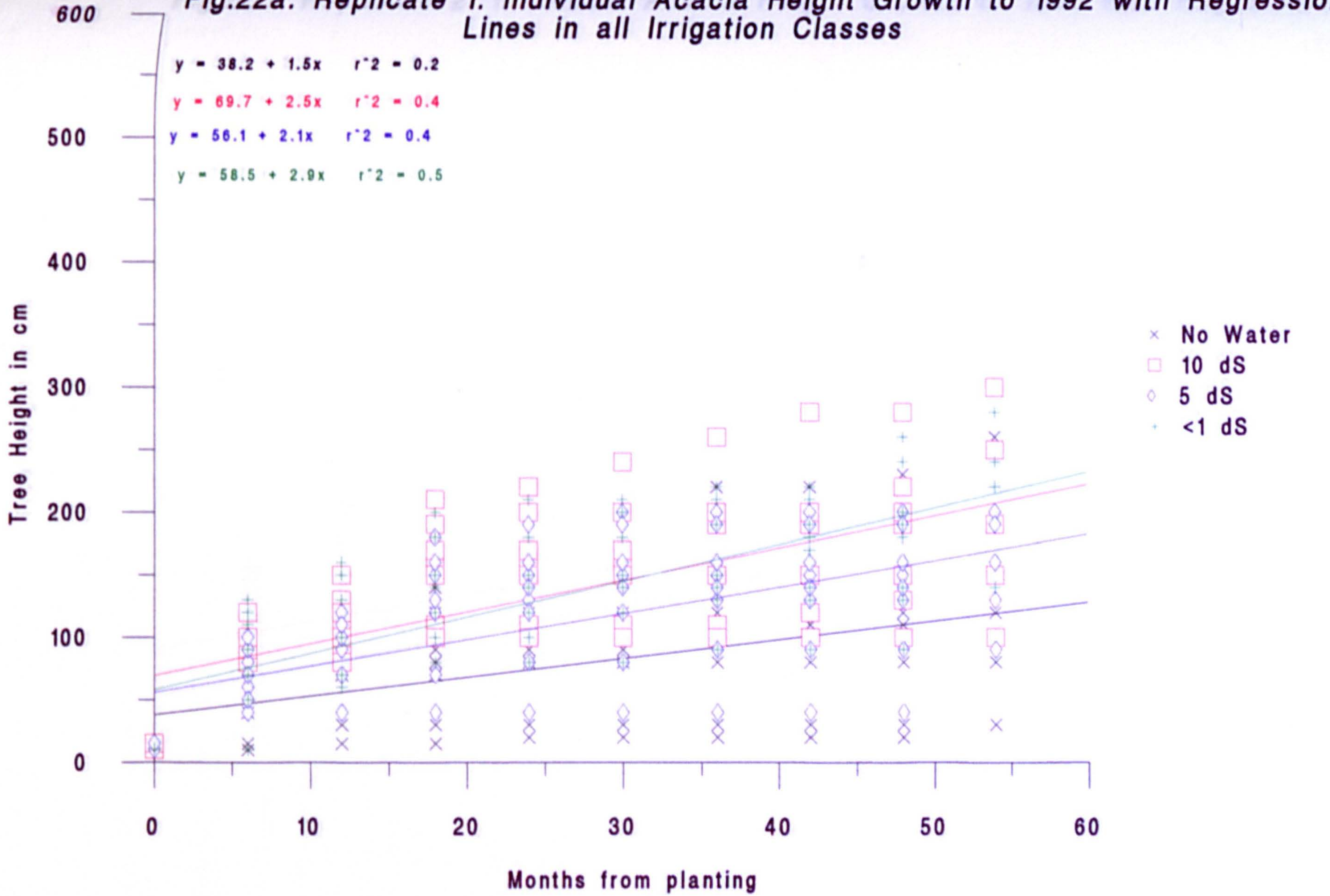


Fig.22b. Replicate 2. Individual Acacia Height Growth to 1992 with Regression Lines in all Irrigation Classes

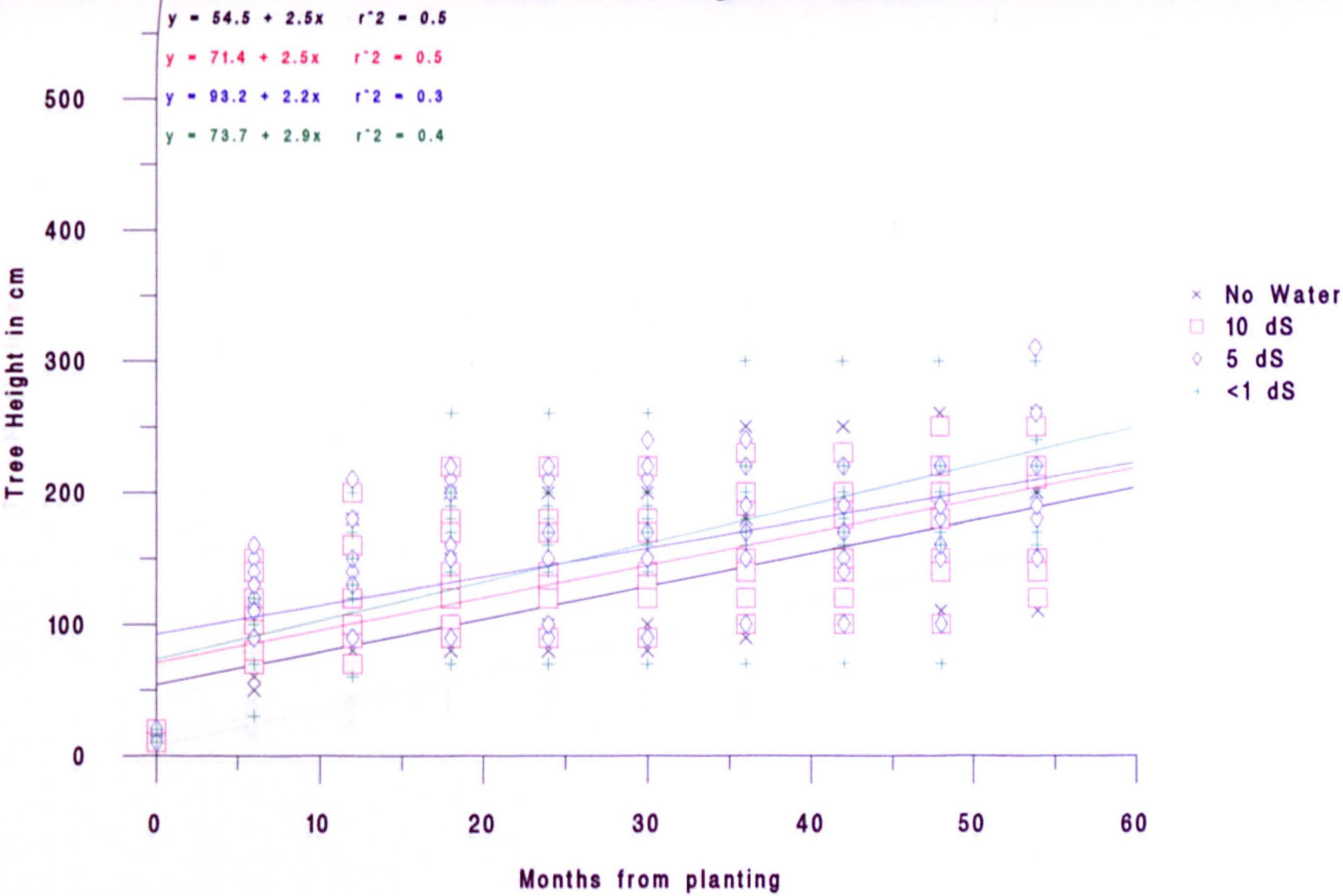


Fig.22c. Replicate 3. Individual Acacia Height Growth to 1992 with Regression Lines in all Irrigation Classes

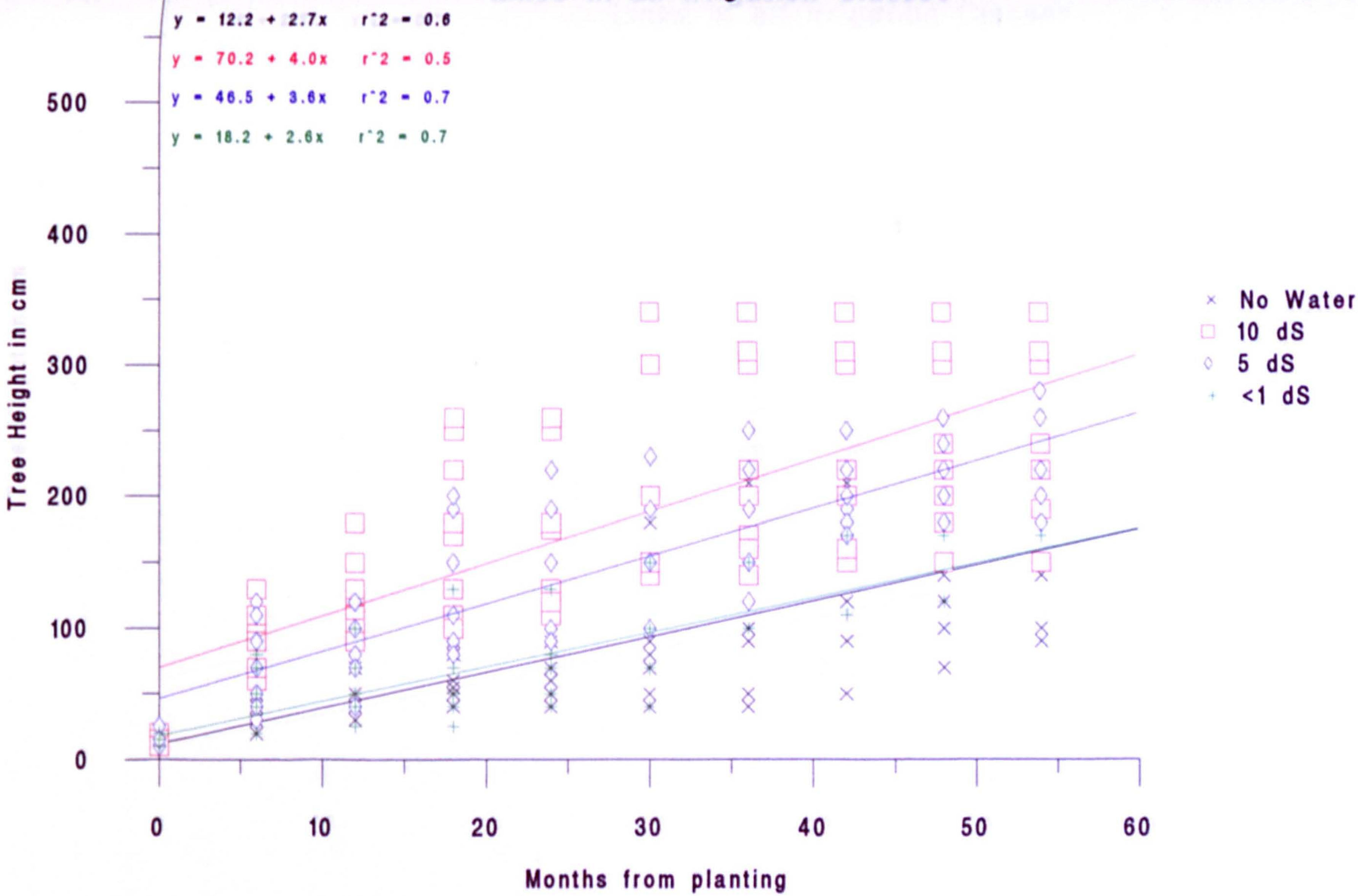


Fig.22d. Replicate 4. Individual Acacia Height Growth to 1992 with Regression Lines in all Irrigation Classes

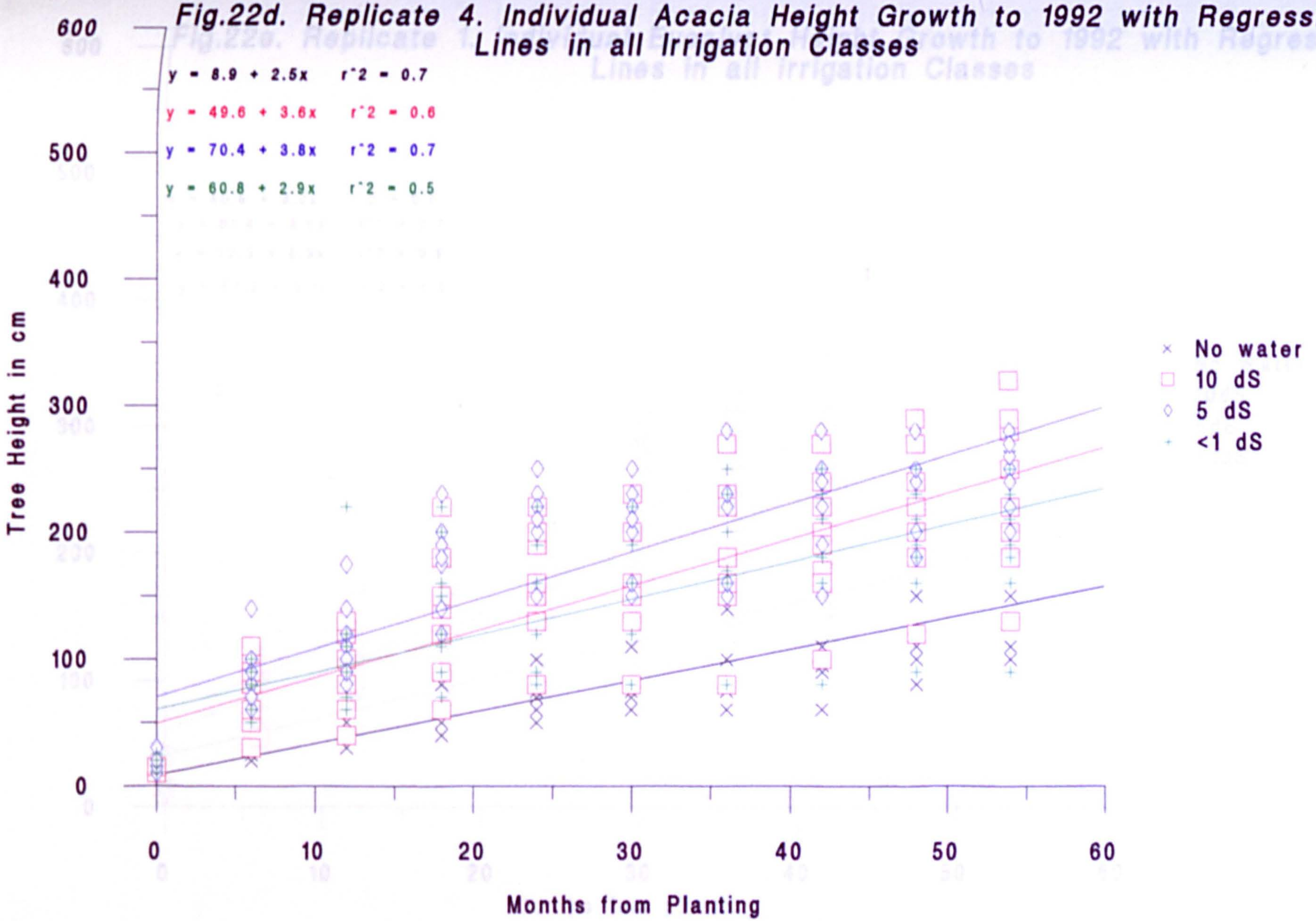


Fig.22e. Replicate 1. Individual Eucalypt Height Growth to 1992 with Regression Lines in all Irrigation Classes

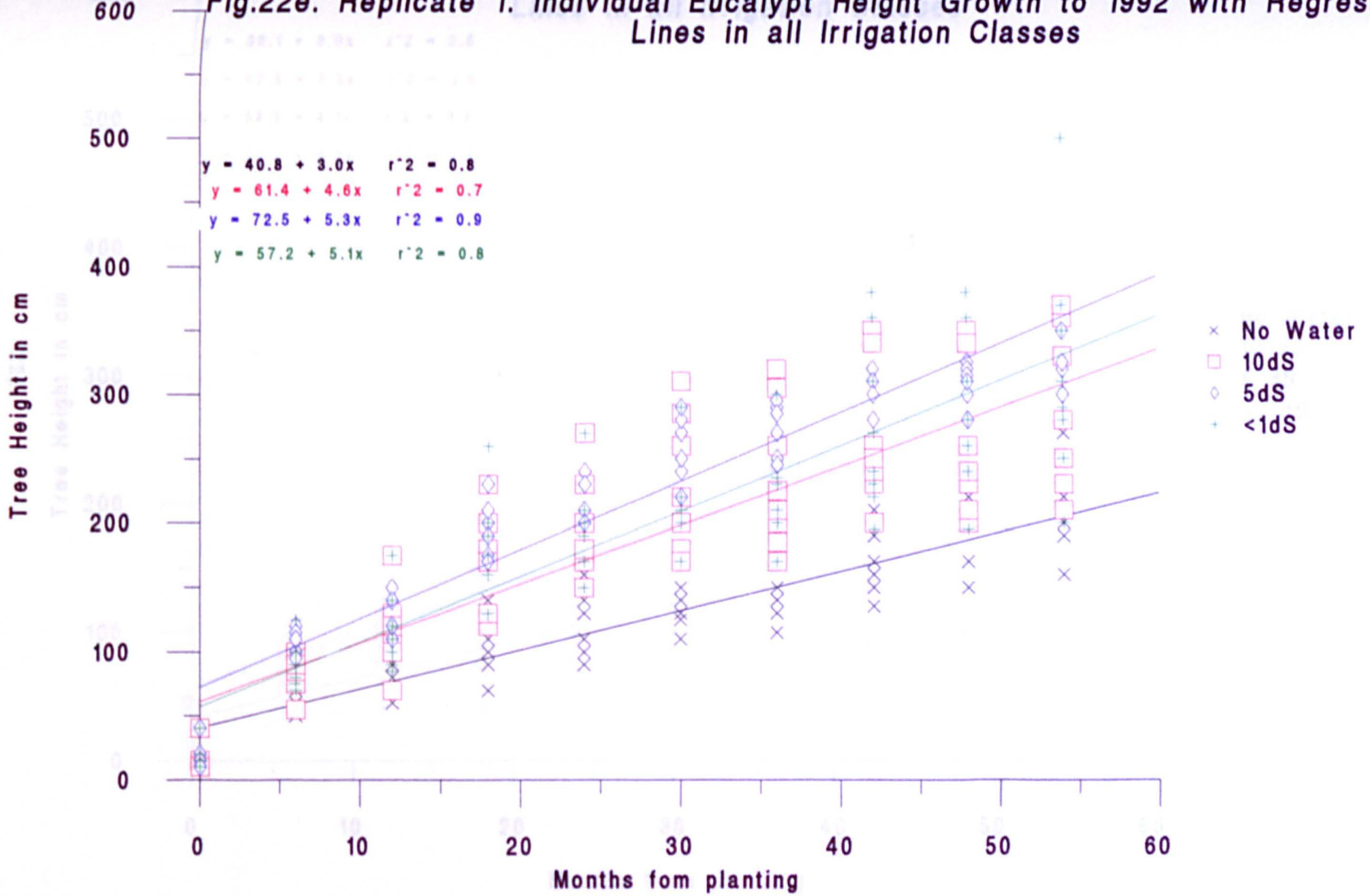


Fig.22f. Replicate 2. Individual Eucalypt Height Growth to 1992 with Regression Lines in all Irrigation Classes

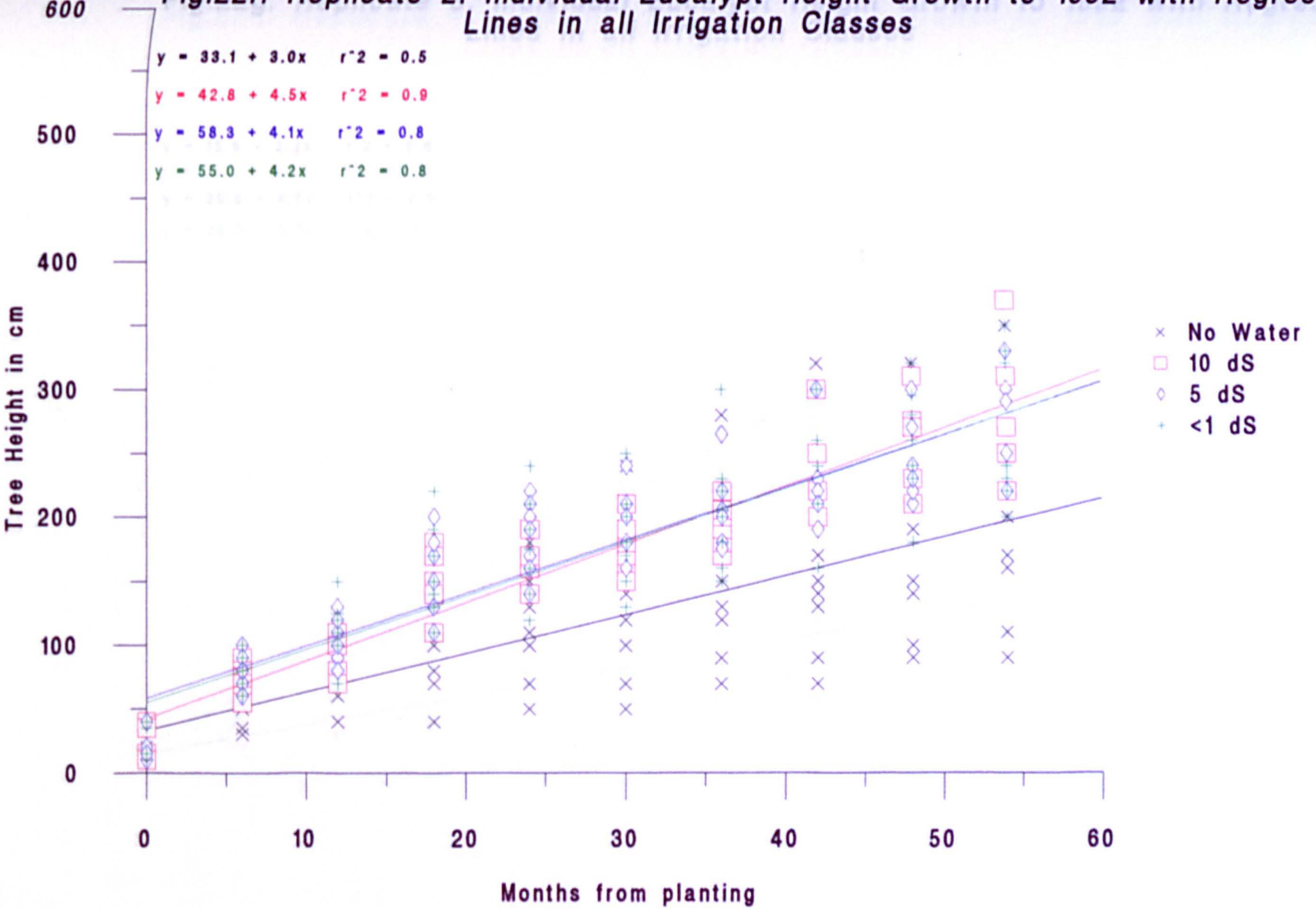


Fig.22g. Replicate 3. Individual Eucalypt Height Growth to 1992 with Regression Lines in all Irrigation Classes

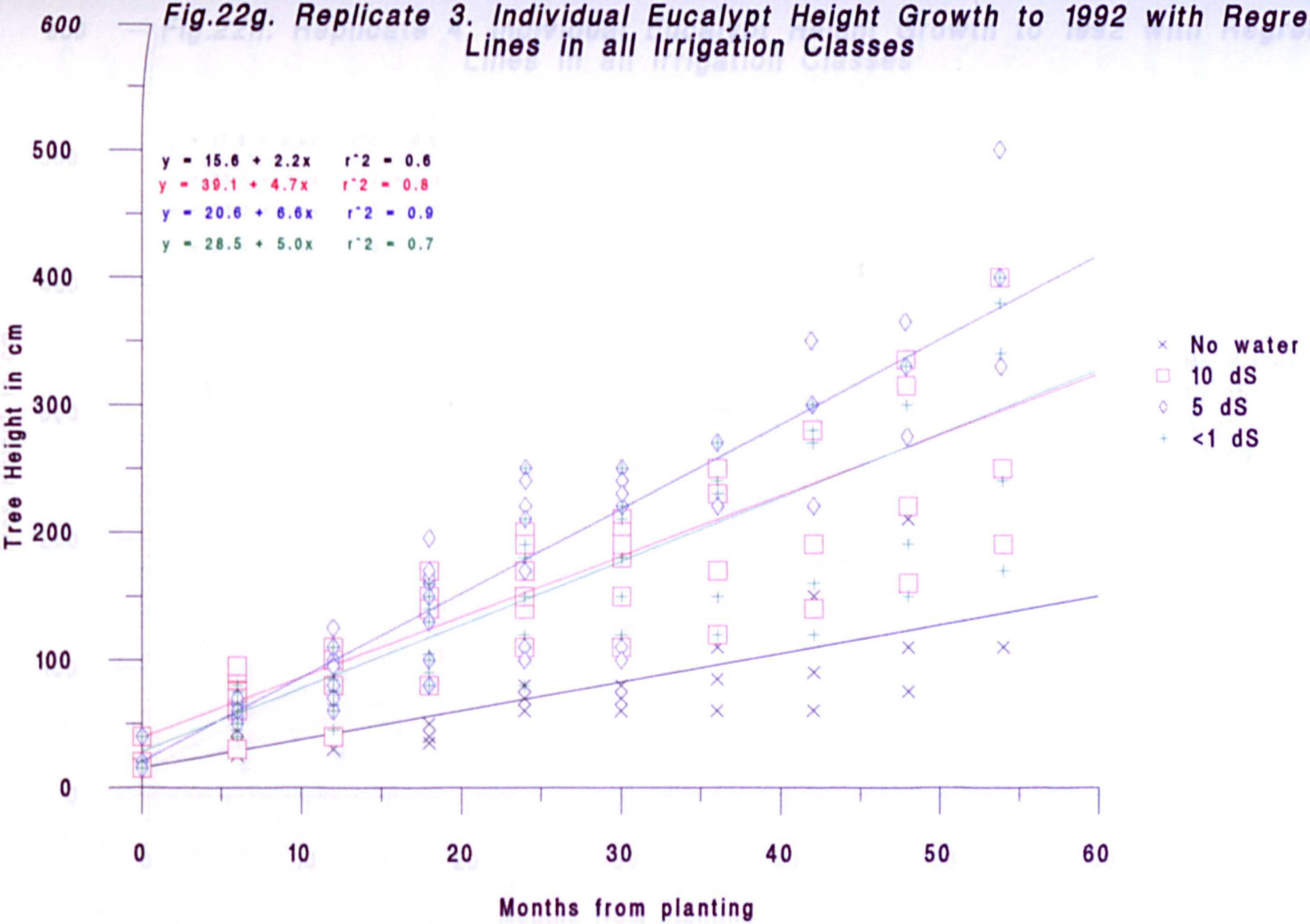
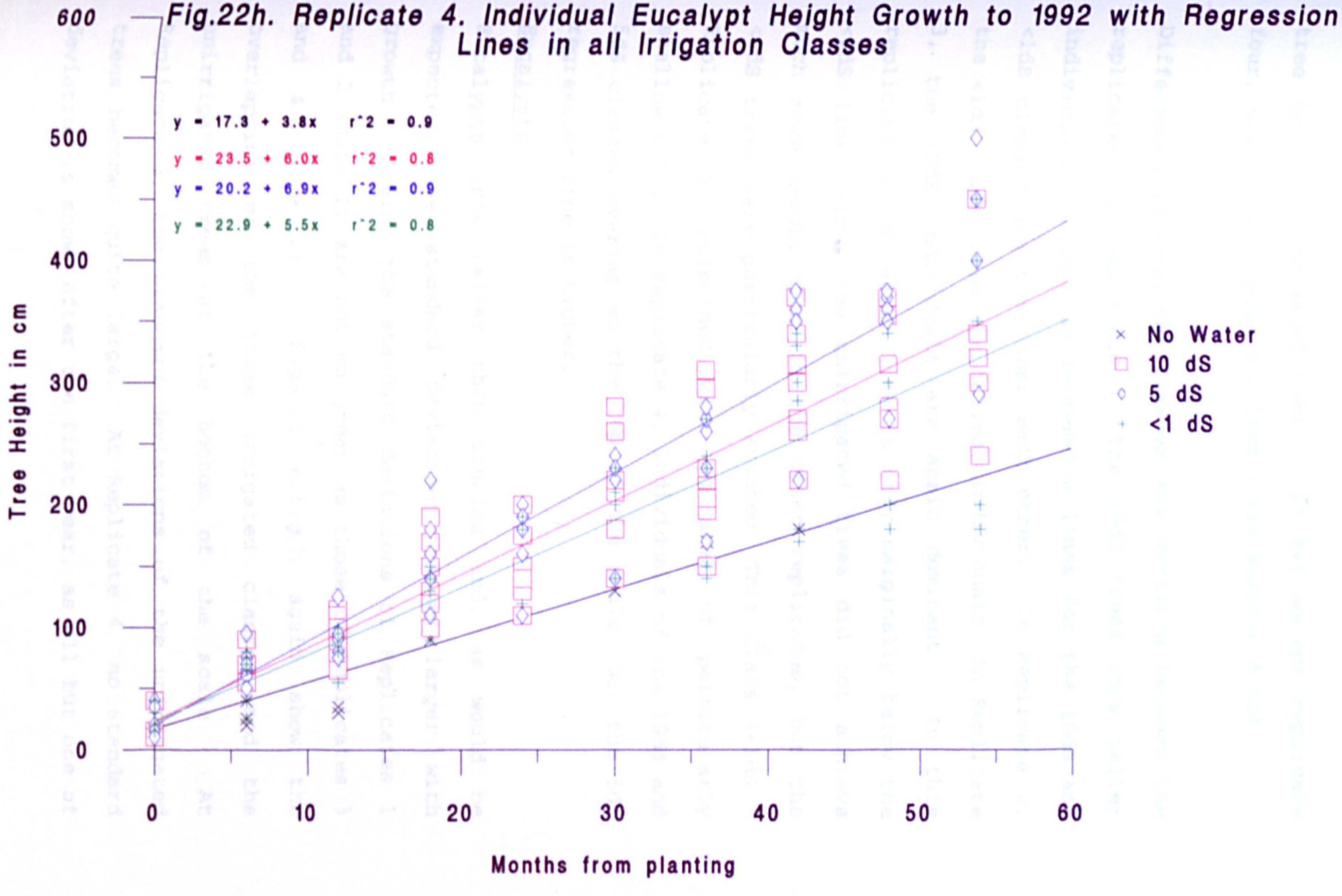


Fig.22h. Replicate 4. Individual Eucalypt Height Growth to 1992 with Regression Lines in all Irrigation Classes



tree in the unirrigated class. In all except replicate four, this is an inside row tree (see Section 5.15).

Differences between the classes are variable between the replicates. In Replicate 1, the 10dS trees show taller individuals, though the regression lines for the 10ds and <1dS classes are very near each other. In Replicate 2, the <1dS class shows the tallest individuals. In Replicate 3, the 10dS individuals are again dominant. In this replicate the No Water line is only marginally below the <1dS line. Here, the unirrigated trees did not achieve much more height than in the other replicates, but the <1dS trees were particularly stunted. This class (<1dS - Replicate 3) coincided with an area of particularly shallow soil. In Replicate 4, individuals of the 10dS and 5dS classes overlap at the top of the scale, but the 5dS regression line is higher.

<u>Eucalypts.</u>

Eucalypts grow taller than acacias and, as would be expected, the standard deviations become larger with growth. Again, the standard deviations of Replicates 1 and 2 (Site 1) are not so great as those of Replicates 3 and 4 (Site 2). Figs.21 e,f,g,h again show the overlapping of the three irrigated classes and the unirrigated trees at the bottom of the scale. At Replicate 3, the standard deviations of the unirrigated trees becomes quite large. At Replicate 4, no standard deviation is shown after the first year, as all but one of the trees in this class had died. After October 1991, there were no trees at all of this class in Replicate 4. As with the acacias, there is no substantial difference between the irrigated classes.

When the individual trees are shown with regression lines (Figs.22e,f,g,h) the lower growth of the unirrigated trees is again evident, as is the similarity of the three irrigated classes. Again, the regression lines are not a particularly good fit, especially at the starting date where again, the predicted starting height varies widely when in fact, it did not. As with the acacias, initial growth was non-linear.

Replicate 1 (Site 1) shows the 5dS class as being the tallest, with the <1dS and 10dS slightly below, although the tallest single individuals are in the <1dS class. The regression lines for the three irrigated classes at Replicate 2 are almost indistinguishable and tall individuals are apparent in all classes. In the unirrigated class of this replicate, there is one very tall individual, an inside row tree (Section 5.15). At Replicate 3, 5dS trees have the highest individuals and the highest regression line, with the 10dS and <1dS lines running below on almost the same line. The regression lines of Replicate 4 are similar to Replicate 1, with the 5dS trees having the higher line, but here the positions of the 10dS and <1dS lines are reversed. There are tall individuals in all classes.

5.17. Height Growth to October 1995.

At October 1995, height and diameter of all trees was again measured. The resulting data showed that previous growth trends continued to operate (Table 38).

Table 38. Acacia and Eucalypt Mean Heights. Sites 1 and 2. 2 year and 4 year irrigation. October 1992 and October 1995. Height and (standard deviations) in cm.

	Oct92		Oct95	
Site 1 Acacia	Height	N	Height	N
No water	150 (73.5)	10	162 (80.9)	10
4 yr:dS10	198 (79.2)	5	212 (74.6)	5
2 yr:dS10	195 (51.0)	8	202.5 (54.7)	8
4 yr:dS5	154 (45.0)	5	172 (39.6)	5
2 yr:dS5	209 (59.3)	7	232.8 (56.8)	7
4 yr:dS<1	220 (51.0)	5	228 (36.3)	5
2 yr:ds<1	216 (53.5)	7	252 (84.7)	5
Site 2 Acacia				
No water	153 (59.3)	12	177.5 (63.4)	12
4 yr:dS10	246 (65.0)	8	280 (71.9)	8
2 yr:dS10	234 (63.2)	8	251.2 (72.6)	8
4 yr:dS5	226 (34.1)	7	261.4 (51.8)	7
2 yr:dS5	246 (28.2)	7	270 (35.1)	7
4 yr:dS<1	170 (.000)	1	180 (.000)	1
2 yr:dS<1	187 (52.5)	7	232.8 (63.9)	7

Site 1 Eucalypts				
No water	197 (63.7)	16	256.9 (97.7)	16
4 yr:dS10	282 (63.0)	8	348.7 (129.2)	8
2 yr:dS10	288 (53.1)	6	355 (70.3)	6
4 yr:dS5	334 (19.0)	8	422.5 (16.7)	8
2 yr:dS5	267 (35.7)	8	365 (48.1)	8
4 yr:dS<1	319 (90.8)	8	336.2 (99.6)	8
2 yr:dS<1	276 (59.3)	8	372.5 (66.7)	8
Site 2 Eucalypts				
No water	180 (99.0)	2	365 (120.2)	2
4 yr:dS10	350 (84.4)	6	416.7 (127.8)	6
2 yr:dS10	310 (106.8)	4	457.5 (172.9)	4
4 yr:dS5	408 (77.9)	5	482 (120.1)	5
2 yr:dS5	410 (85.4)	3	533.3 (76.4)	3
4 yr:dS<1	322 (108.7)	6	418.3 (154.9)	6
2 yr:dS<1	306 (97.9)	5	418 (107.8)	5

5.17.i. Variability in Height Growth in 1992 and 1995.

As Table 38 shows, the trees continued to grow at a steady rate from 1992 to 1995. In most cases, standard deviations tended to increase with increasing growth, as would be expected. In some groups especially where a number of trees had died or been cut down, standard deviations were reduced. The trees had not added height at the expense of girth.

Table 39. Correlation of Height and Diameter of all Trees. 1988 -1995.

		N	df.	P	
October 1988:	.8044	250	248	<.001	
October 1989:	.8382	239	237	<.001	
October 1990:	.8828	230	228	<.001	
October 1991:	.9317	264	262	<.001	(inc 1991 trees)
October 1992:	.8862	242	240	<.001	
October 1995:	.8620	236	234	<.001	

Height and diameter continued to be very strongly correlated.

5.17.ii. Irrigation Duration Effects.

To see whether any effects of the two or four year irrigation had persisted, Mann-Whitney U tests were again performed on all irrigated groups by site and water quality class. The only significant difference in tree height in relation to irrigation duration was in the 5dS eucalypts at Site 1 where the four year irrigated trees were significantly taller than those which had two years irrigation, as they were in 1989.

5.17.iii.Soil Factors.

With the greatly increased number of soil samples taken at October 1995, the possibility of soil factors influencing height growth was explored by correlation. Correlations were calculated for tree height at October 1995 with soil depth, organic matter and ESP of the top and subsoils (see also Chapter 6). Results are shown below.

Correlations were calculated for Tree Height at October 1995 with Organic Matter and Soil Depth. Results were as follows:

follows:	r	df.	P
OM:	.1972	110	<.02
Soil depth:	.0900	110	ns

Correlations were also calculated for Tree Height at October 1995 with ESP of topsoil and subsoil. Results were as follows:

as follows:	r	df.	P
ESP topsoil:	.1252	110	ns
ESP subsoil:	.2527	110	<.01

Correlations between tree height at October 1995 and soil depth were not significant. While soil depth had been shown to have a large influence on survival, no relation was shown between soil depth and tree height. Nor did there appear to be any relation between tree height at October 1995 and ESP of the topsoil.

Correlations between tree height at October 1995 and OM and tree height at October 1995 and ESP of the subsoil showed significance (OM: r = .1972 df.110 p <.02, ESP subsoil: r = .2527 df.110 p < .01). However, this was thought to be a site effect. When correlation was performed separately on the figures at each site, no relationship was shown.

Thus, none of the soil factors measured could be found to influence height growth to any significant effect.

5.17.iv.Survival.

It has been stated earlier (Section 5.14.viii) that up to October 1992, eight trees had died and eleven had been cut down at Site I. At Site 2, forty four trees had died, one had been trampled by a workman and two had been cut down. In 1993, two further trees were cut down at Site 1. No further trees died at either Site between this date and October 1995.

Chi-Square tests were performed on deaths in all soil depth classes for all trees and proved highly significant, Chi-square = 58.23 df.3 P <.001. There were significantly more deaths on shallow soils than would be expected. It would thus appear that soil depth had indeed been a major factor in earlier tree deaths.

However, by October 1995, with no further mortality, the trees seemed solidly established.

5.17.v.Tree Architecture.

Of the standard works on tree architecture, Horn (1971) discusses layering and light together with adaptive strategies; Halle and Oldeman (1970) concentrate on taxonomic divisions and describe models used in conjunction with various tree species. Neither of these texts appeared to have any particular application to the present study. However, it was thought worthwhile to see whether salinity affected the form of the trees.

Tree architecture was examined for the acacias at October 1995 in an attempt to examine the differences in form. The eucalypts were not examined in this way, as there was no marked diversity of form among them. Acacias in all irrigation classes were examined. An index was devised to give a figure for the branching habit of the acacias, as described in Section 4.7. A subjective assessment of form (good/not good) was also made, to see whether such assessment would coincide with any measured variables.
To see whether salinity of the irrigation water could be linked to the form of the trees, the means and standard deviations of the index in each water class were examined. Results were as follows:

Table 40. Tree Architecture Index Means for each Water Class.

	Mean	SD	N
No Water	2.6964	1.4994	22
10dS	3.9300	1.0417	29
5dS	4.2642	0.8529	26
<1dS	4.0689	1.1557	18

The mean index figures are substantially higher for the three irrigated classes. There were more crooked, small or twisted trees in the unirrigated sections than in any of the irrigated classes. Thus no relation could be detected between salinity and form (as described by the index).

Correlation was calculated for tree height at October 1995 with the index figure and produced a figure of .5147 with 93df. P <.001, showing that the taller trees had a 'better' branching habit.

The subjective assessment was tested by Mann-Whitney U with tree height at October 1995 and gave U = 203.0 N 95 P <.0001, highly significant. This was not very meaningful as it showed only that the taller trees with 'better' branching habits were more likely to be subjectively assessed as 'good'.

The examination of tree architecture had not revealed any previously unexplored trends.

5.18. Discussion.

The original objectives of the experiment were to see if it was possible to establish survival and steady growth of the trees with highly saline irrigation water. It is clear from the results that there were major responses to irrigation and that irrigated trees survived and grew better than unirrigated at all salinity levels up to 10dS. The stunting effect remarked on by Shaybany and Kashirad (1978) and Tomar and Yadav (1980) was not evident in this study. When examined graphically (Figs. 15, 16, 21 and 22) no substantial differences could be observed between the irrigated classes. Although these are not direct measures of significance, the balance of the evidence would seem to imply that differences in the salinity of the irrigation waters had little effect on growth.

The possibility of systematic bias may have been partly countered by running the replicates in opposite directions. Any major trends in underlying site factors would probably have been revealed by additive or subtractive effects on tree survival and growth - trees tending to grow better when the site trend coincided with lower salinities, and vice-versa. This was not evident from the plot mean growth values or from the soil depth overlays (Figs.19a and b). The patchiness of growth among the <1dS trees at Site 2 and the large number of deaths at that site appeared to coincide with areas of shallow soil.

The amount of irrigation water applied was very little in forestry terms. An irrigation dose rate experiment could not be incorporated in the experiment, so it is not known what the optimum amount of water would be. Nevertheless, the amounts applied were certainly sufficient to effect major differences between irrigated and unirrigated classes in establishment and growth. Moreover, two years irrigation even at these very low quantities appeared to be sufficient for these purposes. The differences in height between the two year and four year irrigated blocks were very small.

Neither water quality nor irrigation duration appeared to affect survival. The major factor, as mentioned above, was presence or absence of irrigation. Unirrigated trees died at a far higher rate than the irrigated groups. The second most important factor in survival appeared to be soil depth. The soil depth at the seed origin location is not known. A larger number of trees died in the shallowest parts of the fields. There is a question concerning the validity of the pan factor in these conditions. Whilst the factor established appeared adequate in terms of observed growth on relatively deeper soils, it is obvious that where the soil is very shallow, it will dry out more quickly than where it is deeper. On these extremely shallow soils, it is doubtful if any pan factor at all would be adequate without irrigation for the life of the plantation.

However, where trees did manage to establish themselves on very shallow soils, then soil depth had no apparent influence on subsequent height growth. It is thought that there may have been cracks in the rock which the roots penetrated. In some cases it was possible to scrape away the topsoil to examine the rooting pattern. This was extremely complex and there was a very large amount of overlapping, but in several cases, the trees did appear to be rooting into cracks in the rock. This may have distorted height growth figures in some cases (where a tree found a greater rooting depth than its neighbours). However, since there were eight trees of each species and water class group in each block, the mean figures should have smoothed any such anomalies.

The 1995 measurements showed that previous height growth trends continued but at a slower rate than before, as would be expected. Variation between the water quality classes showed similar trends to the previous years. The fact that no further deaths occurred to October 1995 was a useful check on the successful establishment of the trees.

CHAPTER 6.

EXCHANGEABLE SODIUM AND SOIL IMPROVEMENT RESULTS.

6.1. Exchangeable Sodium.

In the winter of 1987, before planting, soil samples were taken from both sites and were analyzed in the laboratory by extraction of exchangeable cations for Exchangeable Sodium Percentage (ESP). Mixings of the waters used were analyzed in the same way to establish the Sodium Adsorption Ratios (SAR).

6.1.i. Soil Analysis and SAR of the Irrigation Water

Table 41: Soil Analysis before Planting.

	Site 1	Site 2
Loss on ignition (%)	4.25	9.50
Organic matter (%)	1.70	4.50
Granulometric:		
>0.05mm(%)	76.50	58.00
0.02-0.05mm(%)	2.00	4.00
0.002-0.02mm(%)	7.00	16.00
<0.002mm(%)	14.50	22.00
Texture class	Sandy loam	Sandy loam
Exchangeable Na(me%)	0.4	0.4
Exchangeable K (me%)	0.2	0.3
Exchangeable Ca(me%)	7.2	8.4
Exchangeable Mg(me%)	0.1	0.3

ESP	5%	4%
pH	8.4	8.0

Site 2 had a larger clay fraction and more organic matter than Site 1 and would be considered a 'better' soil.

Table 42: Sodium Adsorption Ratio (SAR) of the Irrigation Water.

	Sea salt mixes	Saline well water mixes
BAW	11.8	6.9
5dS/m	84.8	13.1
10dS/m	152.1	23.2

Although the conductivities of the mixes at the two sites were equal, it will be seen that the SAR of the 5 and 10dS/m mixes at Site 1 are extremely high, these being derived from sea water. One would therefore expect a decrease in the infiltration rate.

6.2. Sampling

In the samples taken before planting, top and subsoil were mixed together. From October 1988, soil samples were taken at the beginning and end of each irrigation season, as explained in Chapter 4. From this date, six samples at two levels (topsoil and 20cm. deep) were taken from each site to examine conditions in each water treatment block (See Figs.9a and b).

From October 1990, at which date half of the trees ceased to be irrigated, it was necessary to take extra samples in order to cover all classes adequately. For logistical reasons, it was not possible to have the increased number of samples analyzed at that time. For October 1990 and April 1991, therefore, top and subsoil in some classes were mixed together, as the tables show. From October 1991, the increased number of samples were individually analyzed. The results of the analysis for exchangeable sodium are shown in Figs.23a,b,c,d,e and f and Tables 43 and 44.

Table 43: Soil Exchangeable Sodium Percentage. Site 1.

	Topsoil 4 year irrigation	Subsoil 4 year irrigation	Topsoil 2 year irrigation	Subsoil 2 year irrigation
<u>BAW (<1dS/m)</u>				
April 88	5.06	5.06		
October 88	14.92	8.63		
April 89	16.66	13.98		
October 89	21.01	22.22		
April 90	10.45	12.47	10.45	12.47
October 90	7.43	7.43	10.82	11.35
April 91	4.84	4.84	4.06	4.61
October 91	5.98	9.62	2.66	2.54
All irrigation ceased--				
April 92	2.29	3.01	3.88	3.15

October 92	2.71	1.59	2.09	2.42

5dS/m

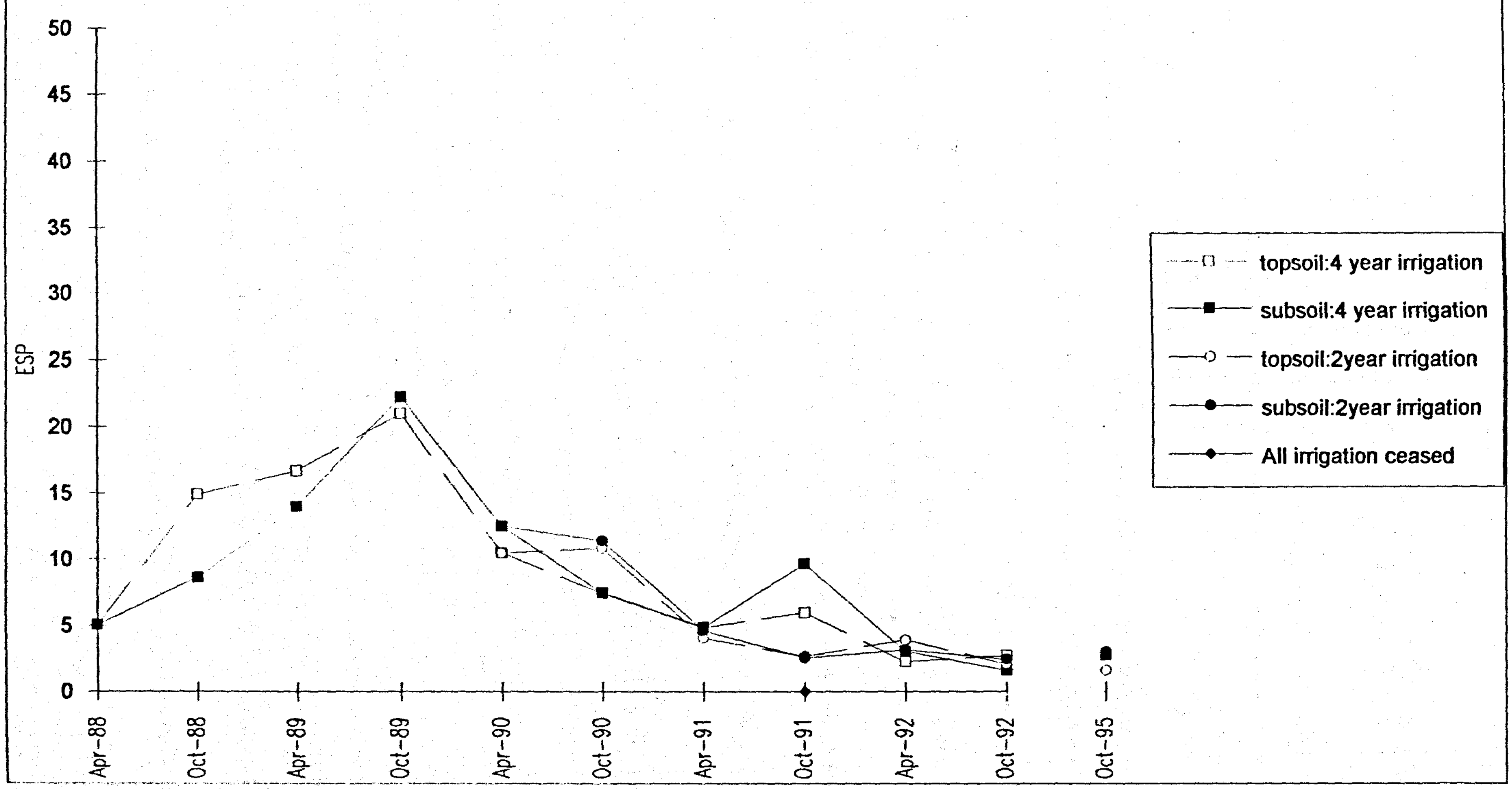
April 88	5.06	5.06		
October 88	15.62	17.30		
April 89	9.99	16.09		
October 89	39.11	47.17		
April 90	8.77	12.92	8.77	12.92
October 90	29.93	31.87	6.31	6.31
April 91	2.98	3.37	2.74	2.74
October 91	19.07	26.64	7.56	16.33
All irrigation ceased--				
April 92	3.71	4.22	1.85	1.96
October 92	2.17	5.62	3.60	3.08

10ds/m

April 88	5.06	5.06		
October 88	15.36	18.83		
April 89	8.80	15.52		
October 89	43.53	46.78		
April 90	16.63	25.17	16.63	25.17
October 90	36.84	36.84	14.43	18.14
April 91	9.63	9.63	12.87	10.68
October 91	28.75	34.51	15.17	21.95
All irrigation ceased--				

April 92	5.30	8.33	3.74	2.51
October 92	5.84	4.89	2.46	4.50

Fig.23a. Exchangeable Sodium Percentage to 1995: Site 1 BAW(<1dS/m)



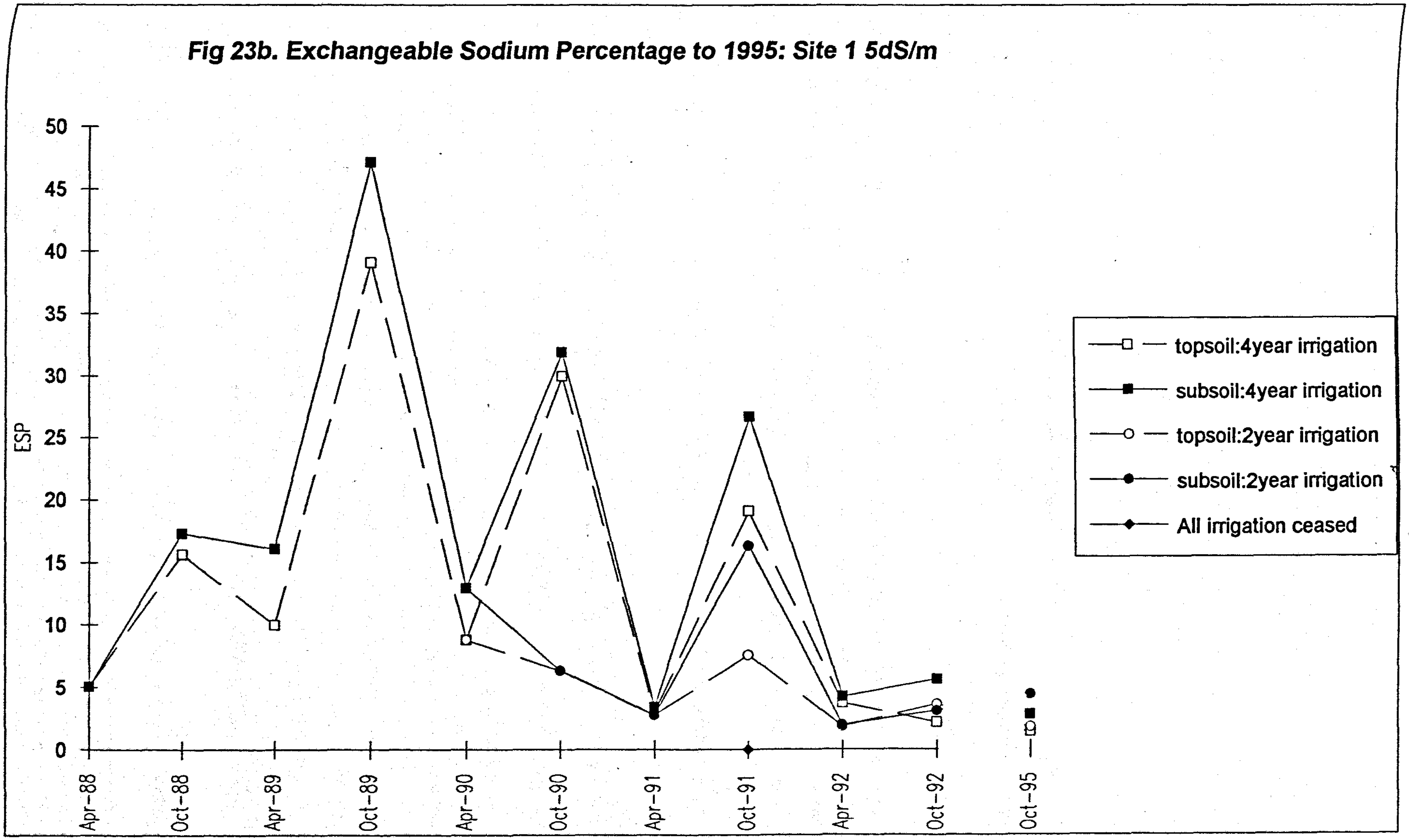


Fig 23b. Exchangeable Sodium Percentage to 1995: Site 1 5dS/m
ESP
50
45
40
35
30
25
20
15
10
5
0
Apr-88
Oct-88
Apr-89
Oct-89
Apr-90
Oct-90
Apr-91
Oct-91
Apr-92
Oct-92
Oct-95
topsoil:4year irrigation
subsoil:4year irrigation
topsoil:2year irrigation
subsoil:2year irrigation
All irrigation ceased

Fig.23c. Exchangeable Sodium Percentage to 1995: Site 1 10dS/m

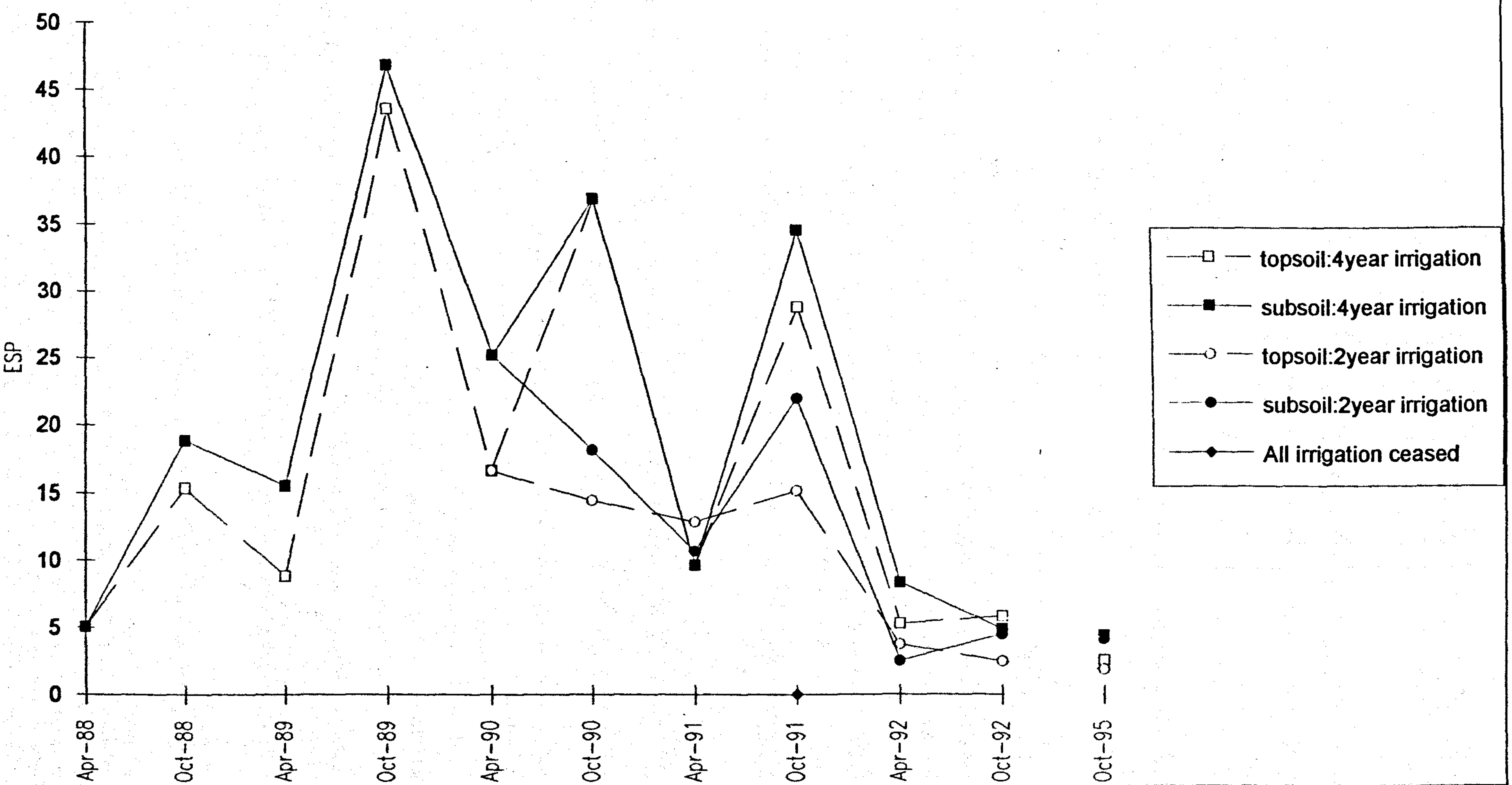


Fig.23d. Exchangeable Sodium Percentage to 1995. Site 2 BAW(<1dS/m)

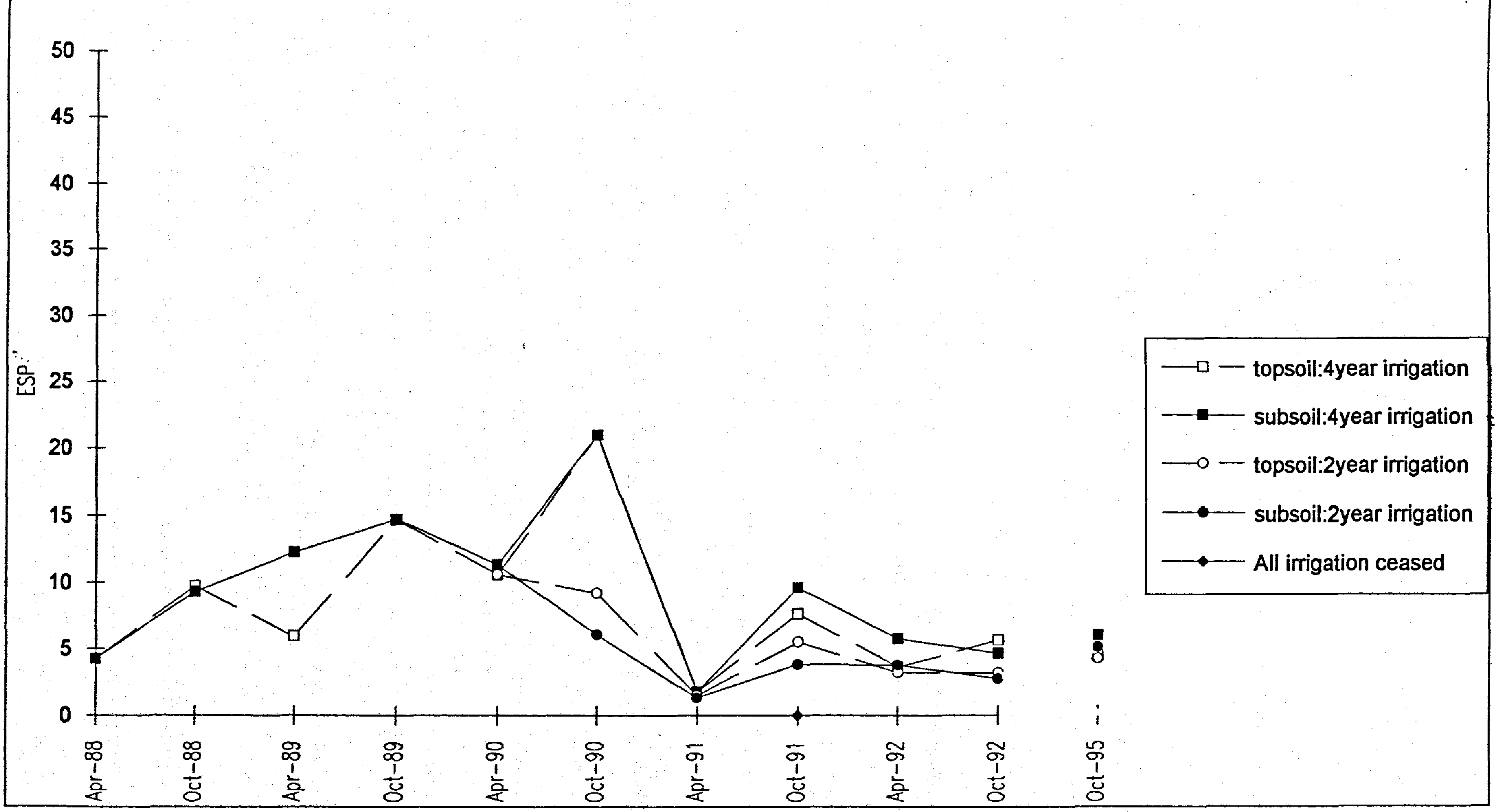


Fig.23e. Exchangeable Sodium Percentage to 1995.Site 2 5dS/m

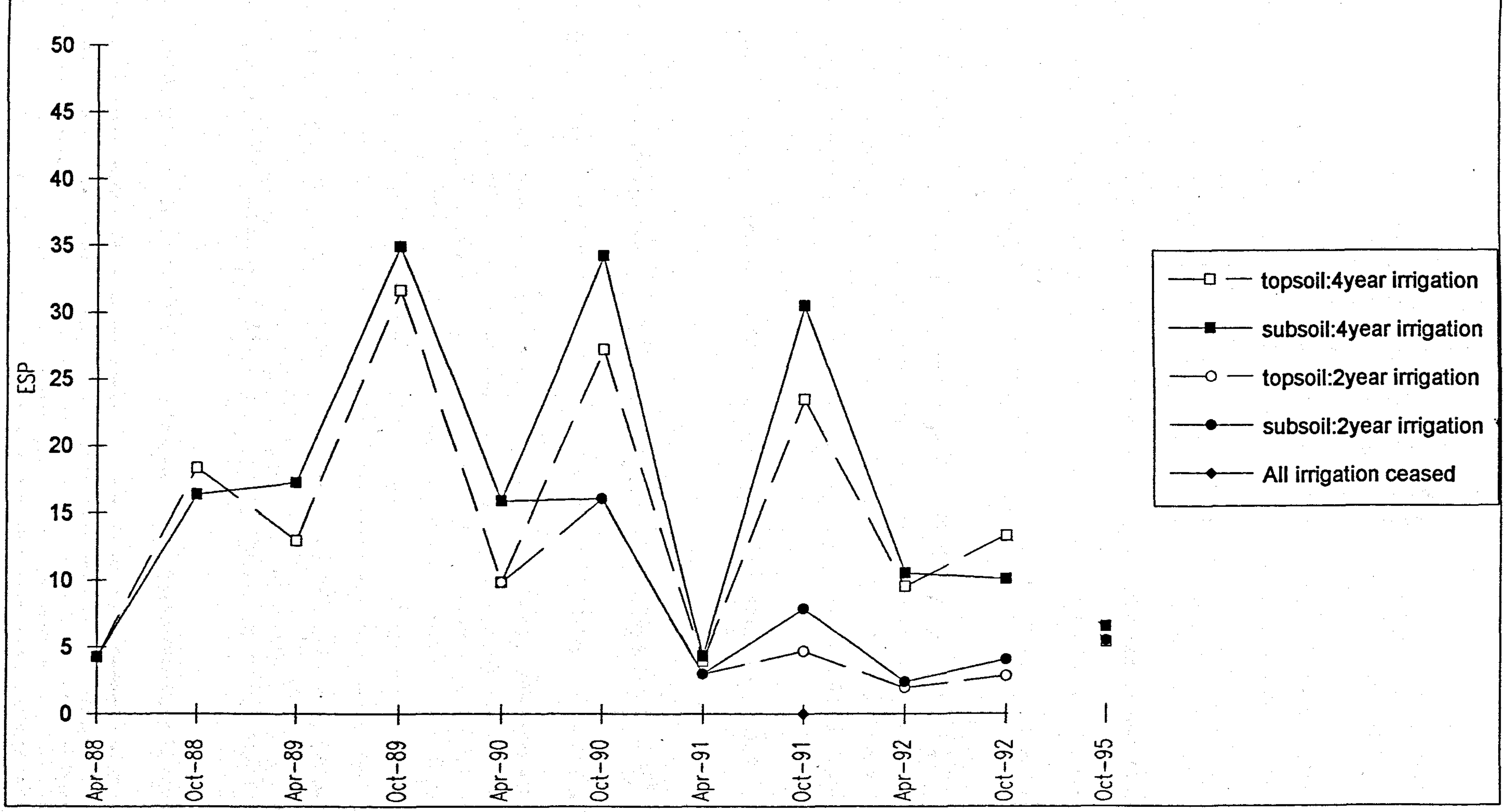


Fig.23f. Exchangeable Sodium Percentage to 1995.Site 2 10dS/m

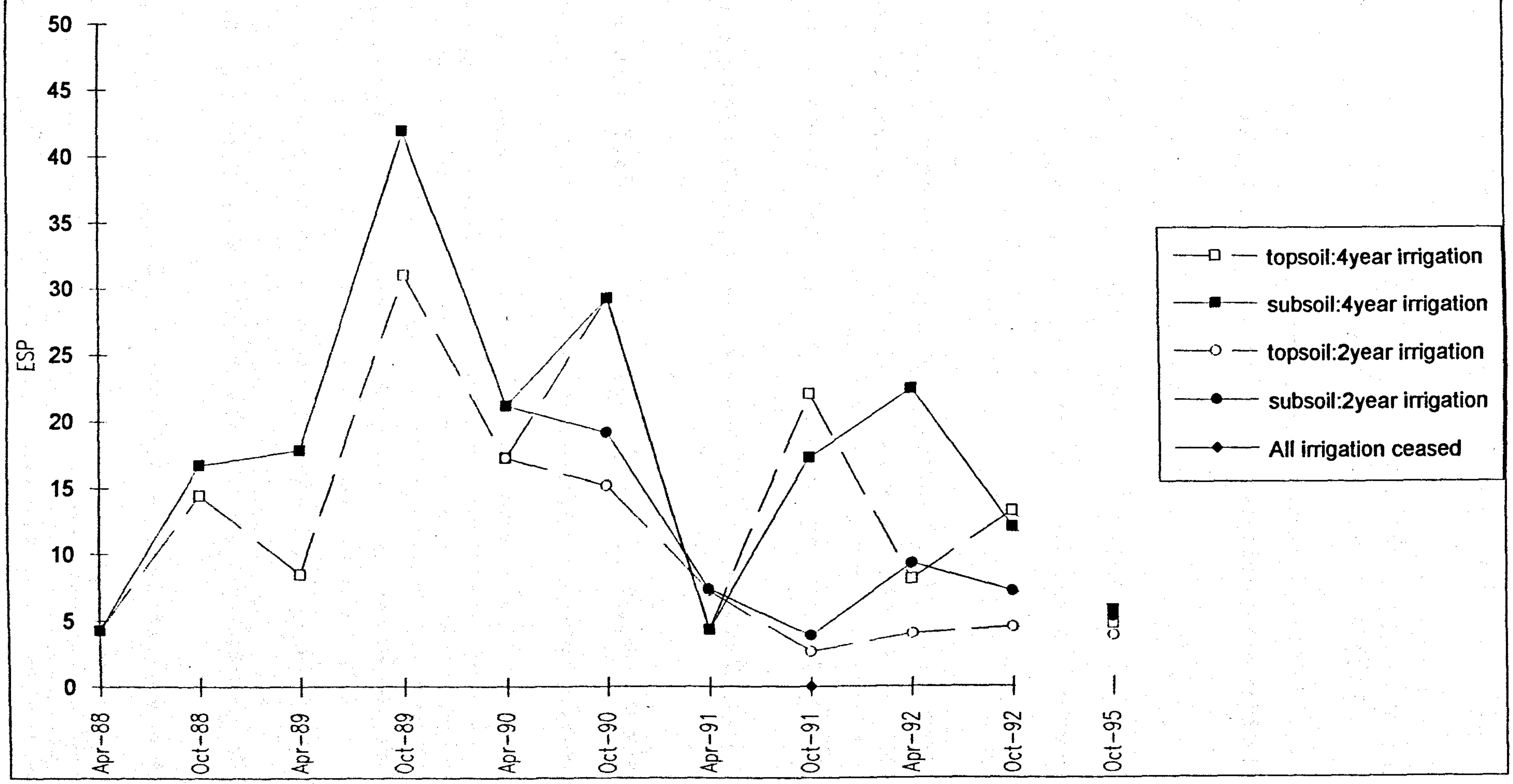


Table 44: Soil Exchangeable Sodium Percentage. Site 2.

	Topsoil 4 year irrigation	Subsoil 4 year irrigation	Topsoil 2 year irrigation	Subsoil 2 year irrigation
BAW (<1dS/m)				
April 88	4.25	4.25		
October 88	9.72	9.29		
April 89	5.98	12.25		
October 89	14.68	14.73		
April 90	10.60	11.36	10.60	11.36
October 90	20.98	20.98	9.22	6.09
April 91	1.74	1.74	1.49	1.31
October 91	7.63	9.62	5.51	3.81
All irrigation ceased-----------------------------------				
April 92	3.62	5.76	3.22	3.78
October 92	5.65	4.66	3.18	2.73

5dS/m

April 88	4.25	4.25		
October 88	18.34	16.36		
April 89	12.93	17.21		
October 89	31.66	34.96		
April 90	9.86	15.87	9.86	15.87
October 90	27.23	34.21	16.04	16.04
April 91	3.92	4.32	2.98	2.98
October 91	23.50	30.49	4.70	7.87
All irrigation ceased--				
April 92	9.51	10.54	1.96	2.38
October 92	13.28	10.07	2.83	4.06

10ds/m

April 88	4.25	4.25		
October 88	14.45	16.72		
April 89	8.50	17.85		
October 89	31.06	41.94		
April 90	17.27	21.20	17.27	21.20
October 90	29.23	29.23	15.21	19.17
April 91	4.34	4.34	7.28	7.39
October 91	22.11	17.29	2.67	3.88
All irrigation ceased--				
April 92	8.12	22.44	4.02	9.27
October 92	13.31	12.08	4.54	7.23

6.3. Site 1

All the figures show increasing sodium concentrations at the end of the irrigation season, even where low salinity water is used. At Site 1, the section irrigated at <1dS/m generally follows this pattern with some exceptions. At April 1989, ESP continued to rise instead of falling. In the topsoil, the rise from 15% to 17% was not as great as the rise of the previous summer, but in the subsoil the rise from 9% to 14% was even steeper. At October 1990, the expected rise in ESP did not occur under the trees which continued to receive irrigation (trees irrigated for four years). On the contrary, there was a decline from the previous April when the readings were 10.45% for topsoil and 12.47% for subsoil to a figure of 7.43% for both top and subsoil. They continued to fall to April 1991. In the six months to October of that year the top and subsoil values of the land where irrigation had been withdrawn (trees irrigated for two years) continued to fall whilst values of the irrigated land (four year irrigation) showed the expected slight increase. From April to October 1992 the concentrations fell again, except in the 4 years irrigated topsoil, where there was a slight increase. The falls were very small. The final figures are extremely low in relation to the initial values for all water classes. (See remarks regarding precipitation above Section 4.9.i.).

The section irrigated at 5dS/m follows the expected pattern very regularly, though the peaks in October 1990 and 1991 are not as high as that for October 1989 (39.11% for topsoil and 47.17% for subsoil). There is again a departure from the pattern in the non-occurrence of the expected rise at October 1990 in the two year irrigated top and subsoils. This continued fall, where a rise might be expected, showed in all classes at both sites at this date. The normal pattern resumed thereafter except for a fall in the value for 4 year irrigated topsoil at October 1992. All other values showed a slight rise. The finishing values are less than those at the start of the experiment except for the four year irrigated subsoil.

The graph for the section irrigated at 10dS/m (Fig. 23c.) is very similar to that for the 5dS/m section. It shows a high peak (43.53% for topsoil and 46.78% for subsoil) at October 1989 and lower peaks at October 1990 and 1991. It is interesting to see that the highest recorded values for ESP at either site (47.17% for the 5dS/m subsoil in October 1989) was marginally higher than the figure for the 10dS/m section at this date (46.78%).

Again there was no rise in the two year irrigated top and subsoils at October 1990. At April and October 1991 and April 1992, the values continue the previous pattern. In the final figures at October 1992, the topsoil of the four year irrigated land and the subsoil of that which was irrigated for two years showed a slight rise. The topsoil of the two year irrigated land and the subsoil of the four year had declined. The differences are small. In this section, the finishing values were nearly equal to the values at the start of the experiment, except for the topsoil value in the two year irrigated section, which was less than the starting value.

6.4. Site 2

At Site 2, the pattern is very similar to Site 1, but the peaks are lower. The highest peak being 41.94% in the 10dS/m section, again at October 1989. The 5dS/m peak at this date is lower at this Site. This may by attributable to the very high SAR at Site 1. Nevertheless with the shallower soils at Site 2, one would have expected higher concentrations of sodium. However, it seems that the 'better' soils at this Site are more able to accommodate the high dosage. They started from a slightly lower base (Site 1:5.06%, Site 2:4.25%).

In the section irrigated at <1dS/m, the only features that do not fit the general pattern are the continued rise of the subsoil concentrations to April 1989 and the continued fall, where one would have expected a rise in the concentrations in both top and subsoil of the two year irrigation at October 1990 - this last having been noted in other sections. At October 1992, the figure for four year irrigated topsoil showed a slight rise. All other

classes were static or falling, with the October 1992 figures for the four year irrigated classes being very similar to those at the beginning of the experiment. The two classes with
two years irrigation show lower figures than the original values.

The section irrigated at 5dS/m, as at Site 1, shows an almost classic pattern. The three peaks (four year irrigated subsoil concentrations at October 1989, 1990 and 1991 at 34.96%, 34.21% and 30.49%) are more regular than in the other sections and although showing a decline year by year do not exhibit the extremely high peak shown in the other saline irrigated sections at October 1989. Even at October 1990, when all other sections exhibited a break in the pattern, all classes in this section showed a rise in concentrations, though the rise in the two year irrigated subsoil was very small. At April 1992, concentrations declined in all classes, with the four year irrigated land showing higher concentrations than the two year. At finishing, in October 1992, the four year irrigated land showed higher concentrations than those at the start of the experiment (13.28% for topsoil and 10.07% for subsoil). That which had received only two years of irrigation had ESPs for both top and subsoil (2.83% and 4.06%) very similar to that of April 1988.

The 10dS/m section was again similar to the others in the initial years, exhibiting the same extremely high ESP of October 1989 and the same unexpected fall in the two year irrigated classes at October 1990. In the later years, the pattern became irregular. The fall in values in the two year irrigated classes from April to October 1991 is paralleled in some other sections. The rising concentrations in the four year irrigated subsoil and to a lesser degree in the two year irrigated topsoils and subsoils from October 1991 to April 1992 were not seen anywhere else, nor was the sharp descent of the four year irrigated subsoils from April to October 1992. The two year irrigated subsoil values also descend anomalously at this date, though not so dramatically. The figures have been checked and rechecked and the samples reanalysed, but no explantation can be found for these figures. The four year irrigated topsoil alone showed readings that accorded with the general pattern at these dates. The finishing figures at October 1992, 13.31% for topsoil and 12.08% for subsoil in the four year irrigated sections are higher than the starting figures, but show a large decline from the higher peaks. The figures for two year irrigated topsoil and subsoil (4.54% and 7.23%) are nearing the starting figure of 4.25%.

6.5. General Pattern

In spite of the unexplained features mentioned, the general pattern is very clear. In the dry months, the exchangeable sodium percentage increases under irrigation. On land which is irrigated at high salinity, the build up is quite sharp during the period of irrigation. There is a decline each year with the winter rains, although not, under saline irrigation, to previous levels. When the saline irrigation is stopped, the ESP does return to previous levels in quite a short time.

6.6. 1995 Sampling and Analysis.

Further to explore the variability within the water quality plots, and also to measure any longer term changes in soil properties additional soil samples were taken between 15 September and 15 October 1995. 64 soil samples were taken at two levels at Site 1 and 48 samples at two levels at Site 2. These were 4 samples at each level within each water treatment block where more than four trees survived. Sampling spots were chosen with dice. 224 samples in all were taken. Some samples were also taken around the mixing tanks and in adjacent unplanted ground to compare salinity levels.

6.6.i. Analysis.

All samples were analyzed in the laboratory as described in Section 4.12. Because of the increased number of samples from each treatment area, it was possible to calculate standard deviations and confidence limits for all species and water groups. This had not been possible with the earlier soil samples.

Table 45. Exchangeable Sodium Percentage of Topsoil under Acacia and Eucalypts, showing Means, Standard Deviations and 95% Confidence Limits. Sites 1 and 2.October 1995

	Mean	SD	N	95% CL
Site 1 Acacia				
No water	4.12	2.47	8	2.46-5.78
10dS	2.30	1.60	8	1.23-3.37
5dS	1.56	1.11	8	0.82-2.30
<1dS	1.44	0.81	8	0.90-1.98
Site 1 Eucalypt				
No water	2.82	1.63	8	1.73-3.91
10dS	2.12	0.64	8	1.69-2.55
5dS	1.59	0.79	8	1.06-2.12
<1dS	2.87	1.25	8	2.03-3.71
Site 2 Acacia				
No water	5.37	0.92	8	4.75-5.99
10dS	4.25	1.03	8	3.56-4.94
5dS	5.25	1.03	8	4.56-5.94
<1dS	3.50	1.00	4	2.32-4.68
Site 2 Eucalypt				
No water	____	____	0	
10dS	4.37	0.52	8	4.02-4.72
5dS	5.75	1.26	4	4.27-7.23
<1dS	4.75	0.89	8	4.15-5.35

Table 46. Exchangeable Sodium Percentage of Subsoil under Acacia and Eucalypts, showing Means, Standard Deviations and 95% Confidence Limits. Sites 1 and 2. October 1995.

Site 1 Acacia.

	Mean	SD	N	95% CL
No water	2.12	0.64	8	1.69-2.55
10dS	4.50	0.92	8	3.88-5.12
5dS	3.25	1.83	8	2.03-4.47
<1dS	3.00	0.75	8	2.50-3.50

Site 1 Eucalypt

	Mean	SD	N	95% CL
No water	1.75	0.71	8	1.27-2.23
10dS	4.25	1.39	8	3.32-5.18
5dS	3.87	2.23	8	2.37-5.37
<1dS	2.75	0.71	8	2.27-3.23

Site 2 Acacia

	Mean	SD	N	95% CL
No water	6.37	2.13	8	4.94-7.80
10dS	5.25	2.43	8	3.62-6.98
5dS	6.50	2.45	8	4.85-8.15
<1dS	6.00	1.63	4	4.08-7.92

Site 2 Eucalypt

	Mean	SD	N	95% CL
No water	____	____	0	
10dS	6.25	2.71	8	4.43-8.07
5dS	6.50	2.38	4	3.70-9.30

<1dS	6.00	2.72	8	4.17-7.83

The above tables and Figures 23 a - f show that the ESP of both top and subsoil had declined to normal levels. The confidence limits demonstrate that variability within the water class groups was in most cases of a similar order. The limits tend to be wider for soils with a higher mean ESP value, but since no values are substantially higher than those at the start of the experiment, the results can be considered satisfactory.

ESP had returned to normal levels in the planted areas. Samples were also taken adjacent to the mixing tanks at both sites. At Site 1, ESP had also declined to 4%, presumably since no further salt mixing had taken place at the site since 1992. At Site 2, the area around the mixing tanks is directly beside the highly saline well, where water is often spilt and here, ESP of the adjacent soil was still 23%.

ESP levels did not show any substantial differences between the water classes, or between species. ESP showed a distinct site effect, with levels higher at Site 2 than at Site 1. However, levels were close to the original values at both sites.

6.7. Soil Improvements.

The ESP results have shown that long term detrimental effects on the soil can be avoided and that once irrigation is stopped, levels of exchangeable sodium return to previous levels quite quickly.

One of the aims of the investigation was to see whether the tree cover achieved contributed to attributes which might be taken as indicative of soil improvement and thus constituted a valid measure of environmental upgrading. To this end, the accumulation and decomposition of litter, the build up of organic matter and soil fauna numbers were examined.

6.7.i. Litter Accumulation.

At first the litter traps were emptied 2 monthly. For logistical reasons, from autumn 1991 this became six monthly. Although there were always wide variations between individual traps, the six-monthly totals remained fairly consistent with a few exceptions, increasing slightly year by year, as one would expect with the increased size of the trees.

Proctor (1983) states that results should be expressed in ovendry weight at tons per hectare. After being airdried on site, the samples were therefore transported to London where they were ovendried at 105 degrees overnight at the University and reweighed. This was repeated with several batches of samples and resulted in a constant weight loss

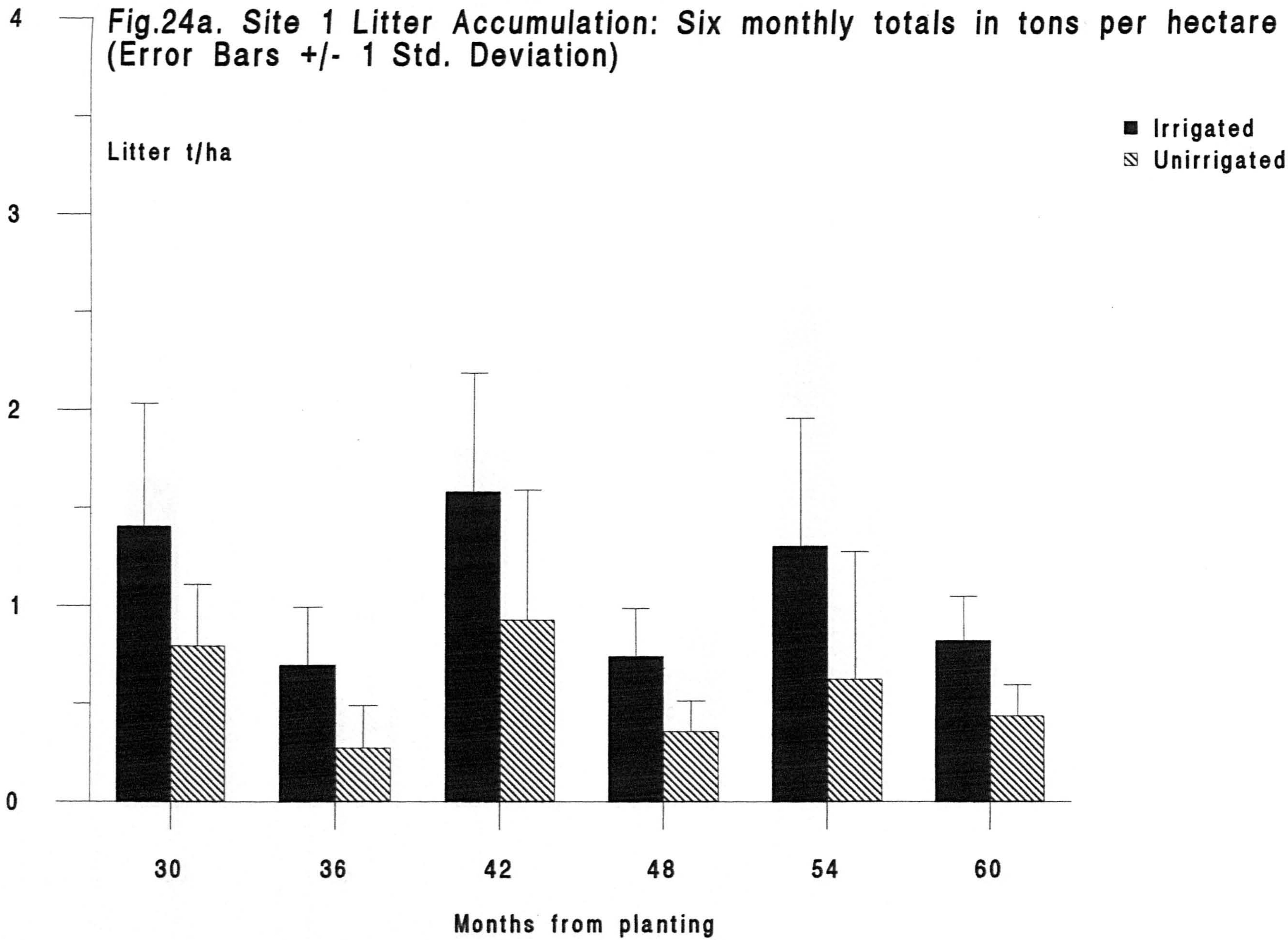


Fig.24a. Site 1 Litter Accumulation: Six monthly totals in tons per hectare (Error Bars +/- 1 Std. Deviation)

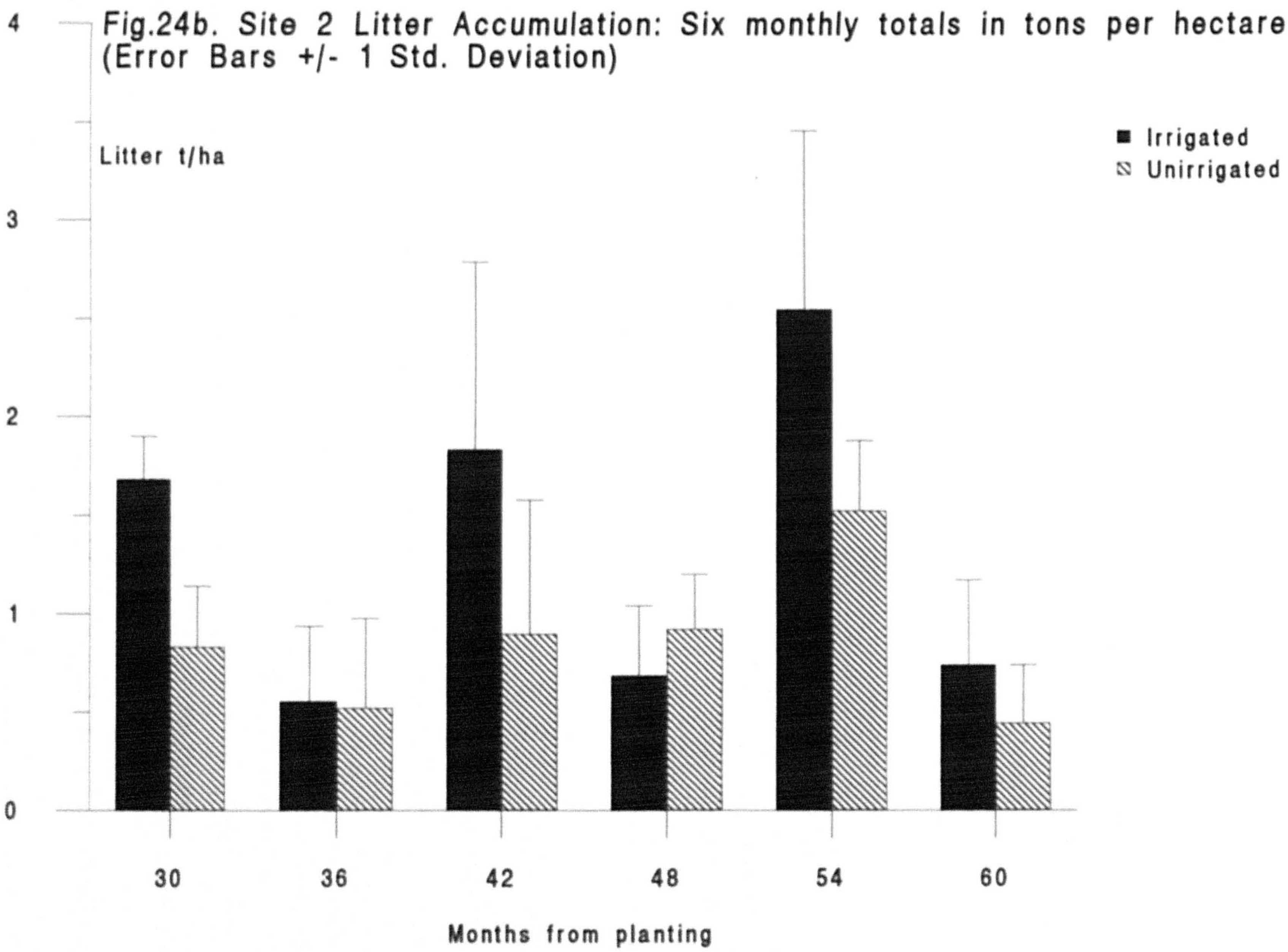


Fig.24b. Site 2 Litter Accumulation: Six monthly totals in tons per hectare (Error Bars +/- 1 Std. Deviation)

of 4.3 to 4.4 percent for both winter and summer samples. From October 1991 therefore samples were airdried on site and a loss of 4.35 percent attributed to them.

Ovendry mean grams per trap were then extrapolated to tons per hectare for comparability to other studies. The total annual accumulation in tons per hectare was as follows:

Table 47: Litter Accumulation at Sites 1 and 2.Standard deviations of trap totals in brackets. 1990 to 1993.

Site 1

	Irrigated		Unirrigated	
	t/ha/yr	N	t/ha/yr	N
Oct 90:	1.405(0.63)	6	0.798(0.31)	4
Apr 91:	0.700(0.29)	6	0.273(0.22)	4
1st yr total:	2.105		1.071	
Oct 91:	1.585(0.60)	6	0.930(0.66)	4
Apr 92:	0.744(0.24)	6	0.358(0.16)	4
2nd yr total:	2.329		1.288	
Oct 92:	1.306(0.65)	6	0.627(0.65)	4
Apr 93:	0.825(0.22)	6	0.438(0.16)	4
3rd yr total:	2.131		1.065	

Site 2

	Irrigated		Unirrigated	
	t/ha/yr	N	t/ha/year	N
Oct 90:	1.683(0.22)	6	0.832(0.31)	4
Apr 91:	0.555(0.38)	6	0.520(0.46)	4
1st yr total:	2.238		1.352	
Oct 91:	1.834(0.95)	6	0.896(0.68)	4
Apr 92:	0.687(0.35)	6	0.922(0.28)	4
2nd yr total:	2.521		1.818	
Oct 92:	2.554(0.91)	6	1.522(0.39)	4
Apr 93:	0.738(0.43)	6	0.444(0.29)	4
3rd yr total:	3.292		1.966	

This table shows the six monthly and yearly totals, for comparability with other studies. Figures 24a and b show the April and October totals for irrigated and unirrigated classes, which demonstrate the seasonal differences more clearly.

There is a clear picture of year by year increase, distorted by the very low figures at Site 1 in October 1992. There was considerably more litter accumulation under the irrigated trees than there was under those which remained unirrigated. The trees had been in the ground for two and a half years at the start of the experiment, so that the irrigated trees were bigger and there were proportionally more of them - there had been a greater percentage of deaths in the unirrigated section. There is an anomaly at Site 2 in April 1992, when the accumulation in the unirrigated section is greater than that under the irrigated trees. The difference is not very large, and is not apparent in the yearly totals, but there were no peculiar circumstances (large pieces of litter in the traps for instance). The differences between traps were, as usual, considerable but there is no very satisfactory explanation of this anomaly.

Standard deviations increase with increasing amounts of litter and are quite large as can be seen in Figs.24a and b. They are largest in the irrigated section at Site 2.

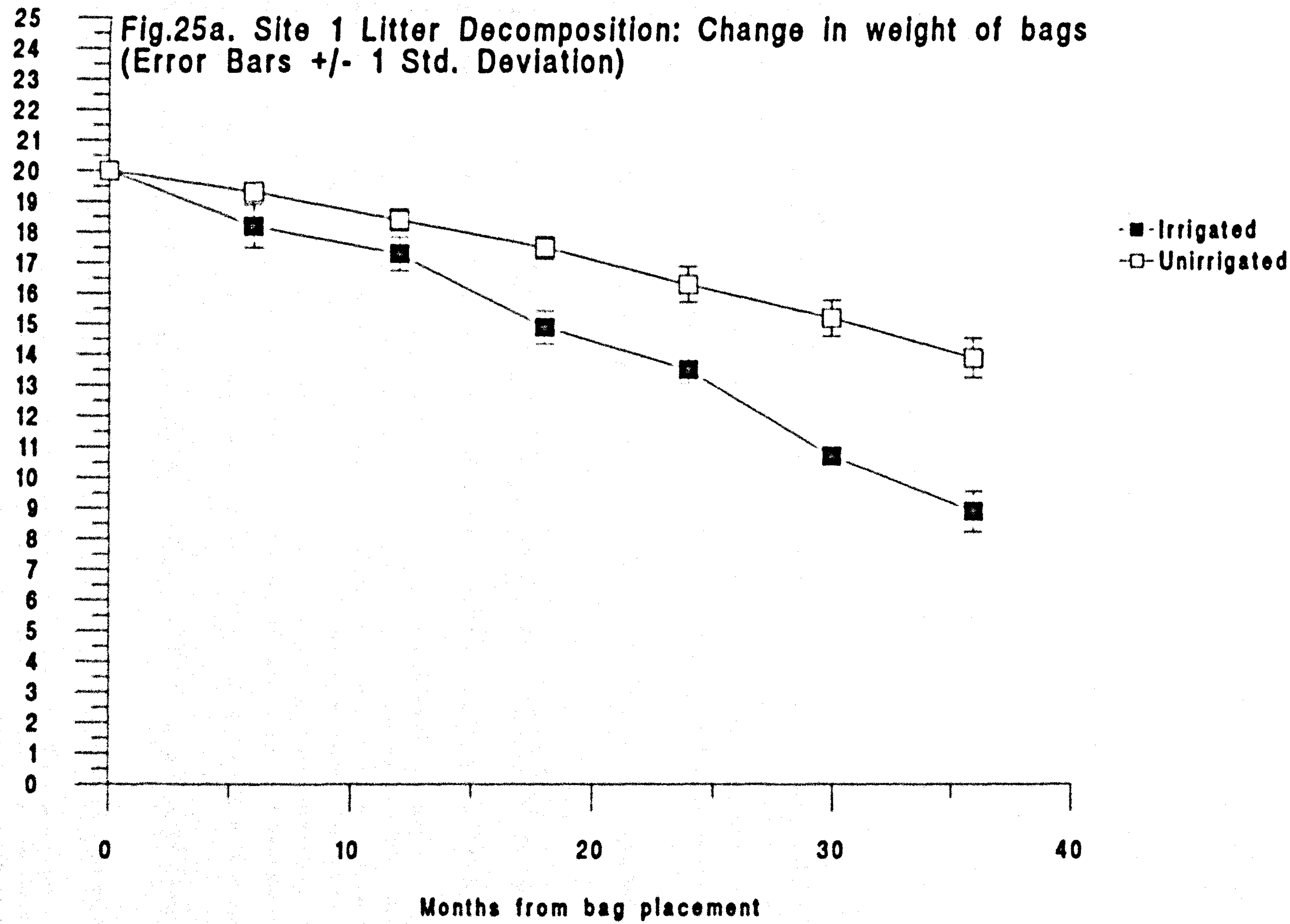
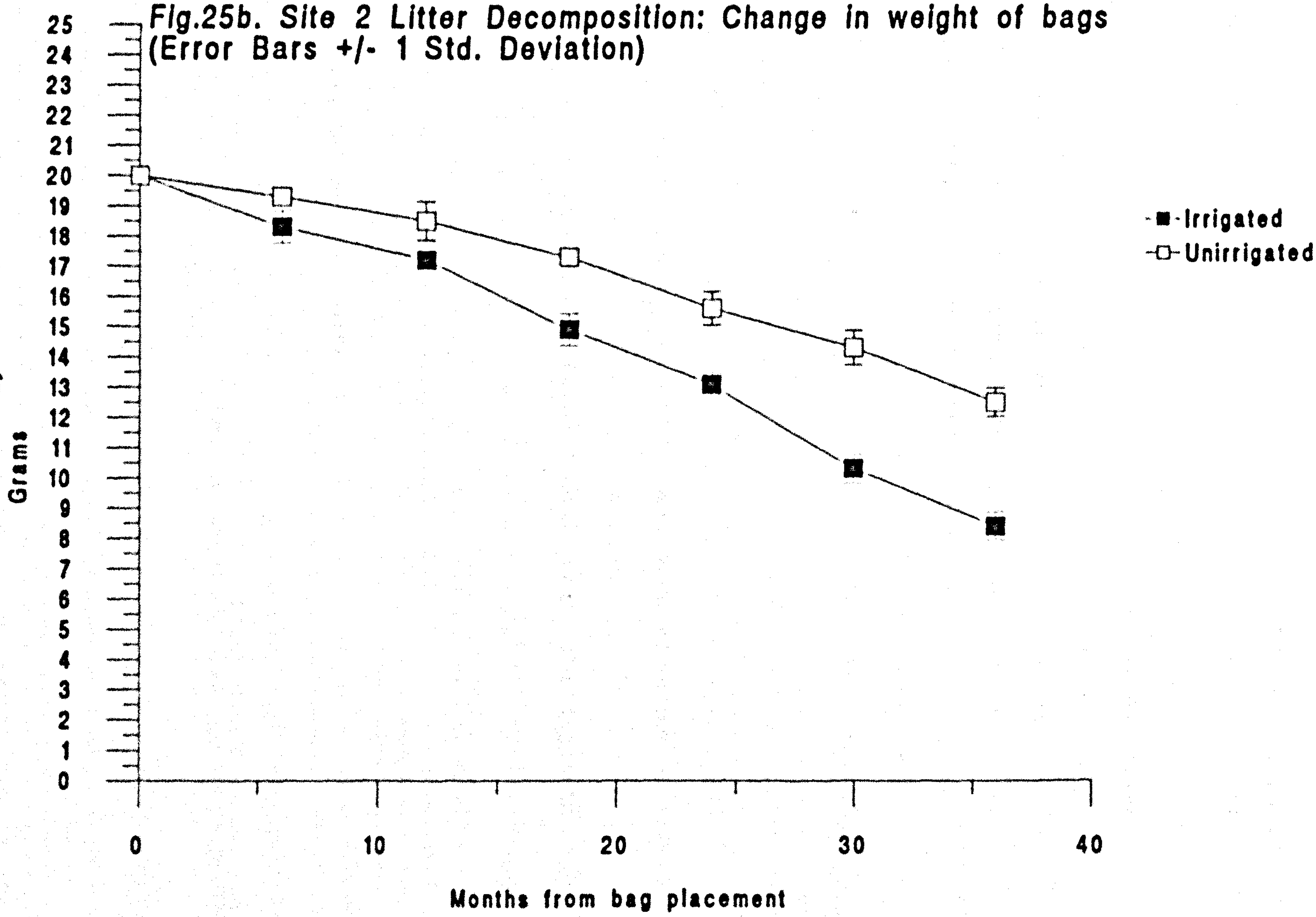


Fig.25a. Site 1 Litter Decomposition: Change in weight of bags
(Error Bars +/- 1 Std. Deviation)
Irrigated
Unirrigated
Grams
Months from bag placement
0
10
20
30
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

Fig.25b. Site 2 Litter Decomposition: Change in weight of bags (Error Bars +/- 1 Std. Deviation)



There was consistently more litter at Site 2 than at Site 1. This accords with the fact that there was overall greater tree growth at Site 2. At October 1992, the greatest difference between the two sites occurred, with a very large accumulation at Site 2 and a particularly small one at Site 1. The Site 2 figures follow the pattern of increasing accumulation year by year as the trees grow taller. The Site 1 figures break this pattern at October 1992, although in April 1993 the pattern is resumed with an increase in both the irrigated and unirrigated sections over the previous winter. This anomaly also is unexplained.

The differences between summer and winter are interesting and are very marked. All the trees shed more leaves in the summer, presumably to conserve energy in the dry months. Although one would expect that the irrigated trees would not experience the same amount of stress, it should be remembered that they were being watered at well under the evapotranspiration rate.

6.7.ii. Litter Decomposition.

At the same time (April 1990) that the litter traps were put in place, small mesh bags were made and samples of litter from under the trees enclosed in them (See above Section 4.13).

The bags weighed approximately 10 grams each and the litter 20 grams. The bags were attached by wire to each litter trap and were weighed at six monthly intervals. The results in grams were as follows:

Table 48. Litter Decomposition. Weight Changes of Bags at 6 Monthly Intervals (standard deviations in brackets) with Six Monthly Percentage Loss. Sites 1 and 2. April 1990-April 1993.

Site 1	Irrigated			Unirrigated		
	wt.g.	N	6 mnth loss	wt.g.	N	6 mnth loss
April 90	20			20		
October 90	18.2(0.70)	6	9.0%	19.3(0.22)	4	3.5%
April 91	17.3(0.55)	6	4.9%	18.4(0.35)	4	4.7%
October 91	14.9(0.53)	6	14.0%	17.5(0.36)	4	4.9%
April 92	13.5(0.44)	6	9.3%	16.3(0.58)	4	6.9%
October 92	10.7(0.30)	6	20.7%	15.2(0.58)	4	6.7%
April 93	8.9(0.67)	6	16.8%	13.9(0.65)	4	8.5%
Total % loss over 3 years:			55.5%			30.5%

Site 2	Irrigated			Unirrigated		
	wt.g.	N	6 mnth loss	wt.g.	N	6 mnth loss
April 90	20			20		
October 91	18.3(0.52)	6	8.5%	19.3(0.29)	4	3.5%
April 91	17.2(0.26)	6	6.0%	18.5(0.65)	4	4.0%
October 91	14.9(0.52)	6	13.4%	17.3(0.22)	4	6.5%
April 92	13.1(0.40)	6	12.1%	15.6(0.55)	4	9.8%
October 92	10.3(0.46)	6	21.4%	14.3(0.56)	4	8.3%
April 93	8.4(0.44)	6	18.4%	12.5(0.48)	4	12.5%
Total % loss over 3 years:			58.0%			37.5%

The rates did not differ greatly between the two sites. Site 2 showed a slightly faster rate of weight change than Site 1. However, there is a substantial difference between the irrigated and unirrigated classes (See also Figs 25a and b). The samples under the irrigated trees lost weight much faster in the summer months than did the unirrigated samples. The unirrigated samples decomposed faster in the winter. Although the process continues all year for all samples, where trees have received no water in the summer the litter is very dry and crumbly and ready to break up fast when the winter rains occur. All rates accelerated with time as the litter broke up into smaller particles.

Standard deviations of the bags' weight were not large in either the irrigated or the unirrigated sections. All bags lost weight at a very similar rate. The % loss appears to increase very rapidly (up to 21.4% in the summer of the third year at Site 2). Nevertheless, it seems doubtful that this method could be extrapolated to indicate a general rate of decomposition in view of the foregoing reservations regarding the effect of the mesh and the probable loss of fragmented particles.

Nevertheless, it is clear that litter both accumulates and decomposes at a faster rate when the trees are irrigated, adding between two and three tons of organic matter per hectare per year to the soil even at this early stage of their growth. The literature indicates that the litter of exotic species may decompose at a slower rate than that of indigenous trees (FAO 1985). Since only exotics were being examined there is no basis for comparison in this investigation.

6.7.iii. Organic Matter.

Analysis of soil Organic Matter was performed before planting in the spring of 1988. At Site 1 the amount of Organic Matter in the soil was found to be only 1.7%. At Site 2 it was 4.5%.

This analysis was not performed again until the autumn of 1991. At this stage, half of the trees in the irrigated section had been watered for two seasons and half for four seasons.

As previously mentioned, soil samples were taken from the same spots as those used for ESP testing. The samples were analyzed in the laboratory by the Walkeley Black method. The increase in the percentage of Organic Matter in the soil under the trees was very marked for all classes and is shown in Table 49 and Figs.26a and b.

At Site 1 in October 1991 whilst adjacent unplanted ground was found to have 1.8% OM, nearly the same value as at planting, soils under the unirrigated trees now showed a mean OM content of 4.1%. For the two irrigated classes - trees which had received two and four seasons of irrigation - the mean figures were 6.8% and 7.4% respectively.

At Site 2, the adjacent unplanted ground gave a slightly lower reading than that of three and a half years before (4.4%). Soils under the unirrigated trees however had 8% of OM. Those which had received irrigation for two seasons had 10.9% and soils under the trees irrigated for four seasons had 11.1% at this date.

Analysis was again performed on soils taken from both sites in April and October 1992. At these dates, the percentage of OM in the soil remained static in the adjacent unplanted ground, but continued to increase for the three wooded classes. Although the soils at Site 2 had a higher initial reading at planting than those at Site 1, the rate of accumulation was roughly the same at the two sites (Table 49 and Figs 26a and b). Accumulation under acacia was marginally higher than under eucalypt (Table 49) but the differences were not substantial.

In the unirrigated section at Site 1, the reading at April 1992 appears anomalous. At 2.3% (0.7% for acacia and 3.9% for eucalypt) it is 1.8% lower than the reading taken 6 months previously. As has been stated, each percentage figure in the unirrigated section is a mean of two samples from each species. One of the acacia samples was abnormally low at this date, thus bringing down the mean. At October 1992, six months later, the figure rose to 4.9% which is in line with the other results. There was another anomalous reading in the 4 year irrigated group at

April 1992 - the only other occasion on which the percentage of
organic matter was substantially higher under the eucalypts than under the acacias.

Fig.26a.Soil Organic Matter Percentage under Tree Canopy to 1995. Site 1

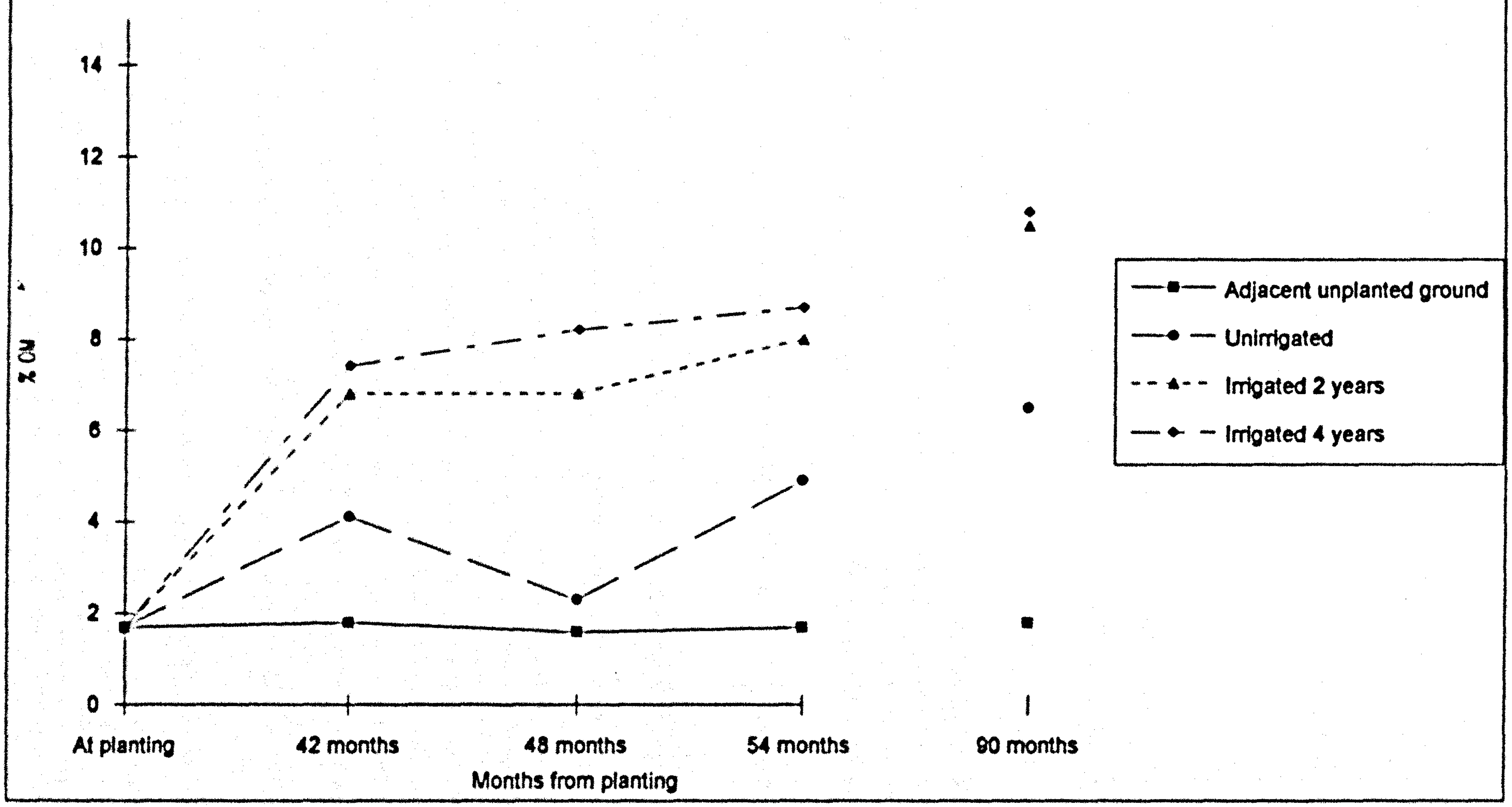
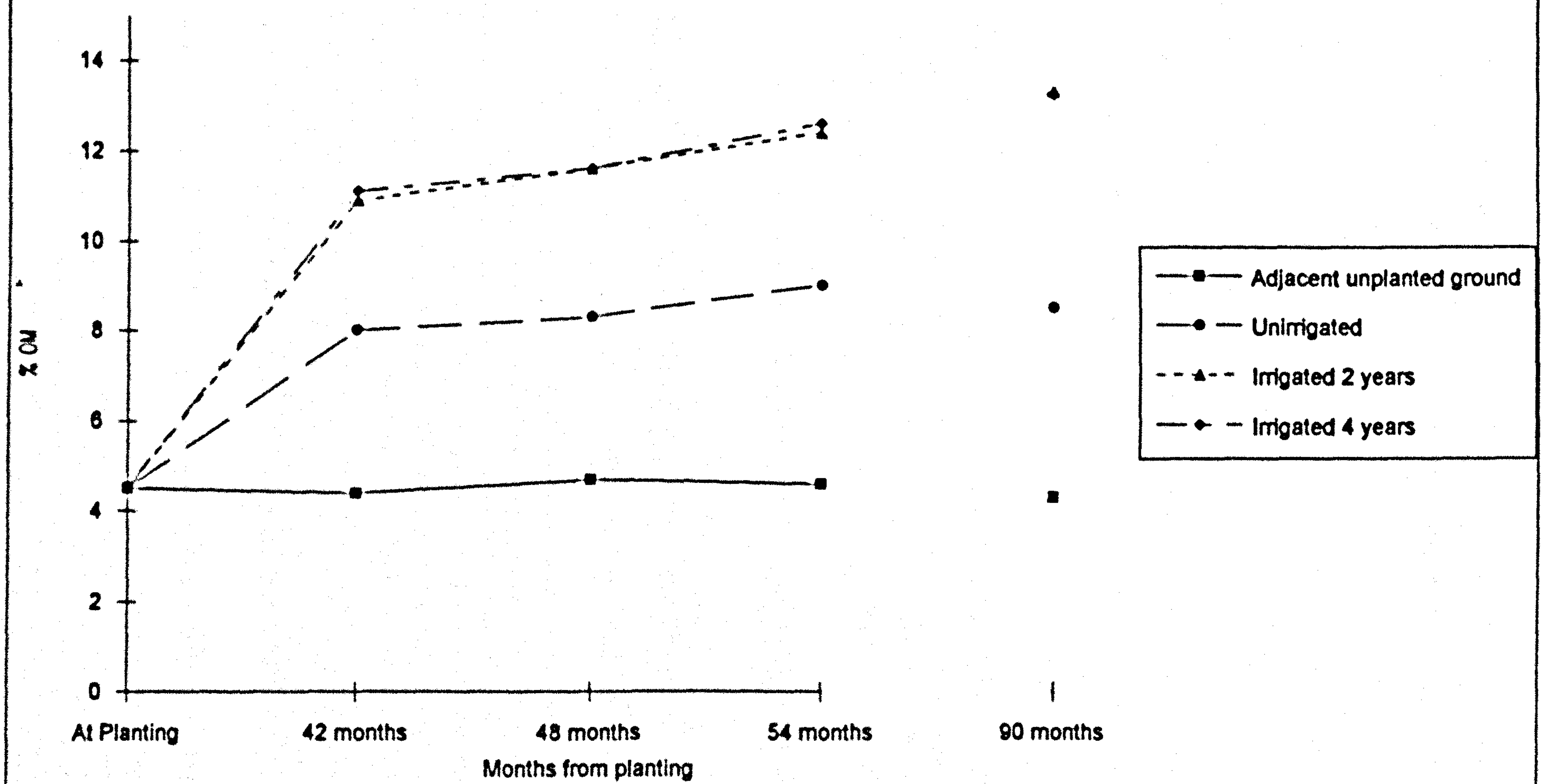


Fig.26b.Soil Organic Matter Percentage under Tree Canopy to 1995. Site 2



Throughout the experiment, the irrigated classes showed a larger increase than the unirrigated, but there was very little difference between soils in the two year or four year irrigation. At Site 1 the difference is more marked than at Site 2, but is nevertheless small. At Site 2 at April 1992 the mean figures are exactly the same for the two irrigated classes.

Table 49. Soil Organic Matter Percentage in Adjacent Unplanted Land, Unirrigated Land and Land Irrigated for 2 and 4 Years. Sites 1 and 2. From Planting to October 1992.

Site 1	Adjacent %	Unirr %	2 years irr %	4 years irr %
At planting	1.7	1.7	1.7	1.7
Oct 91:	1.8			
Acacia		4.4	6.8	7.6
Eucalypt		3.8	6.8	7.2
Apr 92:	1.6			
Acacia		0.7	6.9	5.9
Eucalypt		3.9	6.7	10.5
Oct 92:	1.7			
Acacia		5.0	9.1	9.3
Eucalypt		4.8	6.9	8.1
Site 2	**Adjacent %**	**Unirr %**	**2 years irr %**	**4 years irr %**
At planting	4.5	4.5	4.5	4.5
Oct 91:	4.4			
Acacia		8.9	11.2	11.6
Eucalypt		7.1	10.6	10.6
Apr 92:	4.7			
Acacia		9.2	12.1	13.0
Eucalypt		7.4	11.1	10.2
Oct 92:	4.6			
Acacia		9.4	12.6	13.0
Eucalypt		8.6	12.2	12.2

6.8. 1995 Organic Matter Results.

With the greatly increased number of soil samples taken at October 1995, it was possible to examine the standard deviations and confidence limits of the organic matter percentage in the soils which had received different water treatments. As before, organic matter was examined by the Walkeley Black method for all topsoils. Samples which showed results that were more than two standard deviations from the mean were reanalysed.

Table 50 shows that organic matter had built up at a similar but slightly slower rate than previously. The levels were now quite high. Organic matter percentage was substantially higher in all three irrigated classes than in the unirrigated sections. The build up in the previously irrigated trees was quite similar and Table 50 shows that the confidence limits for the irrigated classes overlap considerably.

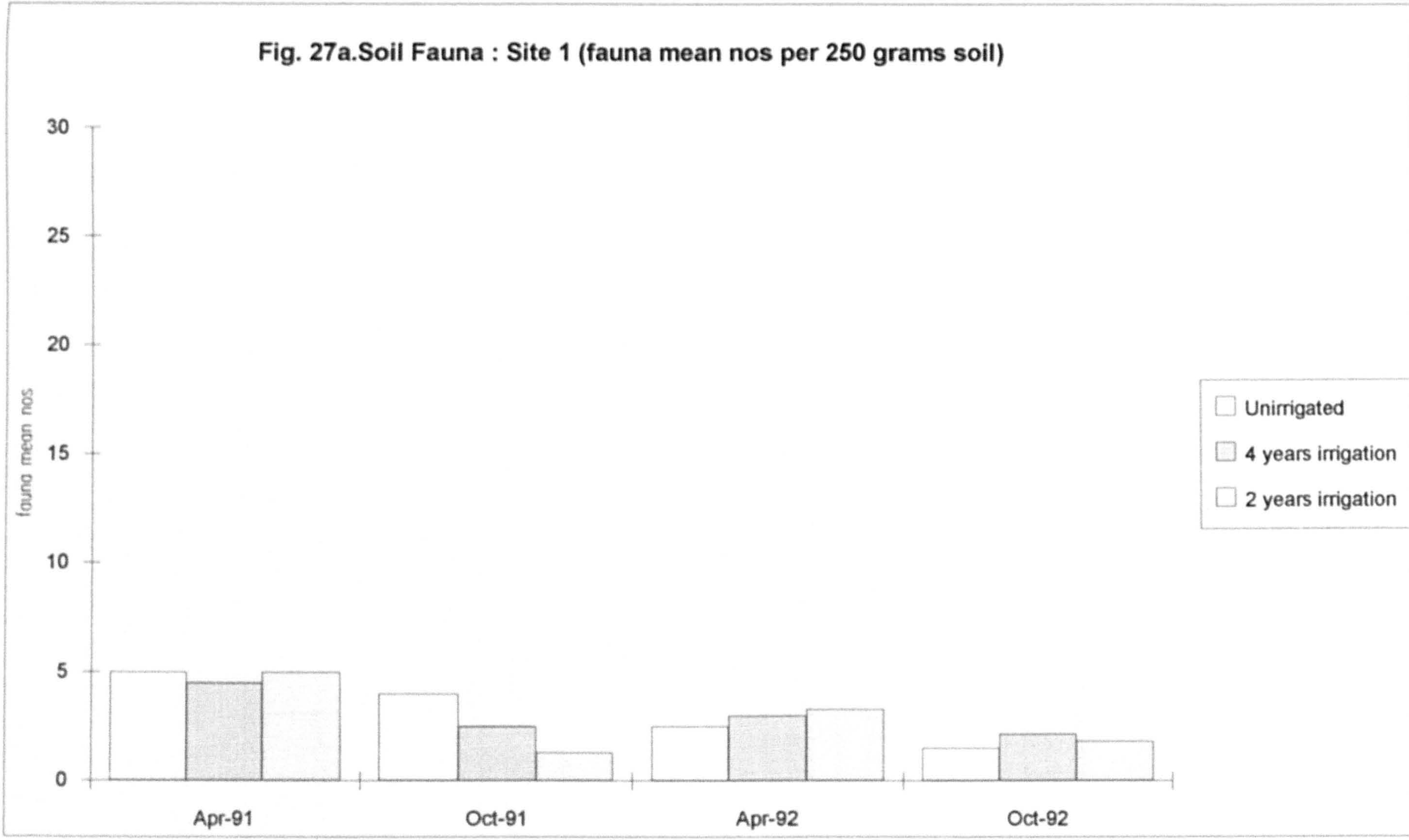


Fig. 27a.Soil Fauna : Site 1 (fauna mean nos per 250 grams soil)
30
25
20
15
10
5
0
fauna mean nos
Apr-91
Oct-91
Apr-92
Oct-92
Unirrigated
4 years irrigation
2 years irrigation

Fig.27b.Soil Fauna: Site 2 (fauna mean nos. per 250 grams soil)

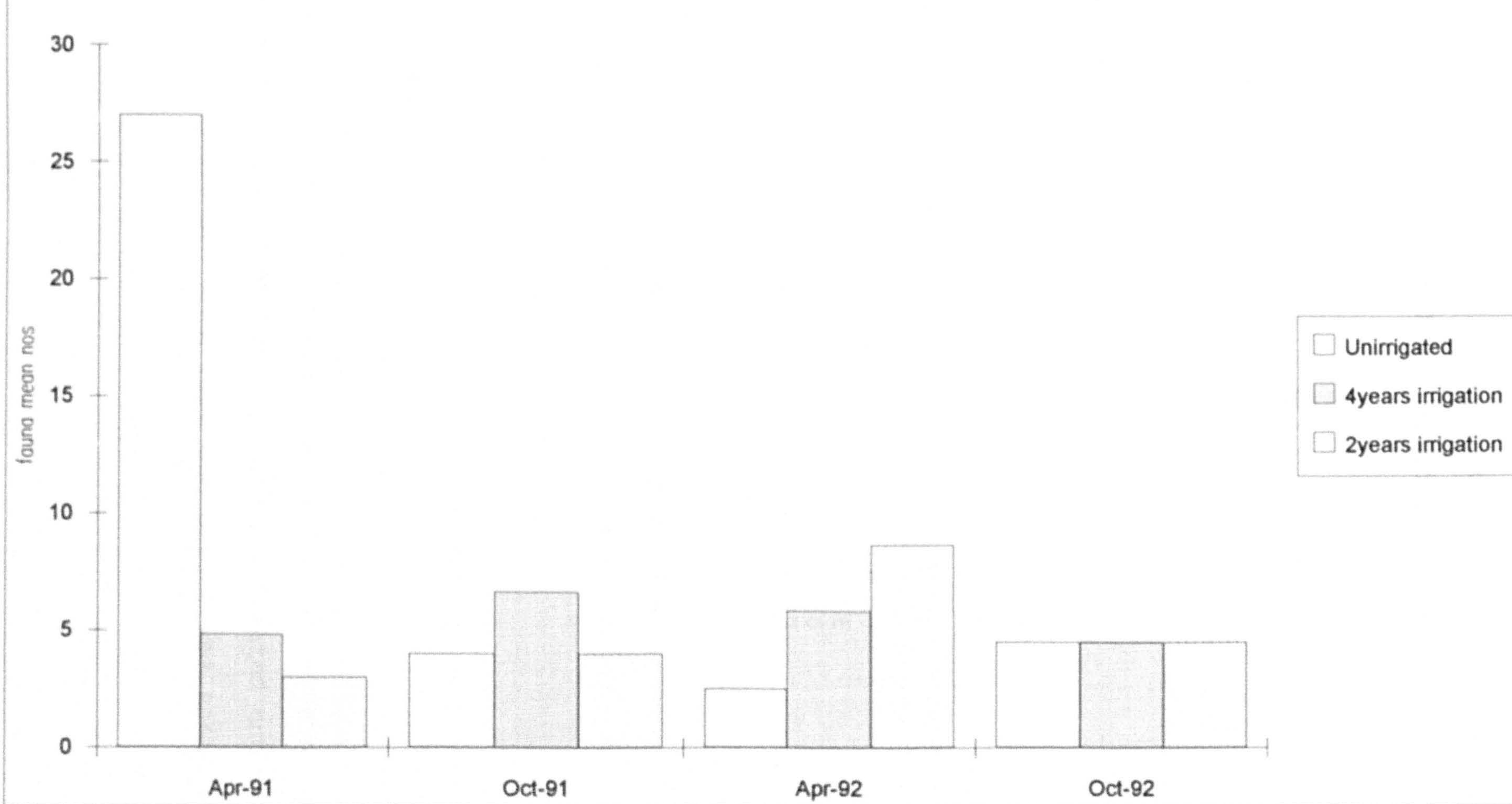


Table 50. Soil Organic Matter Percentage under Acacia and Eucalypts showing Means, Standard Deviations and 95% Confidence Limits. Sites 1 and 2. October 1995.

Site 1 Acacia.

	Mean %	SD	N	95% CL
No water	6.89	1.46	8	5.91- 7.87
10dS	11.01	2.40	8	9.40-12.62
5dS	11.16	2.11	8	9.74-12.58
<1dS	9.98	1.95	8	8.67-11.29

Site 1 Eucalypt

	Mean %	SD	N	95% CL
No water	6.20	1.44	8	5.23- 7.17
10dS	10.29	1.78	8	9.09-11.49
5dS	9.65	2.20	8	8.17-11.13
<1dS	10.63	2.27	8	9.11-12.15

Site 2 Acacia

	Mean %	SD	N	95% CL
No water	8.49	1.01	8	7.81- 9.17
10dS	13.97	4.00	8	11.28-16.66
5dS	13.98	3.15	8	11.86-16.10
<1dS	13.26	2.90	4	9.85-16.67

Site 2 Eucalypt

	Mean %	SD	N	95% CL
No water	____	____	0	
10dS	12.58	3.32	8	10.35-14.81
5dS	12.07	1.81	4	9.94-14.20
<1dS	12.91	2.60	8	11.16-14.66

6.9. Soil Fauna.

An attempt was made to examine the soil fauna with a view to observing possible differences under irrigated and non-irrigated conditions. Much time and effort was spent for inconclusive results.

In April 1991 and again in October 1991 and April and October 1992, soil was collected from the same sixteen spots at each site that were used for soil sampling for other analysis. An area of 25 x 25 cm and about 10 cm deep was dug and 3 large trowels full of soil were removed. Each sample was placed in a tray and sifted for live organisms which could be seen with the naked eye.

In April 1991, about 250 grams of each of the 32 samples of the soil collected was subjected to the Bayermann process for water mobile fauna. This produced no results at all and the experiment was not repeated at subsequent samplings.

About 250 grams of the soil was placed in Tulgren funnels over which the lights were lowered for four successive days. The extracted organisms were examined under the microscope and counted. Those which could not be identified were preserved and transported to London for identification.

The organisms were not properly preserved and in spite of the great help of Dr. Tony South, it was impossible to identify the majority of them.

It was therefore decided that as a full taxonomic picture could not be obtained, a simple count of total organisms per sample (250g) was made and is shown in Table 51 and Figs. 27a and b.

Table 51. Soil Fauna - Mean Numbers per 250 grams Soil. Sites 1 and 2. April 1991-October 1992.

	Unirrigated	4 years irrigation	2 years irrigation
Site 1.			
Apr 91	5.0	4.5	5
Oct 91	4.0	2.5	1.3
Apr 92	2.5	3.0	3.3
Oct 92	1.5	2.16	1.83
Site 2.			
Apr 91	27.0	4.83	3
Oct 91	4.0	6.66	4
Apr 92	2.5	5.83	8.66
Oct 92	4.5	4.5	4.5

In the unirrigated sections, the means are of four samples. In the two irrigated classes, the means are of six samples each. Results should be treated with extreme caution as the differences are small and the absolute numbers very low.

At first glance, the figures for Site 1 seem to show a fairly logical pattern, except for the anomalously high value for unirrigated ground at April 1991. Otherwise the numbers drop, as one would expect, during the summer. They drop more in the two year irrigation than the four year and this also one would expect. At October 1991, the four year irrigated sections had received a summer of irrigation whereas the two year irrigated had had no water during the summer for two years. At April 1992 the numbers in the irrigated sections rise. The figures for all classes fall at October 1992, when the four year irrigated section had received no summer irrigation for a year and the two year irrigated had had none for three years. The differences in the levels at April 1991 and 1992 are not explained by the pre-season rainfall (371.7mm in the winter to April 1991 and 391.8mm in the winter to April 1992).

At Site 2, the values are generally higher, which accords with other findings showing Site 2 to have 'better' soil. The extraordinary value for unirrigated land at April 1991 is inexplicable. Nor do the rest of the figures for this site show any particular pattern.

In spite of these disappointing fauna results, the litter and organic matter aspects were satisfactory. It is obvious that litter will accumulate faster under tree cover than on unplanted ground. Not so immediately obvious, but clearly demonstrated here is that litter added between 2 and 3 tons per hectare of organic matter to the ground and that rates of both litter accumulation and decomposition were considerably higher under irrigation than when the trees were unirrigated. The build up of organic matter in the soil is clearly demonstrated by the figures. The overlapping confidence limits show that the accumulation does not differ substantially in the irrigated classes. It is clear that tree planting, especially with irrigation, will significantly improve the soil status.

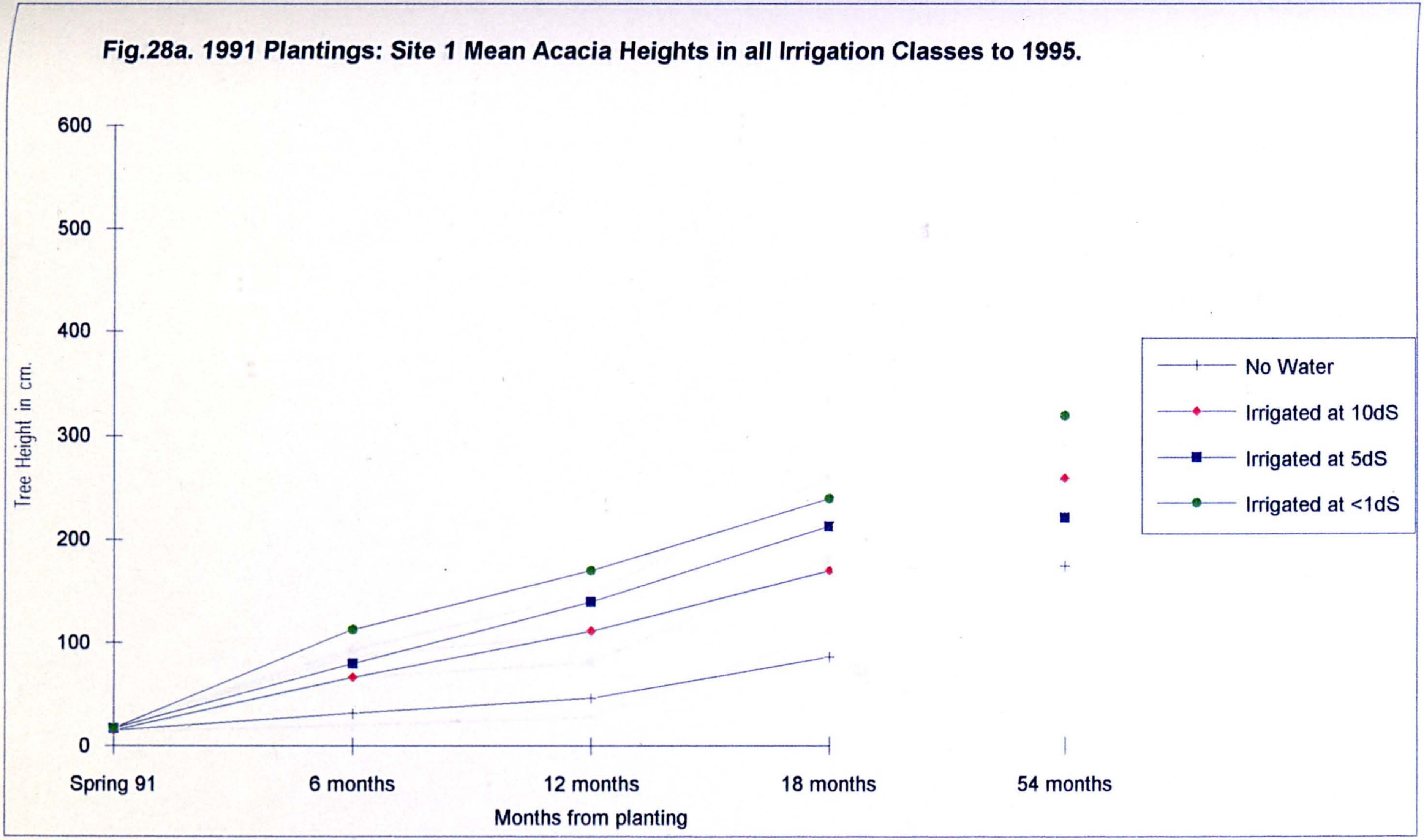


Fig.28a. 1991 Plantings: Site 1 Mean Acacia Heights in all Irrigation Classes to 1995.
600
500
400
300
200
100
0
Tree Height in cm.
Spring 91
6 months
12 months
18 months
54 months
Months from planting
No Water
Irrigated at 10dS
Irrigated at 5dS
Irrigated at <1dS

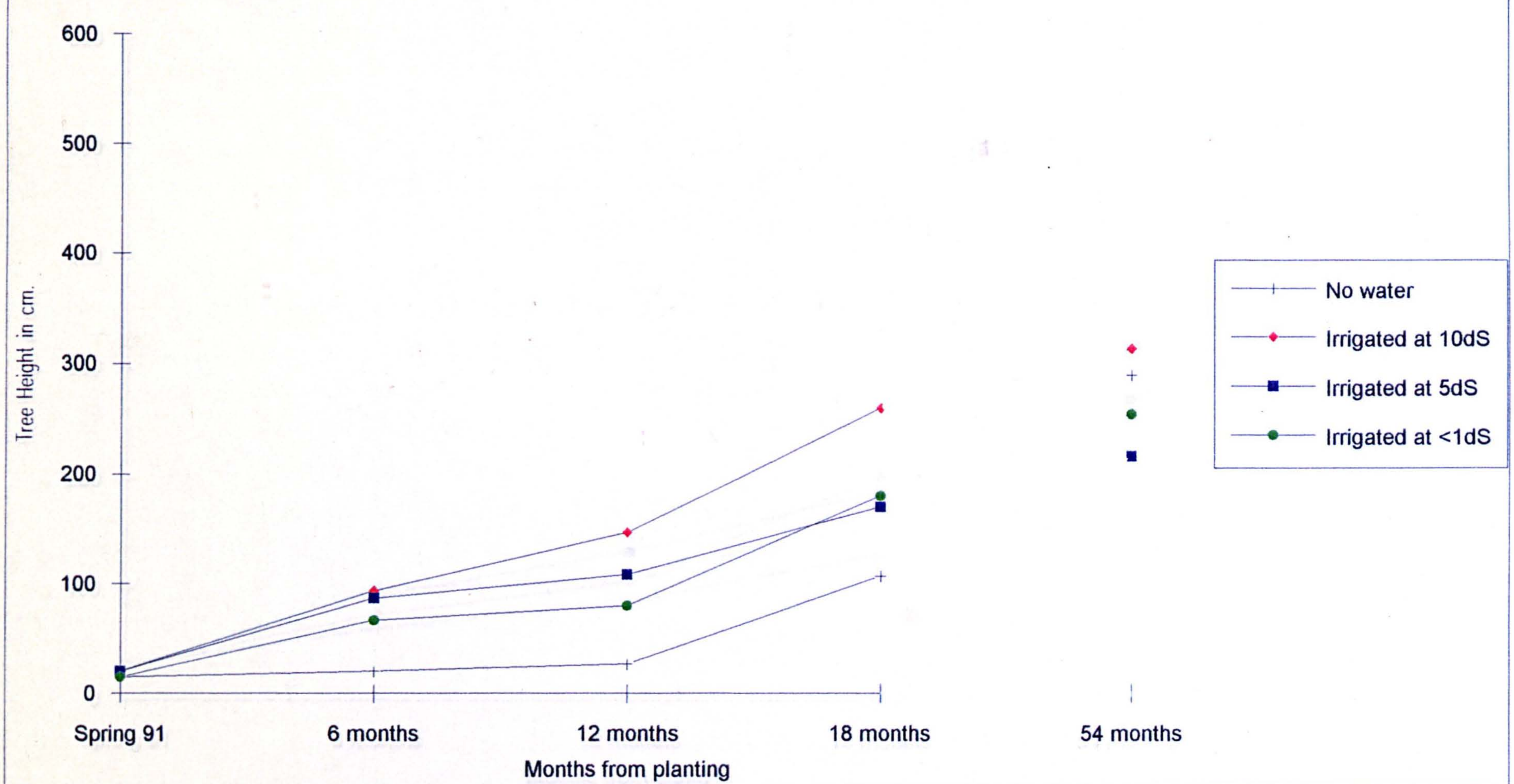


Fig.28b. 1991 Plantings: Site 2 Mean Acacia Heights in all Irrigation Classes to 1995.

Fig.28c.1991 Plantings: Site 1 Mean Eucalypt Heights in all Irrigation Classes to 1995.

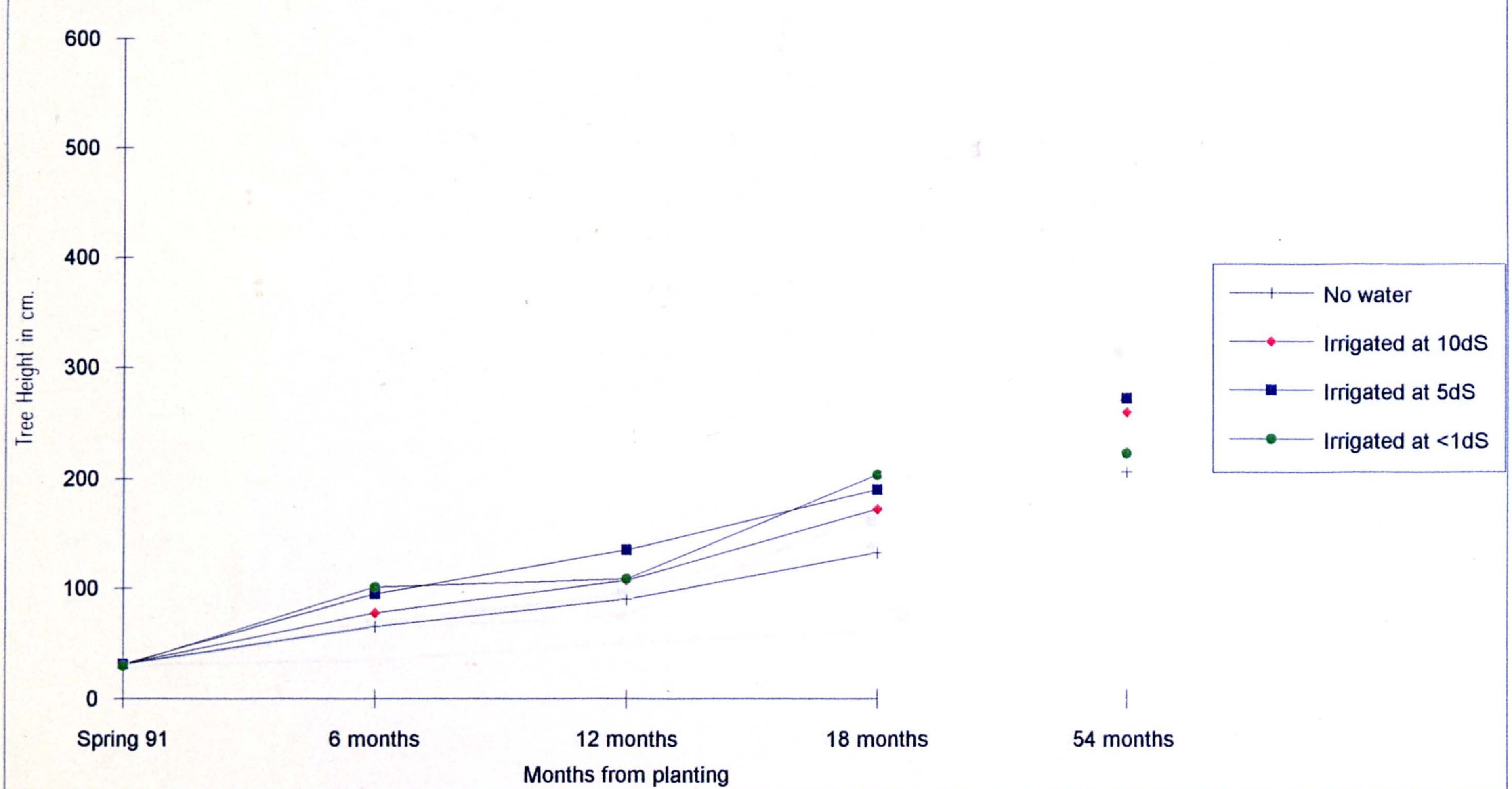


Fig.28d. 1991 Plantings: Site 2 Mean Eucalypt Heights in all Irrigation Classes to 1995.

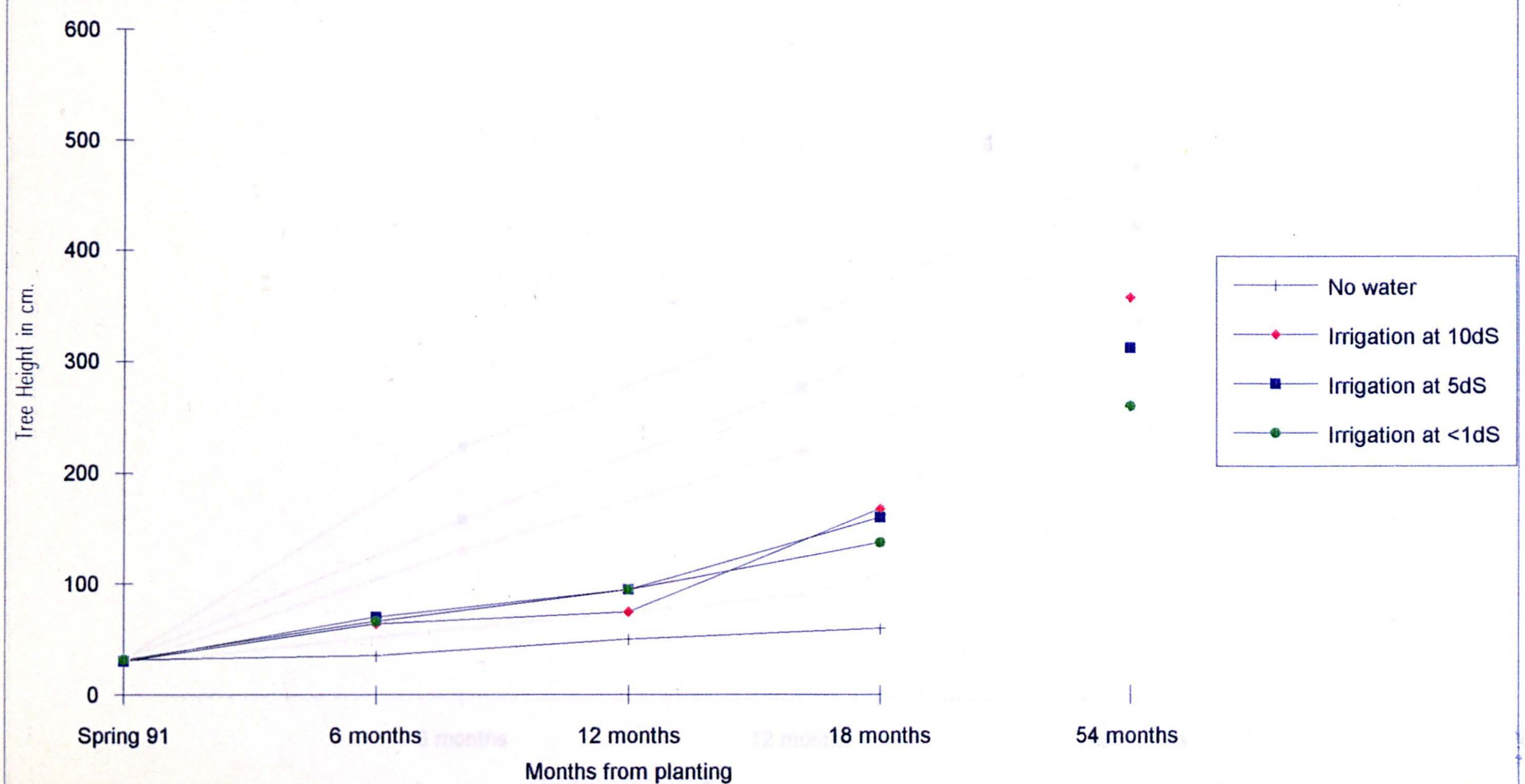


Fig.28e. 1991 Plantings: Site 1 Mean Acacia Heights in all Irrigation Classes to 1992.

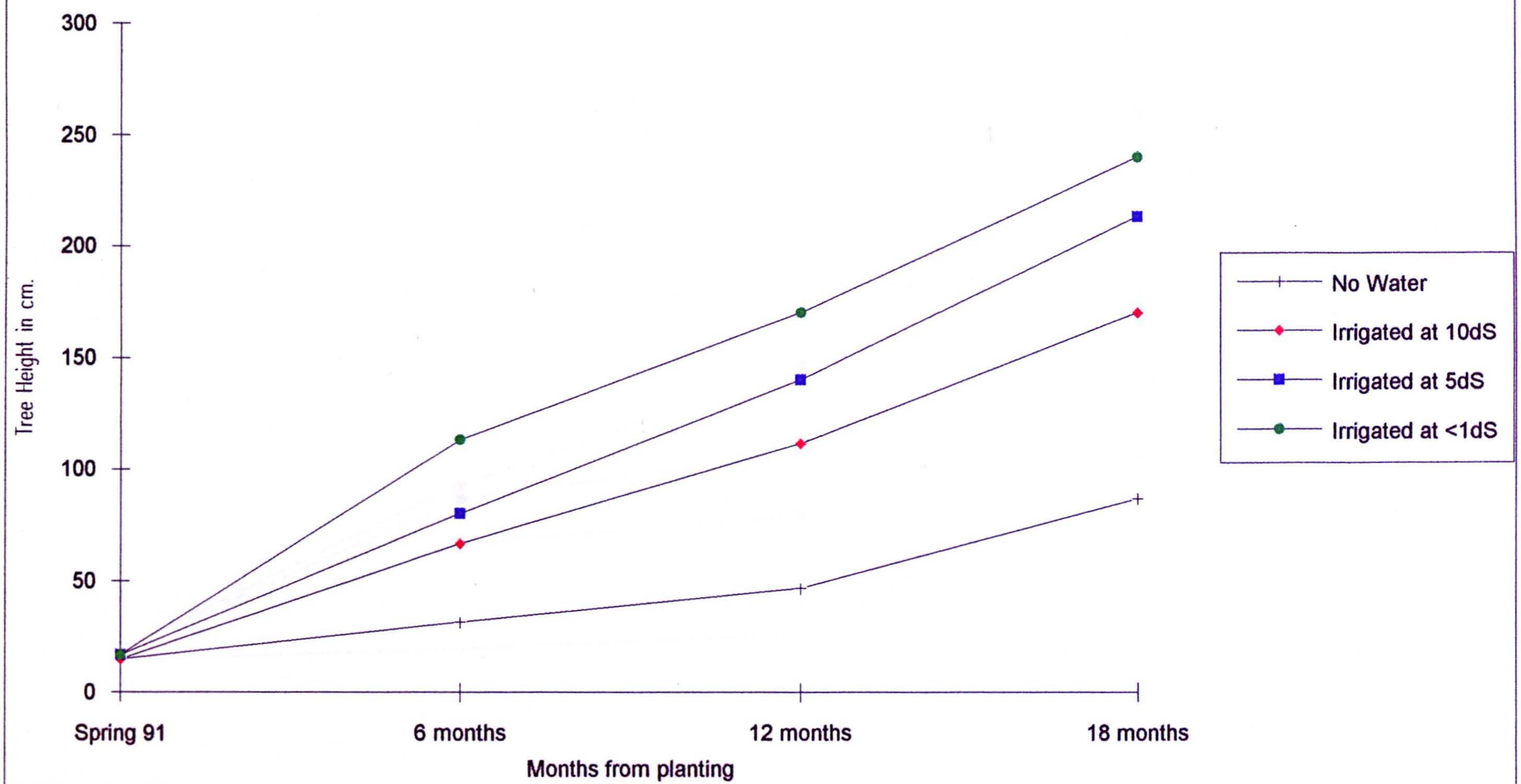
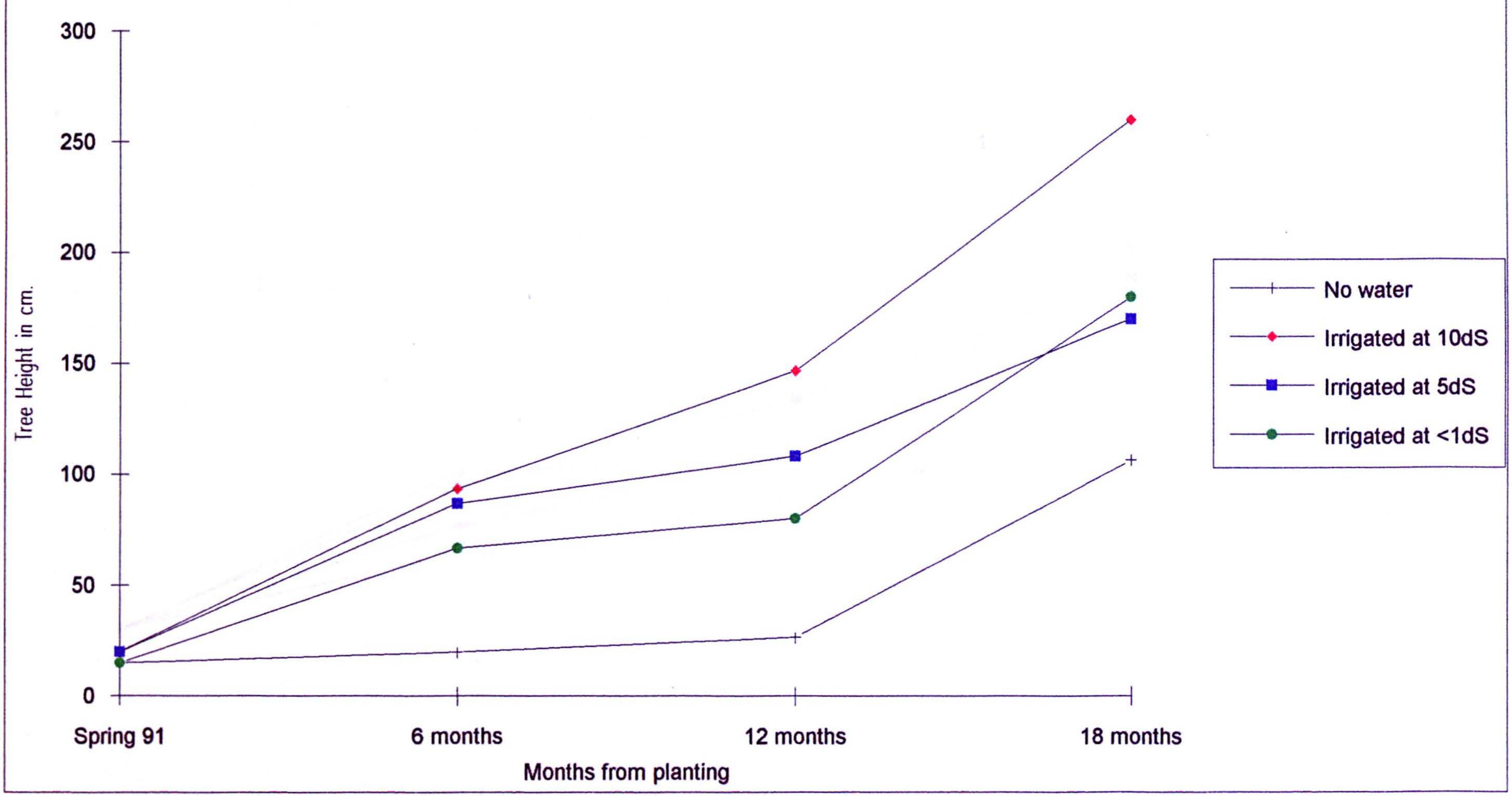


Fig.28f. 1991 Plantings: Site 2 Mean Acacia Heights in all Irrigation Classes to 1992.



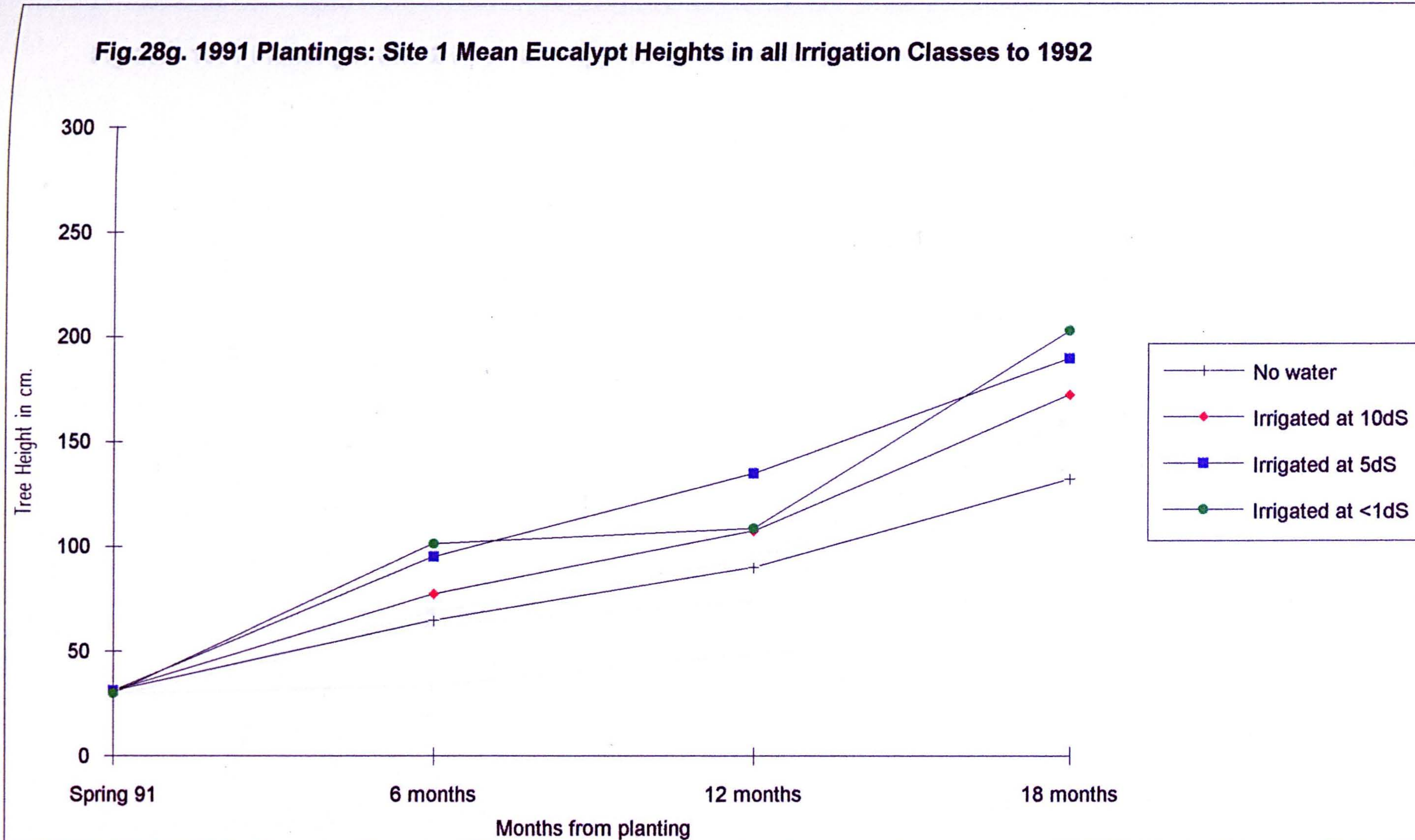


Fig.28g. 1991 Plantings: Site 1 Mean Eucalypt Heights in all Irrigation Classes to 1992
Tree Height in cm.
300
250
200
150
100
50
0
Spring 91
6 months
12 months
18 months
Months from planting
No water
Irrigated at 10dS
Irrigated at 5dS
Irrigated at <1dS

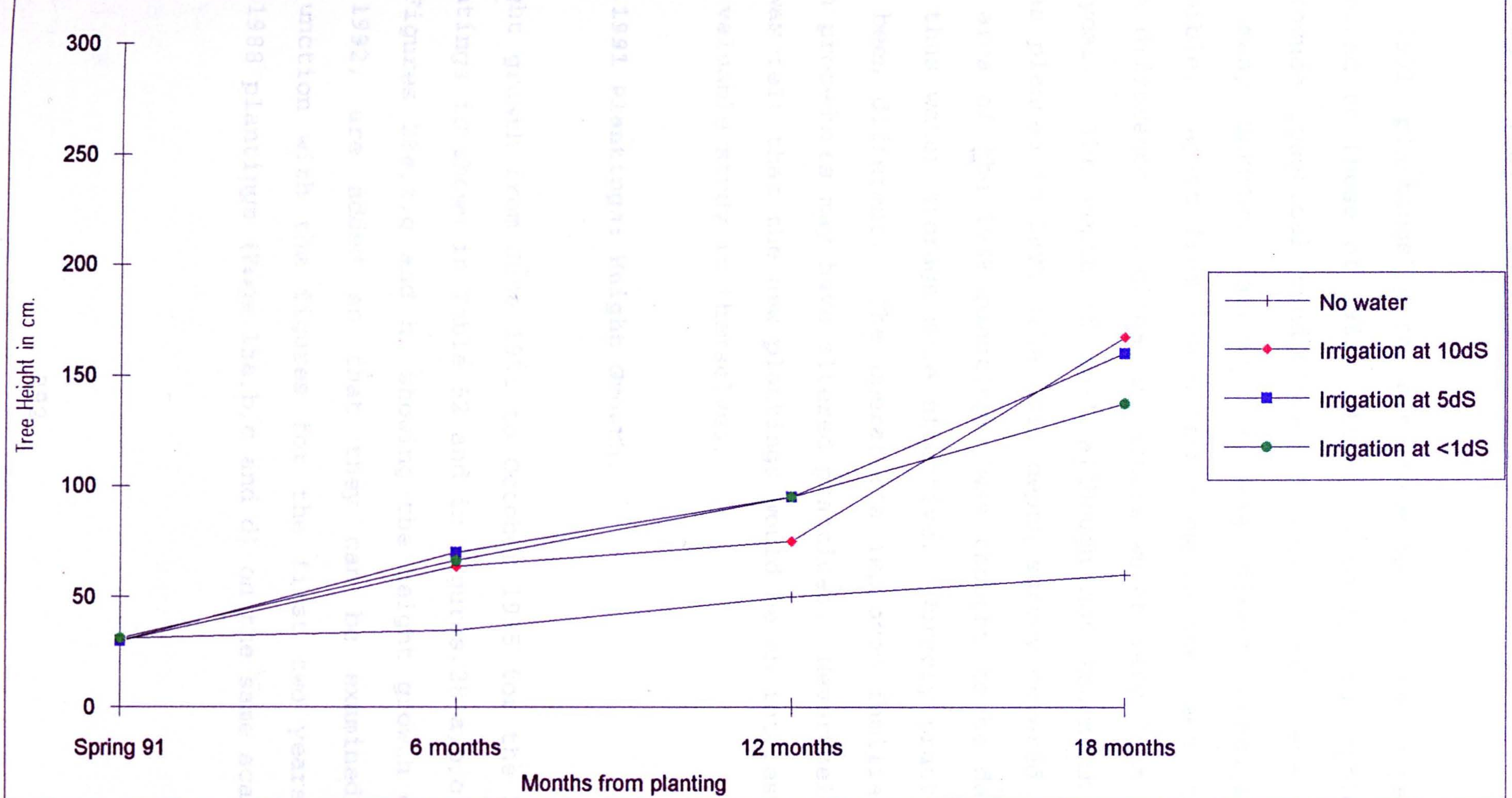


Fig.28h. 1991 Plantings: Site 2 Mean Eucalypt Heights in all Irrigation Classes to 1992.

CHAPTER 7. 1991 PLANTINGS.

The 1991 plantings were not intended to be directly compared to those of 1988. It was clearly impossible to reproduce identical conditions of growth and there were too many unknown factors to make direct comparisons possible. Apart from the differences in the seed, there were differences in climatic factors which vary from year to year. The depth of soil although not known in the areas planted in 1991 (the soil depth survey covered only the area of the 1988 plantings) was thought to be deeper and thus water storage more effective. Nursery practices had been different. The operator's improved familiarity with procedures may have altered practices. Nevertheless, it was felt that the new plantings would be an interesting and valuable study in themselves.

7.1.1991 Plantings: Height Growth.

Height growth from June 1991 to October 1995 for the 1991 plantings is shown in Table 52 and in Figures 28 a,b,c and d. Figures 28e,f,g and h, showing the height growth only to 1992, are added so that they can be examined in conjunction with the figures for the first two years of the 1988 plantings (Figs.15a,b,c and d) on the same scale.

Table 52. 1991 Plantings: Acacia and Eucalypt Mean Heights. Sites 1 and 2. June 1991 to October 1992. Height and (standard deviations) in cm.

	June91 (at planting)	Oct91	Apr92	Oct92
Site 1 Acacia				
No water	15.0 (0.0)	31.7(17.5)	46.7(23.1)	86.7(28.9)
10dS	15.0 (0.0)	66.5(15.3)	111.7(27.5)	170.0(43.6)
5dS	16.7 (2.9)	80.0(20.0)	140.0(26.4)	213.3(28.9)
<1dS	16.7 (2.9)	113.3(41.6)	170.0(45.8)	240.0(34.6)
Site 2 Acacia				
No water	15.0 (0.0)	20.0 (8.7)	26.7 (5.8)	106.7(23.1)
10dS	20.0 (8.7)	93.0 (5.8)	146.7(15.3)	260.0(17.3)
5dS	20.0 (8.7)	86.7(67.9)	108.3(92.5)	170.0(98.5)
<1dS	15.0 (0.0)	66.7(41.6)	80.0(51.9)	180.0(56.6)
Site 1 Eucalypt				
No water	31.2(7.5)	65.0 (5.8)	90.0(24.5)	132.5(61.8)
IOdS	31.2(7.5)	77.5 (9.6)	107.5(22.2)	

				172.5(51.2)
5dS	31.2(7.5)	95.0(17.3)	135.0(31.1)	190.0(53.5)
<1dS	30.0(7.1)	101.2(65.9)	108.7(62.8)	203.3(64.3)
Site 2 Eucalypt				
No water	31.2 (6.3)	35.0 (7.1)	50.0 (0.0)	60.0 (0.0)
10dS	30.0 (5.8)	63.7 (7.5)	75.0 (7.1)	167.5(29.9)
5dS	30.0 (5.8)	70.0(14.1)	95.0(12.9)	160.0(27.1)
<1dS	31.2 (6.3)	66.2(12.5)	95.0(20.8)	137.5(18.9)

Tree growth was well established by the end of the second season. Again there were major responses to irrigation. In these plantings, the acacias were taller than the eucalypts by the end of the second year. By October 1992 at Site 1, both acacias and eucalypts showed a textbook pattern of growth, showing a growth spectrum from least in the no water class to greatest in the <1dS class (Figs 28a and c). At Site 2, as in the earlier plantings, this pattern was not evident (Figs 28b and d).

Standard deviations, as would be expected, became larger with the growth of the trees, and reflected the unevenness of growth, especially among the 5dS acacias at Site 2.

7.2. Water Quality Effects.

Again, trees in the irrigated sections performed substantially better than those which received no irrigation (Figs 28a,b,c and d).

There were no significant height differences between trees assigned to the four water classes at planting when tested by Kruskal Wallis tests. Differences between irrigated and unirrigated trees were substantial at all future dates. Figs.28a-h show that the unirrigated trees performed less well than the three irrigated classes at all dates after planting. When the three irrigated classes are examined

without the unirrigated trees, there is very little difference between them.

7.3. Site Differences.

Mann-Whitney U tests gave the differences between the two sites shown in Table 53.

Table 53. 1991 Plantings. Tests of Height Differences between Sites for Trees in all Water Classes from Planting to October 1992. Mann-Whitney U Tests.

	Acacia: U	N	Eucalypt: U	N
June 1991				
(at planting)	70.0	24	128.0	32
October 1991	169.5	24	57.0*	30
April 1992	53.0	24	56.0*	30
October 1992	65.3	23	69.0	29

* = significant at p <.025

(Site 1 > Site 2 in both significant cases)

Fig.29 a.b.c. 1991 Plantings: Exchangeable Sodium Percentage . Site 1

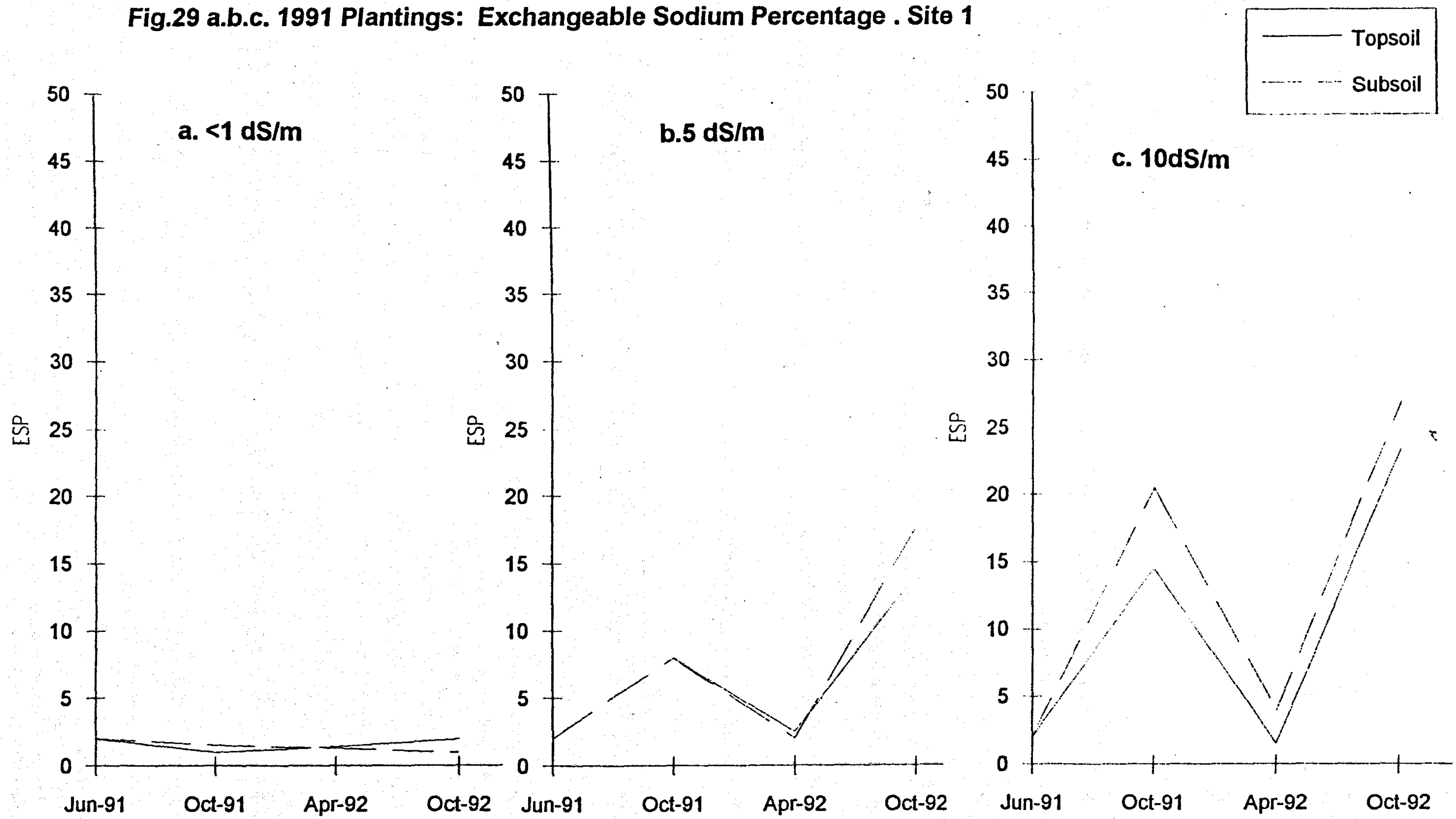
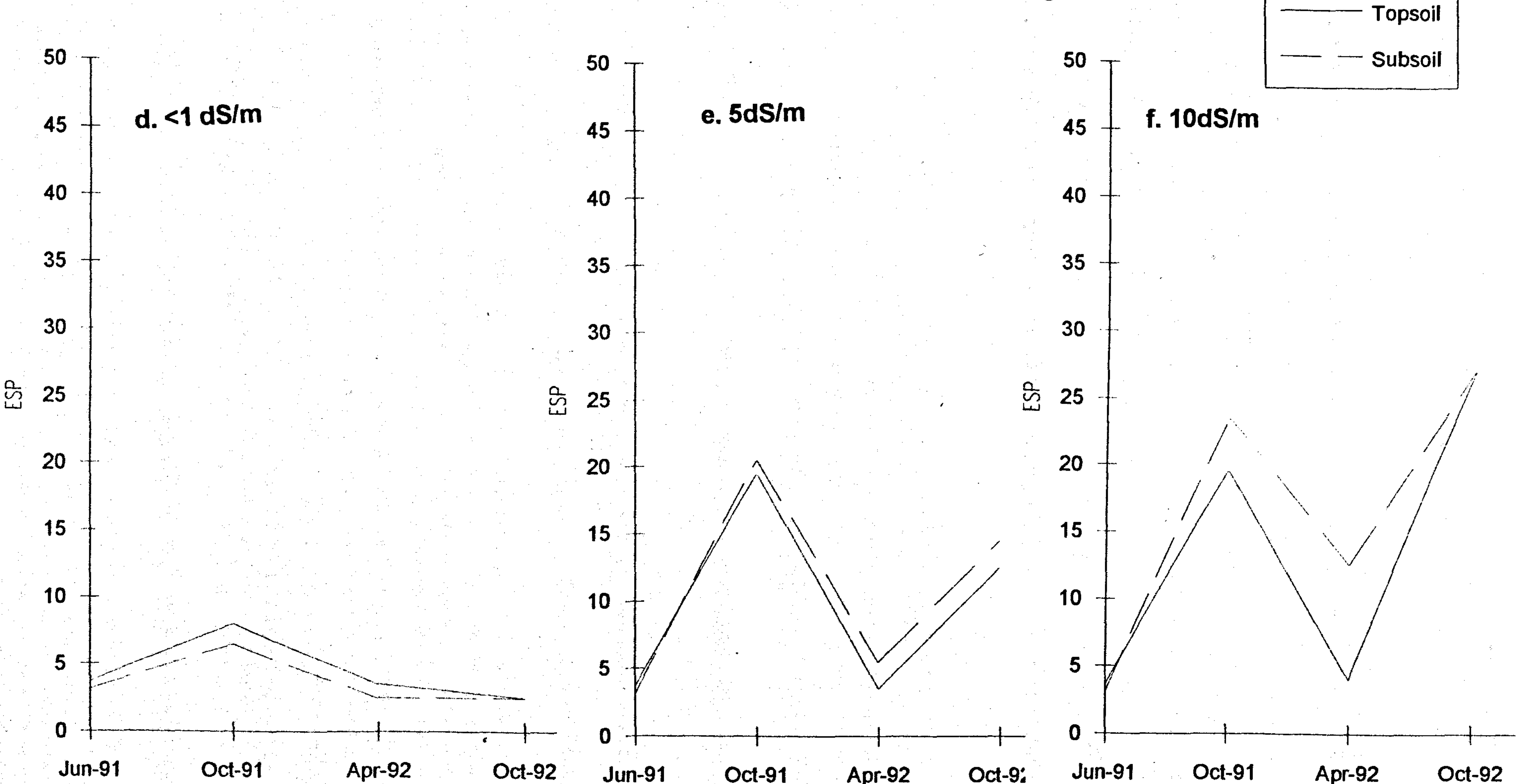


Fig.29 d.e.f. 1991 Plantings. Exchangeable Sodium Percentage. Site 2



7.3.i. Site Effects

There were differences between the two sites for eucalypts at October 1991 and April 1992, when Site 1 trees were significantly taller than those at Site 2. However, the Site 2 eucalypts caught up and there were no significant differences by October 1992.

7.3.ii. Site and Water Quality Effects.

Differences between sites by water quality were examined, to see if the differences between sites for eucalypts at October 1991 and April 1992 shown in Table 53 could be more closely identified. In this analysis, no significant differences were observed between sites in any of the water quality classes. It must be assumed that the differences between sites for eucalypts at October 1991 and April 1992 are spread fairly evenly over all four water quality groups.

7.4. Survival.

In the summer of 1991, 2 unirrigated eucalypts died at Site 2. In the summer of 1992, 1 eucalypt irrigated with BAW (<1dS) died at Site 1 and 1 acacia irrigated with BAW died at Site 2. The deaths of the two irrigated trees may have been related to soil depth, but since the soil depth survey

did not extend to this part of the field, there is no evidence.

7.5. Exchangeable Sodium Percentage: 1991 Plantings.

ESP of the soils under the trees planted in 1991 from the date of planting until October 1992 is shown in the Table 55 and in Figs.29a,b,c,d,e and f, which are drawn to the same scale as Figs.23a,b,c,d,e and f (1988 Plantings).

Table 54. Exchangeable Sodium Percentage: 1991 Plantings.

	10dS		5dS		<1dS	
	Top soil	Sub soil	Top soil	Sub soil	Top soil	Sub soil
Site 1.						
Jun 1991	2.00	2.02	2.00	2.02	2.00	2.02
Oct 1991	14.50	20.50	8.00	8.00	1.00	1.50
Apr 1992	1.50	4.00	2.50	2.00	1.40	1.30
Oct 1992	23.50	27.00	14.00	17.50	1.95	1.00
Site 2.						
Jun 1991	3.72	3.14	3.72	3.14	3.72	3.14
Oct 1991	19.50	23.50	19.50	20.50	8.00	6.50
Apr 1992	4.00	12.50	3.50	5.50	3.50	2.50
Oct 1992	27.00	27.00	12.50	14.50	2.50	2.50

The ESP of the soils under the 1991 plantings started from a lower base than those under the 1988 plantings. At April 1988, readings were 5.06% for Site 1 and 4.25% for

Site 2.

At June 1991, readings were 2% for topsoil and 2.02% for subsoil at Site 1 and 3.72% for topsoil and 3.14% for subsoil at Site 2.

The pattern of rise and fall was substantially the same, exhibiting the usual high percentage at the end of the irrigation season and fall during the winter months. As in the 1988 plantings, the build up of salts was very much higher at the end of the second irrigation season than at the end of the first. However, the peaks were not as high as those of the 1988 plantings. It is possible that the lower base in 1991 was caused by greater pre-season precipitation than in 1988 and that the fewer but heavier waterings compounded this effect in the second season so that the end of season peaks did not reach 1988 levels.

As has been previously stated, these plantings were not intended to be a direct comparison with the earlier ones. Many factors may account for the differences. To take only one, the pre-season winter rainfall was 236.4mm in the winter of 1987-1988 and 371.7mm in 1990-1991. Thus, the 1991 plantings started off with a substantially higher reserve of moisture in the soil.

At Site 1, the curve for the <1dS irrigation is almost flat. There is almost no difference between top and subsoil and the seasonal differences are minimal. At Site

2, in this irrigation group, the subsoil always shows a lower percentage of salts than the topsoil, but a seasonal difference can be observed. The rise at the end of the first season and the fall during the winter are quite marked, but there is no corresponding or greater rise at the end of the second irrigation season.

In the 5dS irrigation at Site 1, the pattern is very similar to that of the earlier planting. The seasonal variations are quite clear and the subsoil at the end of the second season has a higher concentration of salts than the topsoil. The second season peak is higher than the first season. In this group at Site 2, however, although the seasonal fluctuations and the higher subsoil concentrations show the same pattern, the first season's peak is substantially higher than the second. Again like the earlier plantings, the highest peak (19.5% for topsoil and 20.5% for subsoil) at October 1991 are very nearly as high as the values in the 10dS section at this site.

At Site 1 the 10dS irrigation group shows the classic pattern of seasonal rise and fall with the subsoil quickly accumulating more salts than the topsoil and the second season's peak being greater than the first. Site 2 values mirror Site 1, the only substantial difference between the two sites being the convergence of top and subsoil values at October 1992.

Thus, with some small anomalies (the flat curve or the <1dS irrigation at Site 1 and the lower peak in the 5dS section at October 1991) the pattern of salt accumulation in the irrigation season and dispersal with the winter rains is very similar to the pattern of the earlier plantings.

7.6. Comparison of 1988 and 1991 Plantings.

Although, owing to the factors mentioned above, the two plantings cannot be directly compared, it is interesting to look at the differences in height growth at the three stages (end of first irrigation season, beginning and end of second irrigation season). The 1988 growth can be seen in Figs.15a,b,c and d, and the 1991 growth in Figs.28a - h. Difference were examined by Mann Whitney tests and results are given in Table 55.

Table 55. Tests of Height Differences between 1988 and 1991 Plantings. Trees in all Water Classes. Mann Whitney U Tests.

		Acacia:		Eucalypt:	
		U	N	U	N
End of 1st season					
(Oct 88/Oct 91)	No water	47.0	38	64.5	33
	10dS	66.0	38	100.0	39
	5dS	90.5	38	116.5	40
	<1dS	76.5	38	125.0	40
Start of 2nd season					
(Apr 89/Apr 92)	No water	42.0	38	54.0	30
	10dS	65.0	38	102.5	39
	5dS	73.0	38	105.0	38
	<1dS	67.5	37	108.5	38
End of 2nd season					
(Oct 89/Oct 92)	No water	58.5	37	53.0	28
	10dS	40.5	38	78.0	39
	5dS	47.5	38	117.0	38
	<1dS	19.0*	36	89.5	37

Trees of the 1991 planting were, in general, taller at all stages than those of the 1988 planting, but the differences were not significant for eucalypts. For acacias differences only became significant at the end of the second season in the <1dS class, where the 1991 plantings were significantly taller than the 1988. In these plantings, the acacias were still taller than the eucalypts at the end of the second season. In the 1988 plantings, the eucalypts had overtaken the acacias in height growth by this time.

The growth patterns of the two plantings showed more similarities than differences. The most noticeable difference was that only in the 1991 plantings at Site 1 did both acacias and eucalypts approximate to the classic pattern of greater growth with better water. The 1991 plantings were measured again at May 1993. At that time, both acacias and eucalypts of the 5dS classes had caught up with the <1dS classes, but the 10ds classes still lagged behind. It should be remembered that the 1991 plantings represent a very small sample (three acacias and four eucalypts in each water class at each site). It is therefore doubtful if the poorer performance of the three acacias and four eucalypts in the 10dS class could indicate a trend not evident in the rest of the plantings. However, given the evidence of Shaybany and Kashirad (1978) and Tomar and Yadav(1980) it should be borne in mind. It is possible that the local provenance is not as salt tolerant as the Australian provenance. Even so, the effect could hardly be described as stunting as the trees were in fact bigger than those of the earlier planting.

Overall growth was better for the 1991 plantings. Although total irrigation amounts were similar for both plantings, in the second season the 1991 trees received fewer waterings at twice the previous volume. It is possible that this may have had an influence on growth (Shalhavet 1973 and Willens 1978). The pattern of greater initial growth at Site 1, with Site 2 trees catching up after an interval, was repeated. Both plantings responded to irrigation in the same way. Irrigated trees grew better than unirrigated and although this response was not so extreme in the 1991 trees as in the earlier plantings, it was nevertheless clear. There were no substantial differences between the three irrigated classes.

The survival of the 1991 plantings at Site 1 was very much the same as that of the 1988 trees. At Site 2 the survival rate of the later plantings was very much higher. As has been previously stated (See above Section 7.5) ESPs showed a very similar pattern for both 1988 and 1991 plantings.

Growth differences may be attributable to many causes. The seeds were of different provenance. Climatic factors were obviously not identical. In particular, the soil moisture deficit in 1988 must have been considerably greater than in 1991 (See Pre-season Precipitation, Table 9). Soil depth for the 1991 plantings is unknown.

It is nevertheless encouraging that it was possible to repeat the experiment and the later plantings were a useful independent check on the validity of the first results.

CHAPTER 8. CONCLUSIONS

There had been clear and continued growth of the trees, and survival was better than had been expected at the start of the experiment. It was already plain from observation that there were major responses to irrigation, both in height growth and survival rates. Regression analysis of height over time showed the close convergence of the three irrigated classes, with the unirrigated trees generally less tall and less able to survive. The trees grew well with even the most highly saline water. Between the three irrigated classes, differences in height growth or survival due to water quality were hardly detectable. The degrees of variability within the irrigated classes were very similar.

The system of irrigating according to pan/tensiometer readings appeared to give satisfactory results. The threshold figure given by Moore (1983) of 70 pascals was so given because previous experiments had revealed tip and marginal leaf tissue necrosis at that figure. The lower figure of 50-60 pascals was chosen to avoid any such effects and none were observed. The actual amounts of water applied on this basis were very low in forestry terms. Nevertheless, it appeared adequate for survival and steady growth except where the water holding capacity of the soils was drastically reduced owing to their extreme shallowness.

It is not easy to relate much of this research to earlier work, as the conditions were very different. However the amounts indicated by the pan/tensiometer readings fell within the range of those studies where very small amounts of water have been applied to trees. Zohar (1982) used only 10-15 litres per tree at two month intervals in the first year, whilst Sandell et al (1986) found that 20 litres/tree at weekly intervals for the first month and two weekly for a further six months was sufficient for establishment. Burman (1991) in a dose rate experiment found that while 12 litres per tree at two week intervals was sufficient to eliminate mortality, 46 litres/tree every two weeks led to maximum growth and biomass production.

There was very little difference in height growth between trees in the two year and the four year irrigation. Tree heights two years after the division of blocks tended to reflect heights at 1989, when the division for two or four year irrigation was made, rather than irrigation duration. Although there was a certain amount of patchy and uneven growth, analysis showed significant differences between the two duration periods in only one group (eucalypts irrigated at 5dS/m) which had already showed significant differences between the same blocks at October 1989.

It therefore seems that two years irrigation is sufficient to establish the trees. Although high salinity of the irrigation water has, in the literature, been reported as stunting (Shaybany and Kashirad 1978) and Tomar and Yadav (1980), the results of this study showed no stunting effect and not even any graduation in height with increased salinity, except for the very few trees of the 1991 plantings at Site 1. Otherwise, the trees irrigated at the highest salinity grew as well as those irrigated with best available water.

Differences in height growth between the two sites appear rather complex. There were many obvious differences between the sites; aspect, exposure to wind and above all, soil factors (with a greater depth of soil at Site 1 but more organic matter and a larger clay fraction at Site 2) which could well account for height growth differences. The SAR of the irrigation water was much higher at Site 1, but this was not thought to influence height growth, as there were more differences between sites in the unirrigated and low salinity groups than in the groups irrigated with the most saline water. The first two years showed better height growth at Site 1, but in the succeeding years the Site 2 trees caught up and in some cases overtook those at Site 1. Height differences between the sites in this second phase lacked any overall pattern.

The factors responsible could not be established with any certainty. The height growth variations between the sites were in any case not great.

When the survival rates at both sites are considered, the picture is entirely different. The very much larger number of deaths at Site 2, was at first extremely puzzling. Any of the Site factors mentioned above could have contributed to these differences in survival. It was at first thought that the eucalypts, which died in much greater numbers at Site 2 when irrigation was withdrawn, were less able to withstand the stress of irrigation withdrawal where soils were shallow. It was known that the soils were somewhat shallower at Site 2 than at Site 1 and it was therefore thought that soil depth might outweigh the better quality of soil at Site 2 where survival was concerned. It was only when the soil depth survey was undertaken and the figures examined that it became evident that the blocks where large numbers of eucalypts had died fell on ground that was significantly shallower than the average for the site. Both species showed greatly increased mortality on soil depths of less than 25cm.

Thus, the most important finding demonstrated by the experiment is that when the acacia and eucalypt provenances used in this study are irrigated for two years at the irrigation rates and salinity levels employed here, satisfactory establishment and vigorous early growth can be achieved where soils are more than 25cm deep. When compared to the unirrigated trees, the final effect of the initial watering shows the long term value of the early boost.

The monitoring of exchangeable sodium also showed interesting results. By the end of the second summer, the peak at the end of the irrigation season was extremely high. It is notable that in spite of the extremely high SAR at Site 1 (152.1 for the 10dS/m solution and 84.8 for the 5dS/m solution) ESPs in the high salinity groups at Site 1 did not rise substantially higher than those at Site 2. The highest peak of ESP (43% for topsoil and 47% for subsoil for the 10dS/m irrigation at Site 1 in October 1989) was not repeated in subsequent years. It is possible that this is attributable to the higher pre-season rainfall in the 1990 and 1991 seasons. There was very little mortality at Site 1. At Site 2, where mortality was greater, there was no evidence that death was linked to high salinity. By October 1992, the exchangeable sodium in the soils under all but the 10dS irrigation had returned to pre-irrigation levels. At October 1995, the confidence limits established by the 1995 soil analysis encompassed the original exchangeable sodium levels.

The recommendation of van Hoorn (1968) that seasonal leaching was preferable to leaching at every irrigation appeared logical, but since no other leaching practice was tried, results could not be compared. Jain and Pareek (1989) found that winter rainfall alone was adequate for leaching after their irrigation of date palms with waters of up to of 9dS/m. On the other hand Tanji and Karajeh (1993) found that irrigating eucalypts with waters of 10dS/m and a leaching fraction of 16% led to a considerable build up of salts in the soil. The California mean annual precipitation of 187mm was inadequate for leaching.

Jain and Muthana (1982) irrigated several tree species with waters of up to 9dS/m with good survival for some species. Shaybany and Kashirad (1978) found that _A. saligna_ could tolerate relatively high levels of salinity, but noticed the stunting effect mentioned above. Tomar and Yadav (1980) in a study of several forest species found not only stunting but increased mortality with increasing salinity. In the present study, mortality was not found to be linked to the salinity of the irrigation water and a stunting effect was not apparent.

Levels of exchangeable sodium declined each year with the winter rains. In the 5 and 10dS/m classes they did not, however, decline to pre-irrigation levels until irrigation was stopped. From this date (October 1989 for half the irrigated trees) exchangeable sodium in the soil fell off to pre-irrigation levels within eighteen months for all except the 10dS/m classes. By April 1992, two and a half years after irrigation had been withdrawn, exchangeable sodium percentages in the 2 year irrigated 10dS/m classes had also declined to pre-irrigation levels. The 1992 figures indicated that the blocks irrigated for four years would revert to pre-irrigation levels of exchangeable sodium even more quickly. Like the lower end-of-season peaks, this may be attributable to higher precipitation. By 1995, all classes had in fact reverted to pre-irrigation levels.

This seems to demonstrate that when highly saline irrigation is applied in limited quantities and for a limited time with sufficient water to leach (in this case winter rains of approximately 300mm) the soil will return to previous sodium levels once irrigation is withdrawn.

In spite of some anomalies, the pattern of litter accumulation showed a steady increase with time. Some reservations were felt about the method of measuring decomposition in mesh bags, but the acceleration of weight loss in the litterbags with time was clear, as was the fact that litter accumulated, fragmented and disappeared faster with irrigation. In this experiment, litter was being added to the soil at the rate of 1-2 tons/ha/year for unirrigated trees and 2-3 tons/ha/year for those which were irrigated by the time the trees were five years old. This is similar to the findings of Gill et al (1987) and Birk and Turner (1992). Like Lamb (1985), this study found a summer peak of litterfall, well defined in the irrigated sections and not so marked, but still quite evident under the unirrigated trees. Decomposition rates were higher than those found by Lamb, but similar to those of O'Connell (1986). However, the author's own reservations about the validity of the findings from litterbags and the warning of Woods and Raison (1982) against extrapolating long term trends from such findings should be kept in mind.

Organic matter built up in the soil over the whole period from planting. At October 1992, when the trees had been in the ground for four and a half years, adjacent unplanted ground continued to give readings very close to those at the start of the experiment (1.7% for Site 1 and 4.5% for Site 2). All ground with tree cover gave readings well in excess of these figures. Whilst the levels of OM were higher under the irrigated trees than under those which had received no irrigation, differences between the four year and two year irrigated ground were minimal, reflecting the small differences in the size of the trees in the two sections. Tree planting, especially with irrigation, had substantially improved the soil status. The accumulations over the original values of approximately 3-4% in the unirrigated sections and 7%

where the trees were irrigated are higher than the figures given by O'Connell (1986).

Height growth and ESP figures for the 1991 plantings, although they could not be directly compared to the results for the trees planted in 1988, showed that it was possible to repeat the experiment with similar results. This was an important finding, particularly in the light of the limitations imposed by the experimental design. These plantings repeated the trends of the first plantings in all important respects.

The 1995 work was valuable in showing the amount of variation in height growth within the water classes. The 1991 plantings were not included in these investigations, except for taking basic data on height and diameter, as the soil survey had not extended to the 1991 planted area. It was particularly soil variables in relation to height of the 1988 plantings which were examined at this time.

The opportunity to examine soil factors in relation to height gave another perspective to the previous results. The three irrigated classes showed a similar uniformity to that which had been revealed by previous examination. There were no substantial differences between the classes. Again, previously observed trends continued to operate. Variability within the irrigated classes, shown by the standard deviations (drawn as error bars in Figs.21a - h) grow greater with time but overlap in all three classes. The unirrigated trees, with a very few exceptions, had

achieved less height growth even three years after the end of the experiment. All but one of the exceptions were inside row trees and may be assumed to have been 'stealing' water from adjacent irrigated rows.
The consistency of results in both species justified the choice of two, rather than one species for examination and the lack of additional mortality, three years on, appeared to show that the trees were now well established.

The design, although not ideal, had enabled the examination of these trends as a more conventional design would not have done. Within the constraints of these particular sites it would have been impossible to avoid interference between treatments. The evidence for lateral flow - proved by the height growth data and the overlapping roots examined - showed that a randomised design within these constraints could not have revealed the actual situation in the field. The very important differences between irrigated and unirrigated trees might well have been obscured. It was also clear that a 1x1 metre planting scheme would have obscured growth patterns. The crown diameter of both species was far in excess of 1x1.
Three years on, ESP had stayed low. It was not possible to see whether the prediction of 1992, that ESP of soil under the 4 year irrigated trees would return to normal very quickly, had in fact taken place as soil analysis had not been performed in the interim. At 1995, all soils

showed levels of ESP very near the starting values. Organic matter had built up at a slower rate than when the trees were under irrigation. Nevertheless, organic matter continued to accumulate.

There had been practical difficulties such as the initial problems in taking accurate pan readings and the physical difficulties of obtaining the sea salt for mixing and smashing it to a consistency suitable for dilution. The poor germination rate for acacias set the experiment back and the unsuitability of the multiple watering system was a disappointment, as was the failure of the idea of a tube inserted by each tree at planting for conserving water (this still seems to be an idea with possibilities if a much lower irrigation rate was considered - the failure was due to the fact that the rate indicated by the pan/tensiometer findings indicated more water than the tubes would accommodate). Some seemingly simple decisions were difficult in the field. In the first year, when water application fell behind the pan/tensiometer readings in one month, it was decided to compensate with the application of additional water in the following month. When this happened in subsequent years, it was decided not to compensate. It is still doubtful which was the correct decision. On the question of pruning the lower forks of the trees in the winter of 1990, it is still uncertain whether the right decision was taken.

The division of precipitation into summer and winter fractions proved a more useful guideline for calculation of soil moisture at the start of the growing season than the calendar year figures. The concept of 'effective' precipitation was perhaps not particularly useful in the context of this study. It was nevertheless interesting in showing that precipitation figures should be treated with caution. Not only do they give an unrealistically high indication of available water, but it is also clear that the percentage of total rainfall deemed effective varies from year to year. During the period of the study, this percentage varied between 51 and 71 percent of total precipitation.

In appraising the experiment and considering further research needs in this area, it is immediately obvious that a repetition of the experiment on a much larger area, which would allow for an experimental design incorporating randomisation, would be of great value, allowing valid statistical appraisal of results.

Testing other provenances in similar conditions, and the same provenances in other soil conditions would be a useful study, giving an opportunity for comparison and observation of whether the trends noted in this experiment reoccurred. More work of this nature would give an opportunity to generalise from the results.

Since even the saltiest water was well tolerated, then with more space at the sites, another treatment at a higher salinity level would have been interesting. The time to recovery of the soil at this higher level would have been a valuable study as would the effects on survival, growth and form of the trees. Detrimental levels of salt on soils and tree growth are of great interest in land reclamation.

An irrigation dose rate experiment would have been extremely useful. Not only optimum irrigation amounts, but

also minimum necessary quantities could have been established and related to soil depth.

Had resources been adequate, a more comprehensive soil depth survey, extending to the area of the 1991 plantings, would have been useful. Even the hammering in of a crowbar at planting would have helped to determine areas of probable inequality of soil depth and so helped to refine the experimental area.

Excavations to study root growth would also have been valuable in assessing the volume of soil space occupied by each tree, but would have involved an amount of physical labour that was not feasible in the present study. For a further study, it would be interesting to undertake extensive root examination after two years irrigation. Ideally, it would be best to establish a separate small plot incorporating the four water quality classes for this purpose. Thus, the area of the main experiment would not be disturbed, nor the tree numbers unbalanced.

With additional labour, a very great deal more soil analyses could have been undertaken and it would have been interesting to combine salinity levels with a spacing trial in a factorial design, given that spacing in forestry is, in effect, another type of dose rate trial (the space occupied by individual tree roots will clearly affect concentrations of salts or any other applied treatment, as the physical amount of soil available for dilution of salts will affect the concentrations). Growth and survival of

individual trees could have been examined in much greater detail if tree-by-tree soil data had been available.

More and better photographs would have helped considerably with the visual interpretations of trends.

In spite of the difficulties and reservations described above, the research has shown that in these Mediterranean dry land conditions, it is possible to attain rapid tree establishment, environmental protection in the form of soil improvement and canopy cover with small amounts of low quality water on soils more than 25cm. deep. Moreover the results show that two years irrigation at these levels is sufficient for tree establishment. The temporary environmental cost of rising exchangeable sodium percentages in the soil is short lived and the benefits of increased litter production and amelioration of the soil status appear sustainable in the long term. These results, if confirmed by larger randomised studies, could be widely applicable in areas with similar climatic conditions

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