HYDROCARBON PRODUCTION AND GROWTH OF EUPHORBIA LATHYRIS: A WATER USE STUDY

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF SOILS, WATER AND ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN SOIL AND WATER SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1981

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

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To my wife, Margoth,

for her love, support and encouragement

ACKNOWLEDGEMENTS

The author expresses his deepest respect and appreciation to Dr. Marshall Flug for his guidance, suggestions, and encouragement throughout the course of this study. Thanks are also extended to other members of the committee, Professors Delmar D. Fangmeier and Arthur W. Warrick for their critical review of this manuscript.

Sincere thanks are extended to Stephen Husman, for his technical help.

Finally, I would like to extend thanks to the Diamond Shamrock Corporation for financial support of this research through the Office of Arid Lands Studies.

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ABSTRACT

Euphorbia lathyris, a hydrocarbon producing plant was field tested at the University of Arizona. Flood irrigation of small basins was used to determine the growth, percent of biocrude, total biocrude production, and field water use of E. lathyris as a function of soil moisture availability. Two ecotypes of E. lathyris from Palo Alto and Chico, California, were studied.

Four distinct water regimes were used in this experiment. A high supply of water was available to plants in the wettest treatment. Plants in the driest treatment were under water stress during almost all the growing season. The other two treatments were irrigated as a fraction of the water applied in the wettest treatment to provide four distinct irrigated water treatments.

The Palo Alto ecotype clearly outperformed the Chico in all parameters measured even though similar water use was observed for both ecotypes. A positive relationship was observed between soil moisture availability and plant growth, total biocrude production, and water use. However, no relationship was found between percent of biocrude and soil moisture availability. The highest yield recorded in this study was 8.4 barrels/ha of biocrude with a water use of 67 cm in the wettest treatment of the Palo Alto ecotype.

INTRODUCTION

Through history man has always used photosynthetic products to supply his energy demands. First, wood was the exclusive source of energy; in the United States, for instance, wood provided more than the 90% of the neergy required in the middle nineteenth century (McMullan, Morgan and Murray, 1977). In this period, the United States was still primarily under an agrarian economy with large reserves of wood fuel. In the late part of the nineteenth century the traditional use of wood for fuel declined in favor of coal which by 1910 supplied 75% of the energy used in the United States. Petroleum utilization started to increase early in the twentieth century and by the nineteen fifties became the most important energy source in the country. In 1980 oil was still the main source of energy, supplying 45% of the total energy consumed in the United States followed by natural gas with 27% and coal with 21% (U.S. Department of Energy, 1981).

Petroleum and natural gas, which provide the majority of the energy used in the U.S. at present, are being depleted at a much faster rate than new supplies are being discovered. In fact, we are using in a matter of decades the energy supplies that took millions of years to deposit. Estimates vary among experts regarding the quantities of fossil fuels remaining and the length of time they will serve as primary energy sources. Pessimistic estimates mention a few decades, while the most optimistic predict about 300 years (Meador, 1974). Many experts agree that coal and oil shale reserves are large enough to last for hundreds of years. However, the use of these reserves on a very large scale is restricted by pollution from burning and visual scars from large scale mining as well as a lack of adequate technology for conversion to highly demanded liquid fuels.

The U.S. is a high energy consuming country which depends largely upon imports to fulfil energy requirements. With 6% of the world's population, the U.S. consumes one-third of the world's energy (Hammond, Metz and Maugh, 1973). In 1980 the U.S. imported 20.6% of the total energy consumed. During that year, the daily oil demand in the country was 17.03 million barrels with imports of 6.79 million barrels per day, which represented about 40% of the oil consumed (U.S. Department of Energy, 1981).

Forecasting energy prices is a difficult task because political factors are predominant in determining these figures. This is especially true for oil prices which were fairly constant until the early nineteen seventies, but thereafter increased dramatically as shown in Table 1. Although energy price projections vary from source to source, there is general agreement that prices will increase irreversibly.

Fossil fuel depletion, pollution problems, high dependence on imports, and increasing prices of actual energy sources are facts that make the search for alternative energy sources worthy of serious attention. It will be mandatory to shift some day to non-fossil resources. Energy options such as nuclear power, solar energy, geothermal, and others have been investigated and received various levels of support.

Table 1. World oil prices, history and projections.

	World Oil Prices				Projected			
	1965	1973	1978	1979	1980	1985	1990	1995
World oil price*, Dollars per barrel	6.0	6.5	15.5	21.5	30.5	32.0	37.0	41.0

*Cost of imported oil to U.S. refiners in 1979 dollars, Congressional Research Service (1980).

However, none are technologically and environmentally ready to substitute for fossil fuels, particularly for petroleum fuels and products.

One energy option that has recently received serious consideration is the use of green plants as a renewable source of energy (Calvin, 1977; Calvin, 1978b). Through the mechanism of photosynthesis, all higher plants can capture carbon dioxide from the atmosphere and fix it into carbohydrates. In addition, some plants have the ability to reduce carbohydrates to form hydrocarbon-like compounds which substitute for petroleum.

In July 1978 the University of Arizona became involved in a comprehensive research project to identify, cultivate, and industrialize plant species capable of yielding enough quantities of low-molecular-weight hydrocarbons to economically justify their agricultural production on the sunny, uncultivated, dry land of the American Southwest. The overall research project includes plant material collection, plant breeding, agricultural development, plant physiology, plant chemistry, process chemistry, commercialization, cost analysis, etc.

Several hundred plant species, mostly collected from the wild American Southwest and thought to have a potential to produce hydrocarbon-like materials, have been evaluated by the University of Arizona Hydrocarbon Project. Many of these plants did not pass the selection criteria and just a few species remain as successful candidates. Among the actual plant candidates, *Euphorbia lathyris* has been ranked as the most promising candidate with a high potential to produce materials which might be substitutes for petroleum.

The feasibility of energy production from E. lathyris farming depends largely on the water requirements of this plant. The reason is that extremely large areas of land will need to be planted if biomass is going to contribute as a significant source for energy. Land which would be used for energy farming can not overly infringe upon land which is used to produce food and fiber. Calvin (1977) suggested to use the semi-arid and arid areas of the world because they do not have many competing agricultural uses due to the limiting availability of water. Hence, the importance of determinating the water use of E. lathyris lies in the fact that we are trying to introduce a low water-use crop whose water requirements can be maintained adequately in an arid environment.

Calvin (1977) proposed the southwestern U.S. for energy farming because it is a region of high insolation and hence better for solar energy collection than other areas. The American Southwest receives a mean annual insolation of 250 Watts/m^2, one of the highest on the earth.

In addition to the high degree of solar impingement, vast desert areas suitable for energy farming are readily available. Arid and semi-arid lands cover approximately one-third of the earth's land surface (Goodin and Northington, 1979). Furthermore, desert lands are available in many countries, and it is hoped that the results of arid zone research can be transferred to other regions to more effectively develop their agricultural potential.

Objectives

The research of this thesis is concerned with studying the field water use of *E. lathyris* as specifically identified by the following objectives:

1. To determine plant growth as a function of soil moisture availability.
2. To determine percent of hydrocarbon-like materials (i.e. percent of biocrude) related to soil moisture availability.
3. To determine total hydrocarbon-like materials as a function of soil moisture availability.
4. To determine field water use of the plants during the season.

LITERATURE REVIEW

Practically every one of the traditional crops currently used has been developed over hundreds or even thousands of years. With the knowledge of modern science, the development of new crops can be accelerated. Even though the domestication process can be shortened, a relatively long-term period of investigation might be required before researchers can recommend large-scale plantings as an economically feasible enterprise. Evaluation of _E. lathyris_ started a few years ago and research related to this plant is still in the initial stage of development; therefore, published literature regarding _E. lathyris_ development is very limited.

Botany

The genus Euphorbia is a member of the family Euphorbiaeceae. There is a large variability among the approximately 2,000 species comprised within this vast genus; however, nearly all produce a milky latex which is often rich in reduced isoprenoids (Lawrence Berkeley Laboratory, 1981).

E. lathyris, commonly known as caper spurge, mole plant, or gopher plant (due to its rodent-repelling properties), is a biennial herb which normally grows to a height of 50 to 200 centimeters. The plant has a main axis with profusely leaved branches generated mainly from the inferior nodes, leaves are alternate and opposite (Peoples, 1981). The distribution of reduced organic compounds is not uniform throughout the plant; the leaves contain twice as much as the stalk per unit weight (Lawrence Berkeley Laboratory, 1981).

Peoples et al. (1981) found that the origin of E. lathyris is uncertain, it has been stated that the gopher plant could be native of either the central and eastern Mediterranean area, or western mountainous China. Actually, this latex-bearing plant is widely naturalized throughout the temperate regions of the earth. However, it does not occur wild in desert zones of the world (Peoples and Johnson, 1980).

Plant Chemistry

Extracts from E. lathyris were analyzed at the Lawrence Berkeley Laboratory (1981). They reported that 5% of the dry weight is a mixture of reduced terpenoids, in the form of triterpenoids, and 20% of the dry weight is sugar, in the form of hexoses. From the terpenoids, gasoline compounds can be obtained, and alcohol can be produced from the sugars. The same report states that if a biomass of 22.4 dry tons/ha per year is produced, the energy obtained from E. lathyris in the form of liquid fuels is 65 giga Joules (GJ), 12 bbls/ha, in hydrocarbon form plus an additional 52 GJ in ethanol form. This study concludes that E. lathyris is a net energy producer. Furthermore, analysis of the heptane extract fraction from the plant was found to have a high heat value and a low oxygen content, conditions which suggest a potential for use as a fuel or chemical feedstock material.

Studies conducted at the University of Arizona report yields of 3 to 16% in energy-rich-hydrocarbon-like substances, plus 3 to 10%

yields of lower energy materials produced by E. lathyris. This research indicates that it is feasible to use E. lathyris as a source of "crude oil" with a positive energy value, assuming a yield of 15% for hydrocarbon-like materials with an energy value of 34.8 mega joules (MJ)/kg and provided that the bagasse is used to produce steam and electricity (Peoples et al., 1981).

Chemical extraction at the University of Arizona has demonstrated that three fractions can be obtained from the dried plant material (Peoples and Johnson, 1980). The cyclohexane extract, the first fraction obtained, is considered a high quality fuel with an energy value of 40.7 MJ/kg. Then, a second fraction which contains 23.2 MJ/kg is extracted from the ethanol fraction. Finally, bagasse with 12.6 MJ/kg can be used as a low quality fuel.

E. lathyris crude product was cracked on a zeolite-charged fluid bed by Mobil Oil Corporation. The products obtained from cracking have 25 to 40% more economic value than conventional crude oil (Peoples and Johnson, 1980). Thus, E. lathyris has the potential to yield high value products in addition to providing a source of fuels.

Previous Field Experiments

The availability of published field experiments with E. lathyris from which biomass has been obtained is scarce and considered preliminary in most of the cases. A brief discussion of the most relevant field experiments conducted to date and related to this thesis follows.

Initial studies were conducted in Southern California by Calvin (1978a). Wild E. lathyris seed was sown in February 1977 and harvested after a 7 month growing season. Plant height at time of harvest was 1.2 m and a yield of 25 barrels (bbls) of oil per hectare was reported. No water use data are available for this experiment. Based on his research Calvin (1978a) estimated the cost of farming to produce one barrel of oil is $10, and an additional chemical processing cost of $10. The total estimated cost of $20 is without optimization of the agronomic cultivation or chemical extraction process. With genetic and agronomic improvements, Calvin suggested that the yield will go as high as 50 bbls of oil per hectare. This experiment motivated researchers to study the feasibility of growing E. lathyris for fuel production.

Nemethy et al. (1978) established an experiment to test one planting density, one irrigation schedule, and one fertilizer rate on E. lathyris. That experiment was conducted by the University of California at its South Coast Field Station in Santa Ana. Seed was sown in December 1976, and in February 1977 the plants were transplanted to 16 m^2 field plots providing a population density of 108,000 plants/ha. Fertilization was applied at a rate of 112 kg/ha of nitrogen in March and another 56 kg/ha in May. Plants were irrigated every two weeks with about 3 cm of water each time. Irrigation water totaled 48 cm plus 14 cm of rainfall which adds up to a total of 62 cm of water received by the crop. Reported yields for a 9 month growing period in the field are 19 tons/ha of dry matter or an equivalent 11.6 bbls/ha oil. For the 14 month growing season they obtained 26 tons/ha or

16 bbls/ha of oil. Yields in both cases were calculated by multiplying individual plant dry weights by 108,000 plants/ha. A very preliminary study of the economics indicated a total cost of $30 to $45 per barrel of oil including growing the plant and extracting the hydrocarbon.

During a 7 month growing season, Sachs et al. (1981) conducted irrigation and fertilization tests at the University of California, Davis. *E. lathyris* seed from northern California was sown in April 1980 and a density of 148,000 plants/ha was obtained. A sprinkler irrigation line was used to irrigate weekly. The total quantity of water applied during the growing season varied from zero at the edge of the plot to 66 cm near the pipe line where water was applied to replace weekly evapotranspiration. Hence, it was assumed that the water supply was not limiting in the area close to the pipe. A neutron probe was used to measure soil moisture on a weekly basis. Soil moisture depletion by plants was observed in the upper 180 to 210 cm of soil. Harvests from 4.6 m^2 plot samples yielded 9 tons/ha of dry matter which corresponded to oil yields of 2.5 bbls/ha in the area which received no supplemental irrigation (except 2.5 cm applied after seeding). About 18 tons/ha of dry matter, or 5.7 bbls/ha of oil were produced near the pipe where 66 cm of water were applied. Hexane extractables were up to 6% in the non-irrigated plants while the plants which received maximum water applications yielded as low as 4% of hexane extractables. Nitrogen was added to the soil to raise the nutrient level to 112 kg/ha. However, it was determined at the end of the experiment that residual nitrogen of 86 kg/ha was adequate to produce the harvested biomass and no response to the added N was observed.

Peoples and Johnson (1980) reported a yield of 6 ton/ha of dry matter which is the equivalent to 9 bbls/ha of oil as extracted by the University of Arizona's method. This experiment was conducted from October 1979 to April 1980 at the University of Arizona Agricultural Experiment Farm in Marana, Arizona. Peoples and Johnson (1980) suggested that biomass production will be increased to 18 bbls/ha by doubling the plant population density of 520,000 plants/ha which was used in this experiment. The quantity of water used in this research was estimated to be 50 cm including both rainfall and irrigation.

The reader is referred to Peoples et al. (1981) for a description of the research currently conducted at the University of Arizona regarding the agricultural development of E. lathyris - i.e., breeding, pathology, nutrition, and establishment of this plant.

EXPERIMENTAL DESIGN

Several experimental plots were established in the interest of determining the field water use and growth of two ecotypes of *E. lathyris* from California, The field experiments were conducted at the University of Arizona Agricultural Experiment Farm in Marana, Arizona; approximately 32 kilometers northwest of Tucson. Because *E. lathyris* has been introduced as an alternative crop for the desert areas of the United States, the climatic conditions make Marana a logical choice for this study.

Climate of Marana, Arizona

The Marana Farm lies at a latitude of 32° 23' and at a longitude of 111° 12' (National Atlas of the United States of America, 1970). Marana is at an elevation of 625 meters above sea level. Climatic data have been reported by Sellers and Hill (1974) and is reviewed below.

Summer temperatures at Marana are extremely high, peaking above 43°C in the first two weeks of July. Average daily maximum temperature is 38°C during this season having a mean monthly temperature of 29°C. From May to October there are 169 days with temperatures 32°C and above.

During the winter, average monthly temperatures rarely dip below 10°C and mean daytime maxima often rise into the lower twenties. The nights are cool, with temperatures falling below the freezing point about forty days in an average year. However, temperature rarely drops low enough to damage traditional crops grown in the area.

Marana has a desert climate, receiving 280 millimeters of precipitation in most years. Amounts have remained relatively constant over the years. The wettest period occurs from July to September, when the total precipitation averages 142 millimeters. Winter precipitation is lower than the summer rains, having an average of only 69 millimeters. Drought conditions are most prevalent in May when in two out of three years, no measurable precipitation occurs.

Soil Characteristics

The soil texture at the west end of field E-1, the field plot location, is considered to be uniform in the top 120 centimeters and is classified as clay loam (Coelho, 1974). Soil bulk density was determined by driving an oakfield probe into the soil and obtaining an uncompacted core of known volume within the tube. The soil samples were then oven dried and weighed. Results from 28 soil samples yielded an average soil bulk density of 1.35 gr/cc for the 120 centimeter profile, with variability of only $\pm$ 0.06 gr/cc.

Field capacity , for the 120 cm soil profile, was measured by determining soil moisture content two days after an irrigation which was sufficient to insure thorough wetting of the soil to be tested. A field capacity of 35% by volume, with a variability of $\pm$ 3%, was recorded from 20 samples taken at different sites in the field. The tension at which permanent wilting point occurs is not known for *E. lathyris*. However, the tension in the soil moisture when the soil is at permanent wilting is generally considered to be 15 bars. Whether in reality it is 10 or 20 bars is not extremely important, since change of moisture is small with rather large changes of moisture tension in this range (Israelsen and Hansen, 1962). Therefore, soil moisture of 20% was determined in the laboratory at a tension of 15 bars and was considered the permanent wilting point. Hence, the difference in moisture content of the soil between field capacity and permanent wilting point is 15% by volume or 4.5 centimeters of water per 30 centimeters of soil. This difference represents the available moisture for use by plants.

Also, soil moisture was measured in the laboratory at 0.1, 0.3, 1.0, 3.0, and 9.0 bars to obtain a curve of soil moisture variation with tension which is given in Figure 1. Samples submitted for laboratory analysis were taken from five locations in the field plots at 0 to 60 and 60 to 120 cm depth. Results were similar for both depths with a variability of $\pm$ 1.6%.

Construction of Field Plots

Thirty six field plots were established to provide units capable of monitoring plant growth and water use under controlled water application rates. Flood irrigation of small basins meets these needs and permits controlled water application by use of a metered pipe system. These elements, combined with the fact that flood irrigation is a representative commercial method used in Arizona made the method a logical choice for this study.

Eight 190 meter long raised beds spaced at 1 meter intervals were constructed for each of the two hydrocarbon producing plants (see Figure 2). Then, each of the eight bed wide field plots were subdivided

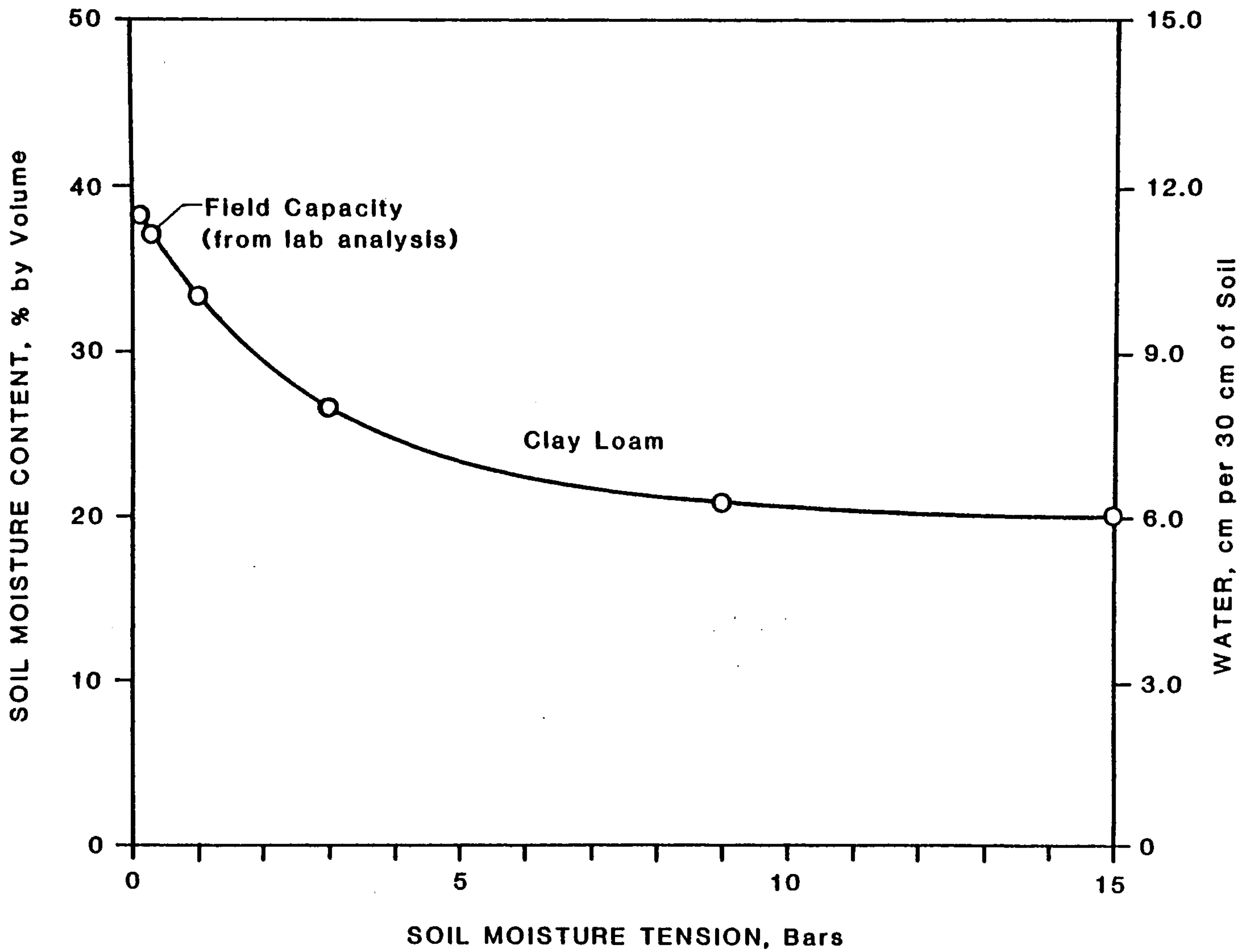

Figure 1. Soil moisture variation with tension.

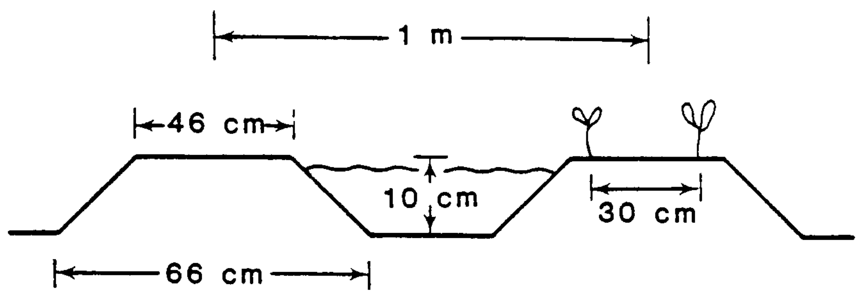

Figure 2. Cross section of the beds.

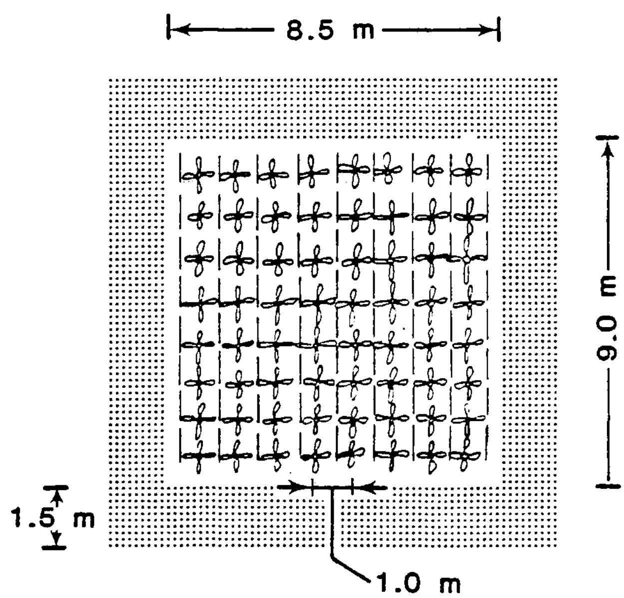

Figure 3. Individual basin.

into sixteen experimental basins plus two extra basins. Each basin was created by forming a border around the perimeter of the eight planted beds and by discing across the 190 meter long bed at 10.5 meter intervals. This spacing accomodated the 9.15 meter lengths of pipe and the required valves and connections. Thus, each basin was initially eight beds wide and 10.5 meter long. However, after forming the 1.5 meter wide dividing ridge the remaining undisturbed area within each basin was only 9.0 m long and 8.5 m wide giving an inside area of 76.5 m^2 (Figure 3). The ridges creating the individual basins served to contain the measured water applied and to create a buffer zone between plants and water in adjoining basins. Unfortunately, creating the basins prevented mechanical cultivation of the field; therefore, periodic hand weeding was necessary.

Following discussion with a statistician from the University of Arizona, it was decided to arrange the experimental units in a randomized complete block design. Each set of sixteen basins included four replications, identified as I, II, III, and IV, of four different water treatments, designated A, B, C, and D from the wettest to the driest.

Water Application

Water was pumped from the nearest farm ditch using a portable gasoline driven pump and piped through an aluminum pipe network. Tee valves were installed in line on the pipe at the head of each basin. A portable pipe extension with propeller type flow meter and valve opening elbow connected to the tee valve provided easy access for irrigating from each outlet. Water was directly applied at the head of each basin and the quantity dispensed was accurately measured by the flow meters installed in the extension pipe outlets. Figure 4 shows the water application and irrigation equipment used.

Care was always exercised to apply the water at an adequate rate which would provide a uniform distribution and would not cause erosion of the soil. Large plastic bags were tied to the pipe outlet to dissipate energy and, hence, avoid scouring from water discharging at a high velocity.

During the first irrigation water was not allowed to overflow the beds since subsequent crusting of the soil could have adverse effects on seed germination. After the plants germinate, the level of water was allowed to go up to almost the top of the beds in order to move salts away from the plant rows.

Soil Moisture Determinations

Weekly moisture measurements were taken to monitor water use and to schedule irrigations. Initially, soil samples were taken and soil moisture was determined by the gravimetric method. This method is time consuming, especially when many samples had to be handled every week. Hence, a neutron probe was acquired (Model 510 of the Campbell Pacific Nuclear Corporation) to speed and facilitate the work. Also, repeated non-destructive sampling in the same location is feasible by using the neutron probe.

To provide access holes for the neutron meter, aluminum tubing 5.1 cm diameter and 1.5 m long was placed in the middle of the plot,

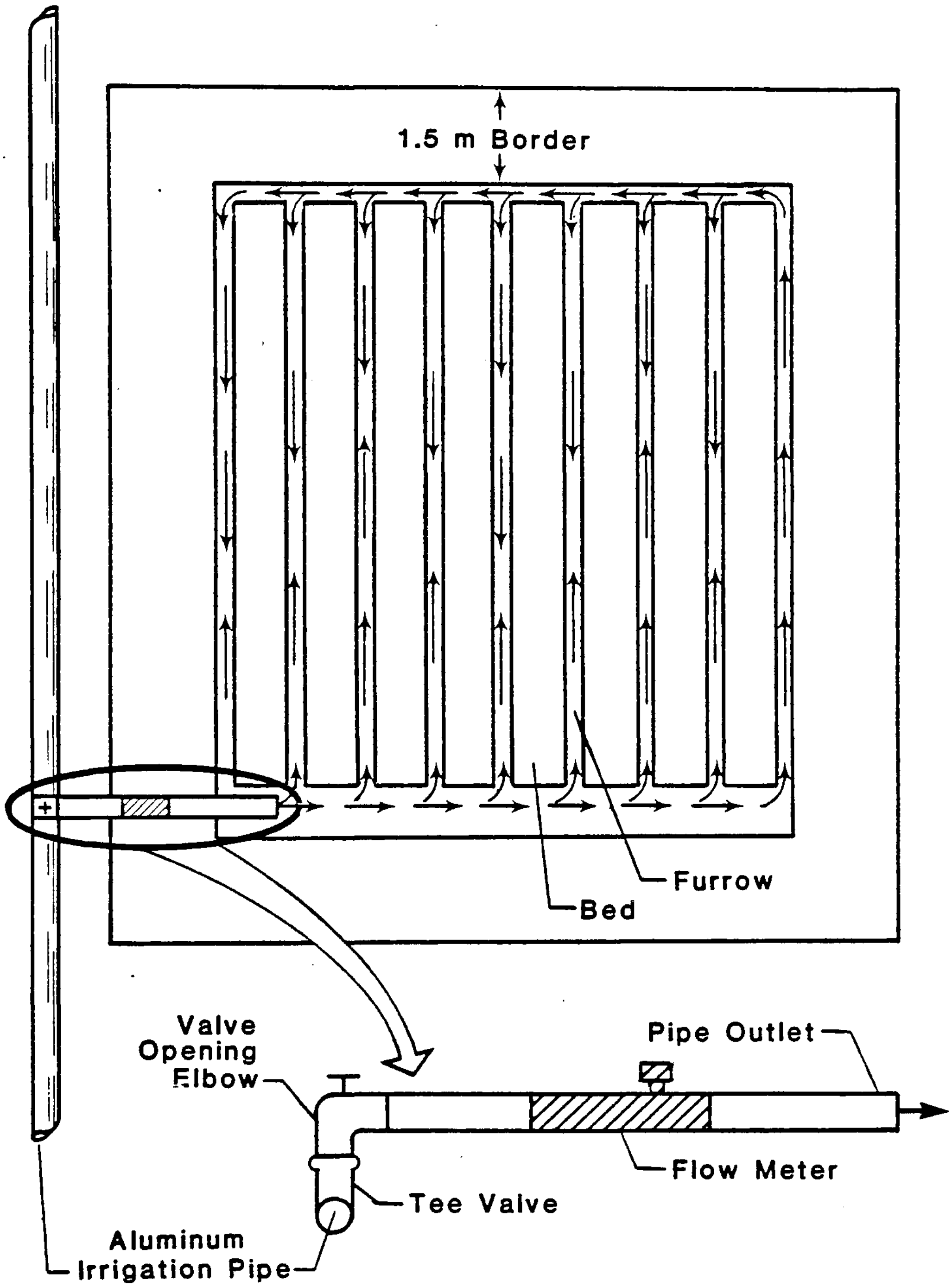

Figure 4. Water application.

and in the center of one of the four interior beds. Weekly readings were taken at 15, 45, 75, and 105 cm corresponding respectively to depths of influence between 0 to 30, 30 to 60, 60 to 90, and 90 to 120 cm from the soil surface.

The procedure outlined by Dickey and Schwankl (1978) was used to calibrate the neutron probe. A regression analysis was done, and the following linear correlation was found: Field count/standard count = 0.13 (soil moisture in cm per 30 cm of soil) + 0.31. An R^2 of 0.8 was determined. Because of the large quantity of readings that had to be handled on a weekly basis, a computer program was developed to calculate soil water content and water used by the plants between any two periods. After initial calibration, the neutron probe was checked periodically against oven dried samples; re-calibration adjustments of less than 13% in the intercept of the regression line were made.

Field Plantings

Field studies were undertaken over a thirteen month period, from March 1980 to May 1981. Two plantings, Spring and Fall, were carried out during this period. Each planting will be discussed separately because of the different manner that they were treated.

Spring 1980 Planting

One ecotype of *E. lathyris* from Chico California was used for this experiment during the Spring 1980 season.

In early March, the field was fertilized with 240 kg/ha of 21-0-0 and the beds and furrows were prepared. Seeds were sown on March 14, 1980 at a depth of 3.8 centimeters using a sorghum planter. One row was planted per bed at a delivery rate of 1 seed every 8.9 centimeters. Thus, the density of planting was 112,000 seeds/ha.

On March 17, a post-plant furrow irrigation was applied to wet the raised beds for seed germination and to bring the root zone soil moisture level to field capacity. After the post-plant irrigation, soil moisture determinations were taken approximately every 10 days using, primarily, gravimetric methods because of the limiting availability of the neutron probe at this time.

Subdivision of the 190 meter long rows into smaller plots, individual basins, occurred on April 25, 1980. A total of 18 basins were constructed, providing four replications of the four water treatments and two extra experimental basins. The field layout is shown in Figure 5.

Initially, targeted water applications were at 100, 75, 50, and 25 cm per season corresponding, respectively, to the A, B, C, and D water treatments. These quantities were just an initial estimation because of the lack of available information concerning the water use of *E. lathyris*. These estimates were then adjusted proportionally according to observed soil water depletion.

Fifty days after planting, the emerged *E. lathyris* were counted. Plant counts ranged from 142 to 359 plants per basin providing an average of germination rate of 28% which corresponds to 31,600 plants/ha. This low germination and high variability was due to the low seed viability and also to low spots in the field. The uneven field caused a

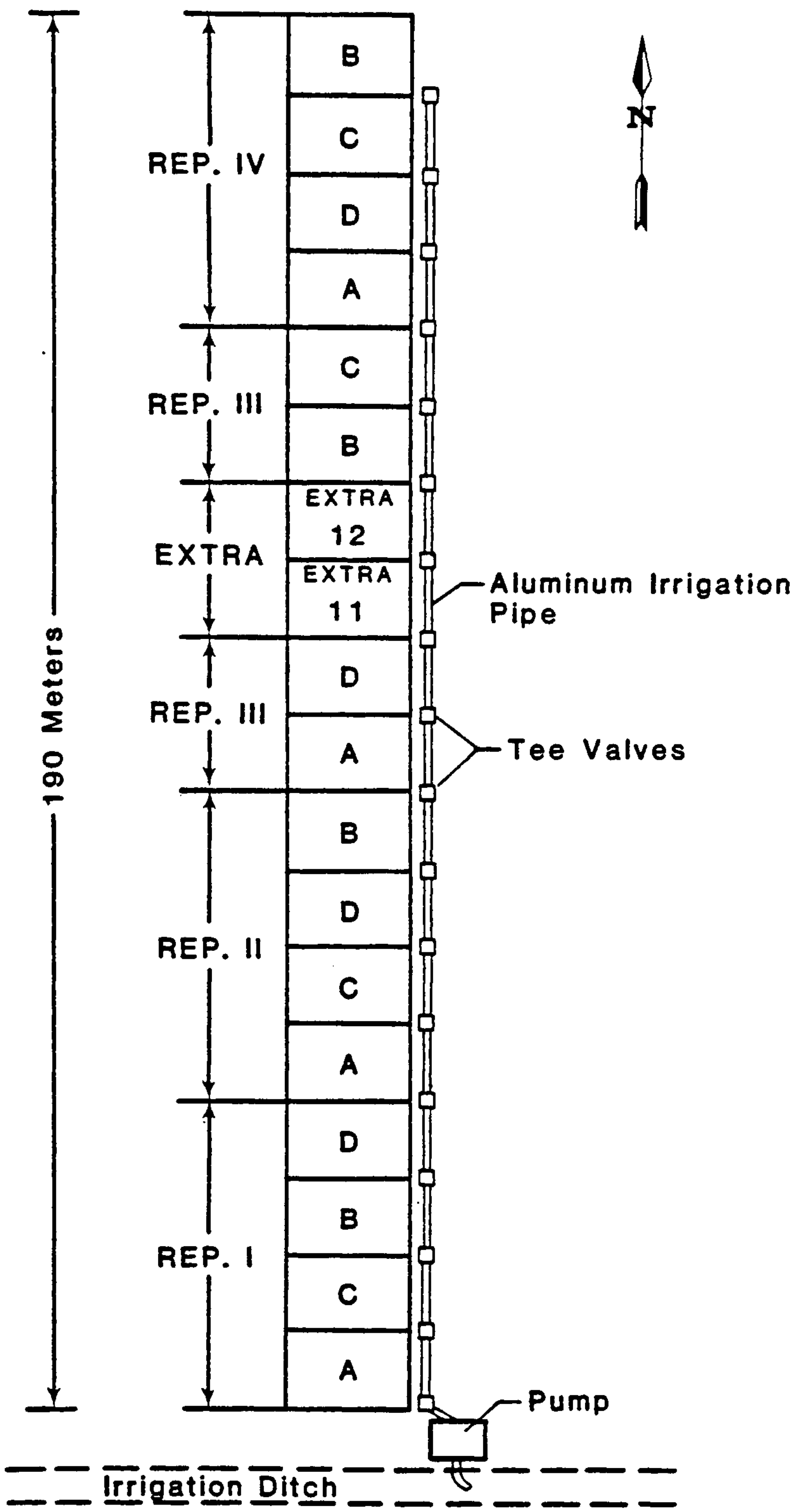

Figure 5. Field plot layout for spring planting - Chico, *E. lathyris*.

non-uniform post-plant irrigation with some soil crusting, especially in the north half of the field. Although several problems were encountered, the Spring planting became a valuable experience. The problems of uneven water applications and subsequent uneven germination needed to be dealt with before a good experiment could be assured.

Fall 1980 Planting

Based on the earlier experiences gained by the project personnel, two ecotypes of hydrocarbon producing plants were used for the Fall planting, E. lathyris from Chico and from Palo Alto, California. Before planting, the field was leveled to provide for better water distribution within the plots. By late September, the field was fertilized with 336 kg/ha of 16-20-0 and the beds and furrows formed.

Other studies conducted by the hydrocarbon project team indicated that 1.0 meter plant rows would not provide complete ground cover (Peoples, 1980); therefore, on October 7, 1980, both Chico and Palo Alto E. lathyris were seeded with two rows per bed on beds spaced 1.0 m apart and at a delivery rate of 1 seed every 7.6 centimeters. Thus, the density of planting was approximately 263,000 seeds/ha.

Immediately following seeding the long rows were subdivided into individual experimental basins. The field plot layout is given in Figure 6. Initially, targeted water applications were at 50, 40, 30, and 20 cm of water corresponding, respectively, to the A, B, C, and D treatments. As for the Spring planting these quantities were then changed according to the observed water use during the growing season.

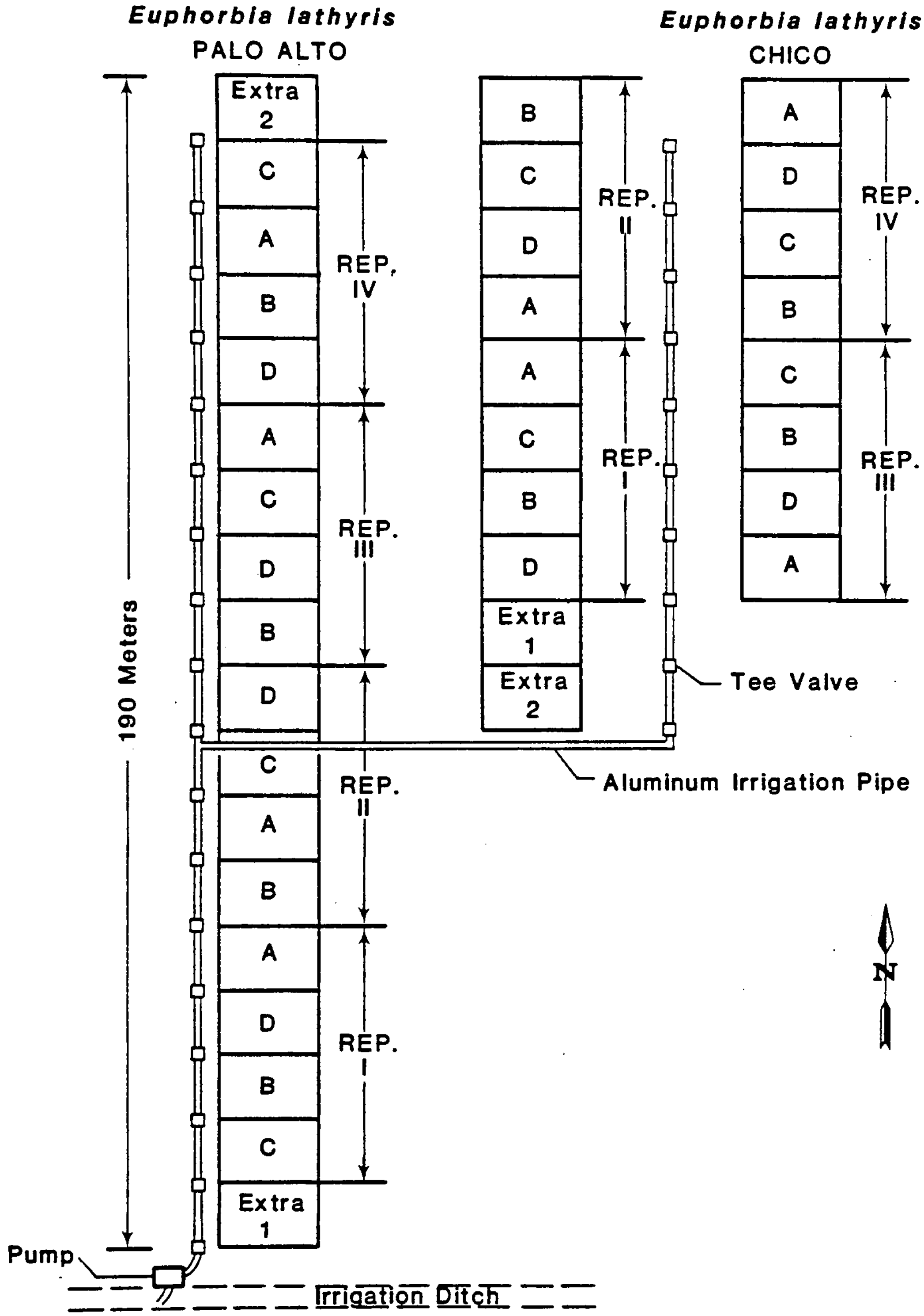

Figure 6. Field plot layout for fall 1980 planting.

A post-plant irrigation was applied on the day after planting to provide moisture for germination. This first irrigation was not enough to fill the soil profile at a depth more than 45 centimeters, especially in the Chico field which had not been irrigated for over one year. Root penetration beyond 45 cm could have been prevented under these conditions. Hence, continued irrigations were applied until October 29, at which time all treatments had received equal amounts of water within each ecotype. However, due to widely varying initial soil moisture content, there was some variability in soil moisture. Gravimetric analysis and neutron probe readings provide an accurate determination of available soil moisture starting in late October.

Emerged Chico, E. lathyris were counted 40 days after planting, yielding an average of 1225 plants per basin or 160,000 plants/ha which indicated a 65% germination rate. Variability from basin to basin was only ± 100 from the average in the number of plants for the Chico plots.

The Palo Alto, E. lathyris were counted 45 days after planting. A uniform stand with an average of 1,133 plants per basin or 148,000 plants/ha and a 60% germination rate were observed. Again, the variability was only ± 100 plants from the average.

RESULTS AND DISCUSSION

The Fall 1981 field plots were redesigned based on experience gained from the Spring 1980 plantings, and therefore, the results obtained will be discussed separately in this chapter.

Spring 1980 Planting

Some serious problems were encountered during this first planting of Chico, E. lathyris in March 1980. First, a low germination combined with a high variablity were obtained due to the reasons explained in the foregoing chapter (i.e. soil crusting, low seed viability). Second, limited availability of the neutron probe meter precluded its use most of the time, hence, soil moisture was determined mainly by the gravimetric method. Unfortunately the number of weekly soil samples was reduced due to the difficulty of handling a large number of samples by this method.

A third problem appeared by late May when daytime temperatures rose to the low thirties and plant disease became widespread. The attack was so severe that by mid-July, a plant count showed an average mortality rate of 48%. The hydrocarbon project plant pathology team identified a root soil fungus, Macrophomina phaseolina, as the pathogenic agent. It is known that the invasion of this pathogen to plant tissue is dependent upon high temperature and water stress. In fact, an inverse relationship was observed between water availability and plant death. Thus, by the end of the curtailed growing season, at the end of August, the mortality rate was 81%, 88%, 91%, and 90%

for the A, B, C, and D treatments, respectively. The number of living plants ranged from only 10 to 89 per basin. Previous experiments conducted at the University of Arizona during the summer 1979 showed even higher mortality rates for E. lathyris growing in the vicinity of Tucson (Peoples, 1981).

The plant pathology team for the University of Arizona hydrocarbon project is trying to identify methods to protect the plant from M. Phaseolina infection. So far from the 1979 and 1980 experiences, the best method identified is to avoid infection by planting in early October when temperatures are high enough to produce seed emergence and M. Phaseolina pathogenicity in soil is lower than in the summer.

On August 22, 1980 dead and alive plants were harvested, but due to disease, the low number of alive plants never attained complete maturity. The largest plants only reached 33.0 cm. Therefore, the harvested biomass for this initial planting did not provide any quantitative results.

Fall 1980 Planting

Chico and Palo Alto, E. lathyris planted in October 1980 showed different growth characteristics through the growing season, and therefore, are presented separately in the discussion below.

Palo Alto, E. lathyris

Water applications and rainfall. Initial targeted water applications were adjusted according to observed water use during the growing season. Table 2, shows the dates and quantities of irrigation

Table 2. Irrigation dates and depths. Palo Alto, E. lathyris

Treatment	Water Applied, Centimeters									
	1980		1981							
	10/8	10/17	10/29	2/2	2/26	3/27	4/8	4/23	5/6	Total
A	6.35	3.80	6.35	3.80	7.62	6.35	7.62	7.62	7.62	57.13
B	6.35	3.80	6.35	--	6.35	5.08	6.35	6.35	5.08	45.71
C	6.35	3.80	6.35	--	5.08	--	5.08	5.08	--	31.74
D	6.35	3.80	6.35	--	--	--	--	--	--	16.50

water applied during the growing season considered. As shown, treatments A, B, C, and D were irrigated 9, 8, 6, and 3 times, respectively. The three irrigations in October were to provide uniform soil moisture near field capacity in all test plots. Total irrigation water applied until May 6, 1981 were 57.1, 45.7, 31.7, and 16.5 cm from the wettest to the driest treatments.

D treatment plants were not irrigated anymore after October 29, 1980 and therefore they were under water stress when initial soil moisture in the root zone was depleted. In fact, after April 6, soil moisture in the top 90 cm of the soil profile was always below the soil moisture corresponding to 15 bars of tension (i.e. 20% volumetric water content). Although plants in treatment D showed symptoms of water stress they continued to grow.

A high supply of water was always available to the plants in treatment A in an attempt to maintain the root zone close to field capacity. From October to May 16, soil moisture as recorded by using the neutron probe meter in the top 90 cm of soil was never below the soil moisture corresponding to 15 bars of tension. Furthermore, soil moisture recorded in the top 30 cm of soil was higher than 25% by volume during 60% of the growing season and was never lower than 20% prior to May 16.

The B and C treatments were then irrigated as a proportion of the water applied in the A plots to provide four distinct irrigated water treatments. Soil moisture in the top 90 cm of soil for treatment B was below 20% once for 6 days from May 13 to May 19. After May 4, soil moisture in the 90 cm soil profile for treatment C was below the soil moisture equivalent to 15 bars of tension for 15 days.

Precipitation dates and depths are shown in Table 3, a total of 121.3 mm of rainfall was received during the growing season.

Water use. At the end of the experiment a soil water balance was computed based on weekly soil moisture depletion as measured with the neutron probe meter, irrigation depths applied, and rainfall received. From October 1980 to March 1981, soil water depletion was observed from the top 90 cm of soil, then E. lathyris started to use water from the top 120 cm of soil which indicated root penetration at this depth starting in April. In this experiment, deep percolation water was not measured. Nevertheless, it is believed that deep percolation was neglible because neutron probe readings showed that the lower part of the 120 cm soil profile was never filled to field capacity, indicating that the water applied remained in the top part of the soil profile. Furthermore, high water application efficiency and uniform water distribution in the basins were obtained because of the small size of the level plots and the method by which water was applied.

From Figure 7, the rate of water use and total water use at any given time can be calculated. During the cold period, October 7 to the end of January, the rate of water evapotranspired was approximately 1 mm/day for all treatments. Soil water in the soil profile was enough to provide the small plants water requirement during this period and therefore plants were not irrigated until February 2, 1981 when 3.8 cm of water were applied to treatment A (see Table 2). Thereafter

Table 3. Precipitation dates and depths.

Date	Precipitation, mm
10/15/80	4.6
10/16/80	1.3
12/6/80	2.0
1/11/81	15.2
1/12/81	9.1
1/15/81	2.3
2/9/81	6.4
2/10/81	14.0
2/28/81	5.1
3/2/81	5.1
3/3/81	19.1
3/4/81	7.6
3/5/81	3.8
3/6/81	1.3
3/20/81	2.3
4/3/81	3.9
4/12/81	2.5
4/30/81	7.6
5/1/81	8.1
Total as of 5/17/81	121.3

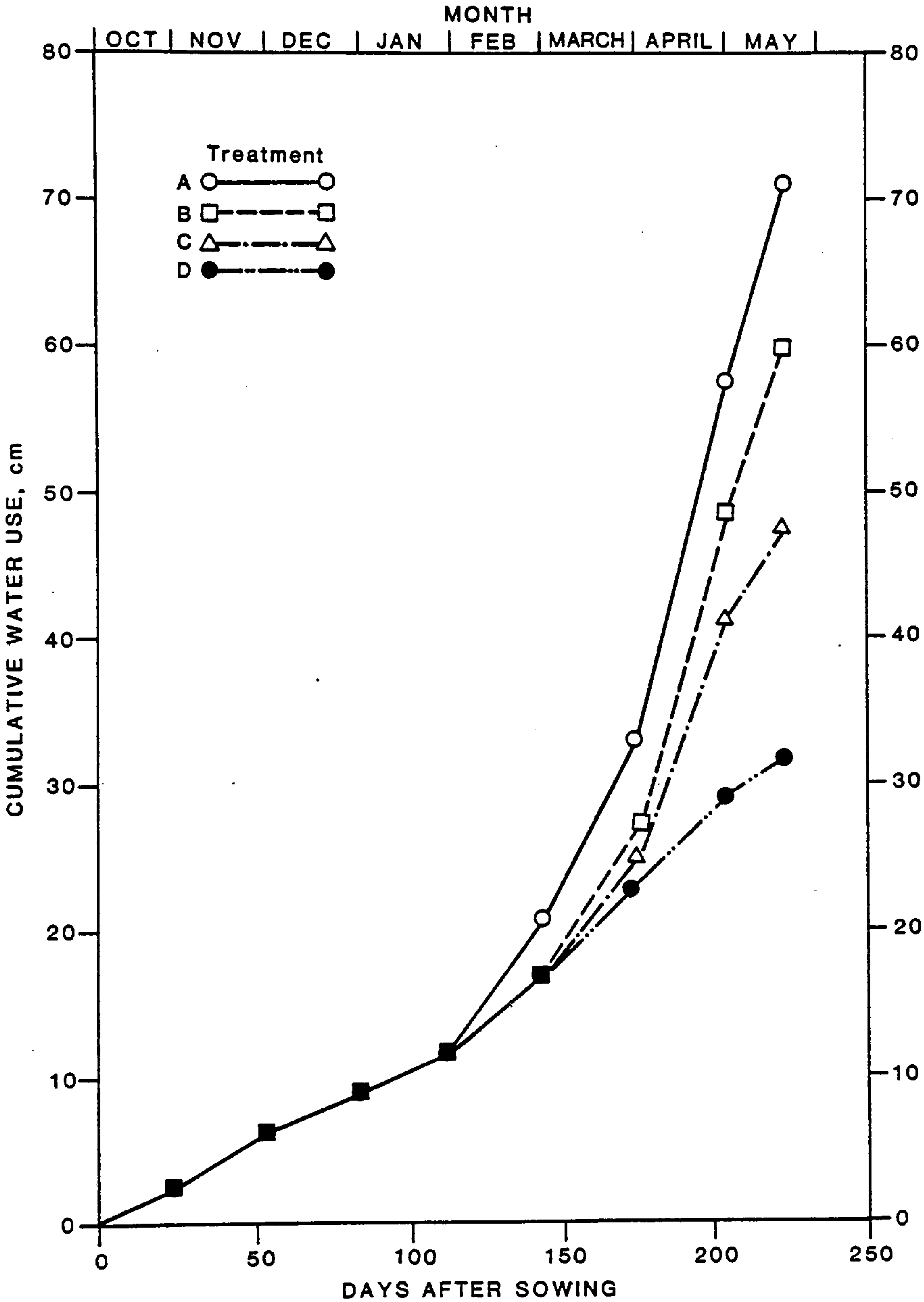

Figure 7. Cumulative water use - Palo Alto, *E. lathyris*.

a positive correlation between water use and water applied was observed. By the middle of May, nearly 71, 60, 48 and 32 cm of water had been used by plants in treatments A, B, C, and D, respectively. The peak evapotranspiration rates for all treatments were observed in April as indicated in Figure 7 by the steep slope of the curves. During this period, evapotranspiration rates were 8.3, 7.1, 5.5, and 2.0 mm/day for treatments A, B, C, and D, respectively.

Plant Height. Plant heights were measured throughout the growing season and are given in Figure 8. Five randomly selected plants were measured each time in each basin and then the average from all four replications for each treatment was computed. During the winter months, plant height increased very slowly at a rate of approximately 5 cm/month. Thereafter a positive relationship was observed between rate of increase in plant height and soil water availability. Peak rates of plant growth occurred during the months of March and April for treatments, A, B, and C with approximately 30, 26, and 21 cm/month, respectively. Plant in treatment D increased at an approximate constant rate of 14 cm/month from early February until the end of April. As can be seen in Figure 8 after the first week of May plant growth rates started to level off for all the treatments.

Harvest. According to past experiences by the University of Arizona hydrocarbon project, Palo Alto, E. lathyris planted in October would flower in early April, at which time plant hydrocarbon content was believed to be at a maximum (Peoples, 1980). Therefore, weekly harvests were planted to begin in early April. In fact, during the

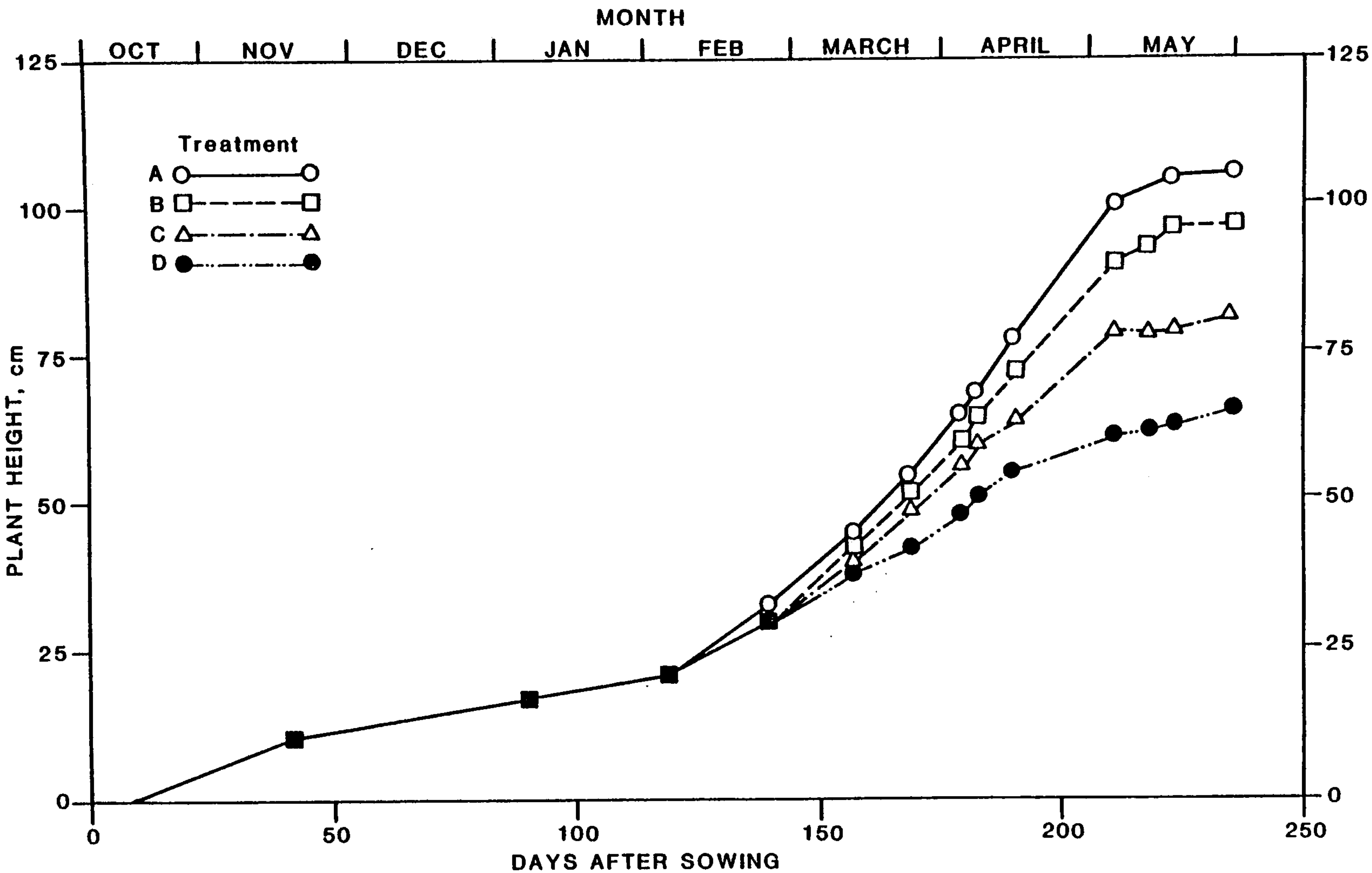

Figure 8. Plant height – Palo Alto, *E. lathyris.*

first days of April, the plants started to flower. It was decided to harvest several times to determine the change in dry matter production and percent hydrocarbon with respect to time of harvest and continuing water use in the four different treatments. Thus, seven weekly harvests were made from April 6 to May 19.

Two randomly selected 0.5 m^2 samples were hand harvested from each basin. These two samples were combined in a burlap bag and weighed fresh in the field. Hence, a 1 m^2 sample was collected at each harvest from each one of the 16 Palo Alto, E. lathyris basins. A checkerboard pattern was formed so that any subsequent harvest would not be affected by having a vacant one-half meter square area nearby. The first three harvests were taken to a drying room where they were hung. Three weeks later the first harvested plant material was still not dry enough to determine the quantity of dry matter produced and to perform the chemical analysis. Hence, a subsample was taken from only one replication in each of the four treatments for rapid drying (a total of 4 subsamples per harvest). The subsamples were placed in an oven from 3 to 6 days at 70°C until no change was observed in weight. Then, the percent of oven dry matter was computed. This oven drying procedure was used for the 4 last harvests also, but without pre-drying. Figure 9 shows the percent oven dry matter obtained at each harvest. Due to the difficulty of taking a representative subsample from the three first semi-dry harvests, which were in the drying room for several weeks after harvest, the percent oven dry matter obtained was inconsistent for these initial harvests (see Figure 9). However, the last 4 harvests showed a

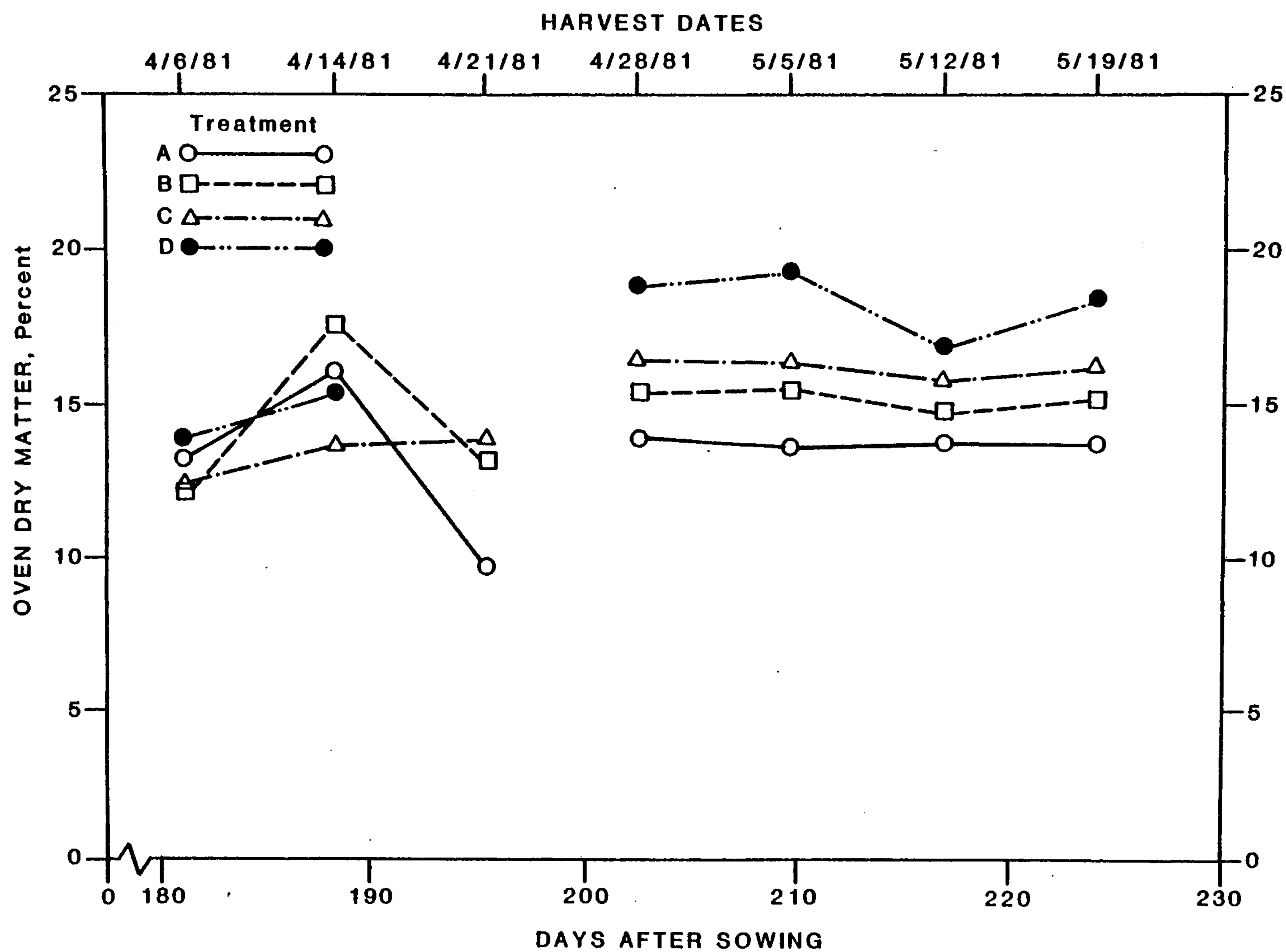

Figure 9. Oven dry matter as a percent of harvested weight – Palo Alto, *E. lathyris.*

consistent percent oven dry matter due to the higher uniformity of fresh plant material harvested. Therefore, the percent oven dry matter for the first three harvests were not used to calculate the dry matter production, instead, the averages of the percent oven dry matter from the last four harvests were used for each treatment. As expected, the data shown in Figure 9 for the last four harvests indicate an inverse relationship between water availability and percent dry matter, the drier soil conditions produced plants containing less moisture.

Dry matter production related to time of harvest. Figure 10 shows the variation of dry matter production with time for the four water treatments. The data used to plot Figure 10 are the averages obtained from all four replications for each treatment. In general, dry matter production increased slowly in early April and rapidly in the later part of the month until the yield started to level off in early May. A direct relationship was observed between dry matter production and soil water availability in all seven harvests. However, in a few instances some points did not follow this trend, for example the third and last harvests of treatment A. Since the results presented are based on harvests of a small subsample from each plot at any given harvest date, an extreme value may be recorded in a given treatment. However, over the season this deviation would be subdued. The one meter square subsample, for example, may include a relatively sparse area of plants or conversely a low spot in the field which contained higher soil moisture than the treatment as a whole.

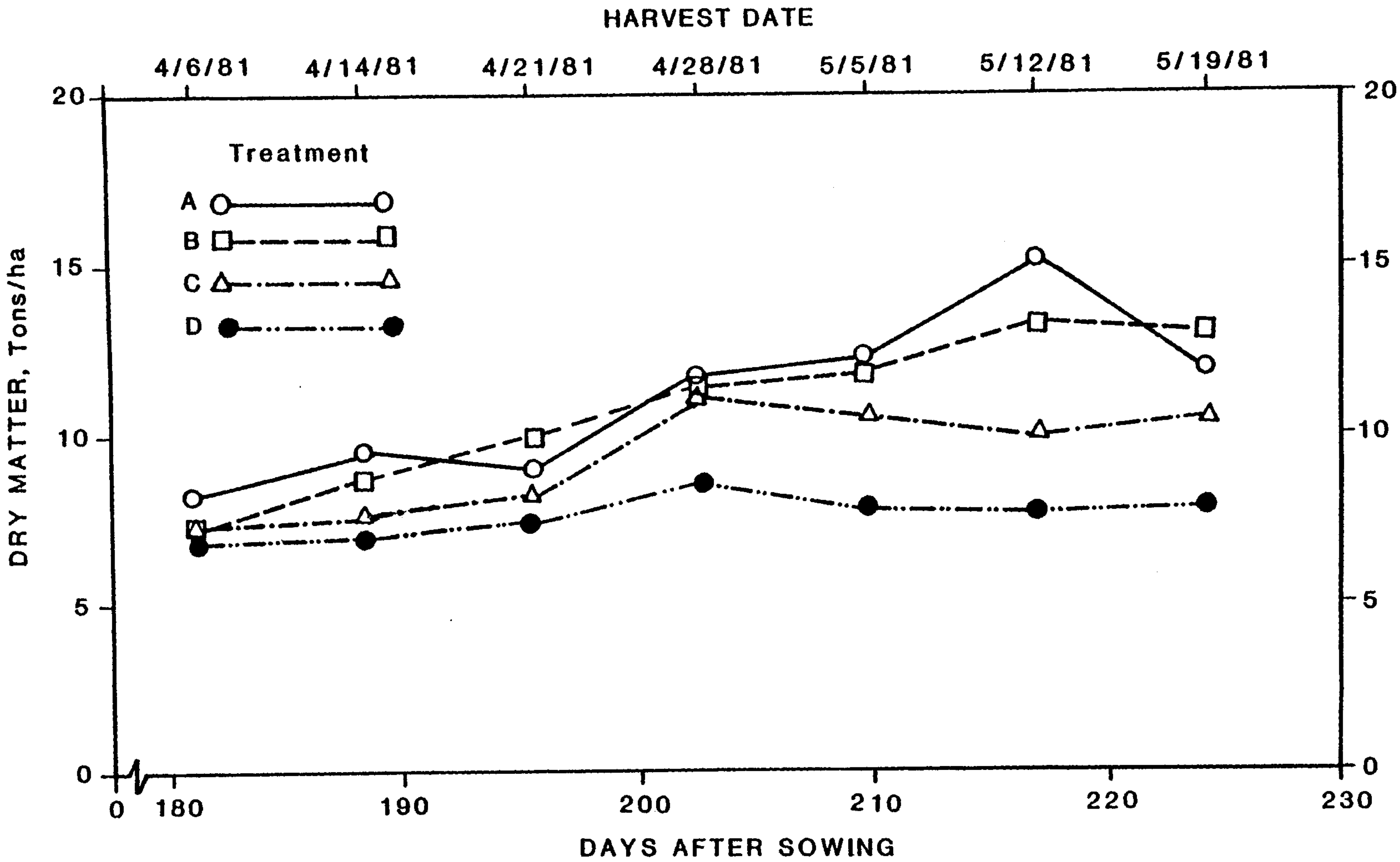

Figure 10. Dry matter production related to time – Palo Alto, *E. lathyris*.

The average dry matter yields for the last two harvests were 13.5, 13.2, 10.3, and 7.8 t/ha for treatments A, B, C, and D, respectively. These values indicate that yields increased 64, 83, 42, and 11%, from the wettest to the driest treatment, with respect to the yield obtained from the initial harvest. According to the above results, treatment B increased yield at a higher rate than treatment A, consequently, the difference in dry matter production between these two treatments was less than 0.5 t/ha for most of the harvests. Treatment B and C produced 7.2 t/ha in the first harvest; thereafter, treatment B clearly outperformed treatment C, with the exception of the fourth harvest when they produced similar amounts of dry matter. The yield in the last two harvests for treatment B was approximately 2.9 t/ha higher than for treatment C. Dry matter production in treatment C was nearly the same as in D until late April when the yield of treatment C increased sharply. Thereafter, treatment C yielded an average of 2.6 t/ha more than treatment D.

Dry matter production related to water use. The relationship between dry mater production and water use was analyzed for all four water treatments. Disregarding elapsed time since planting, Figure 11 shows the average data for the four replications and fitted regression line within the range of observations for all treatments lumped together. A coefficient of determination, R^2, of 0.83 was computed for the lumped regression line. The amount of change in dry matter production associated with a unit change in water use is given by the slope of the regression line. The data indicate increasing dry matter

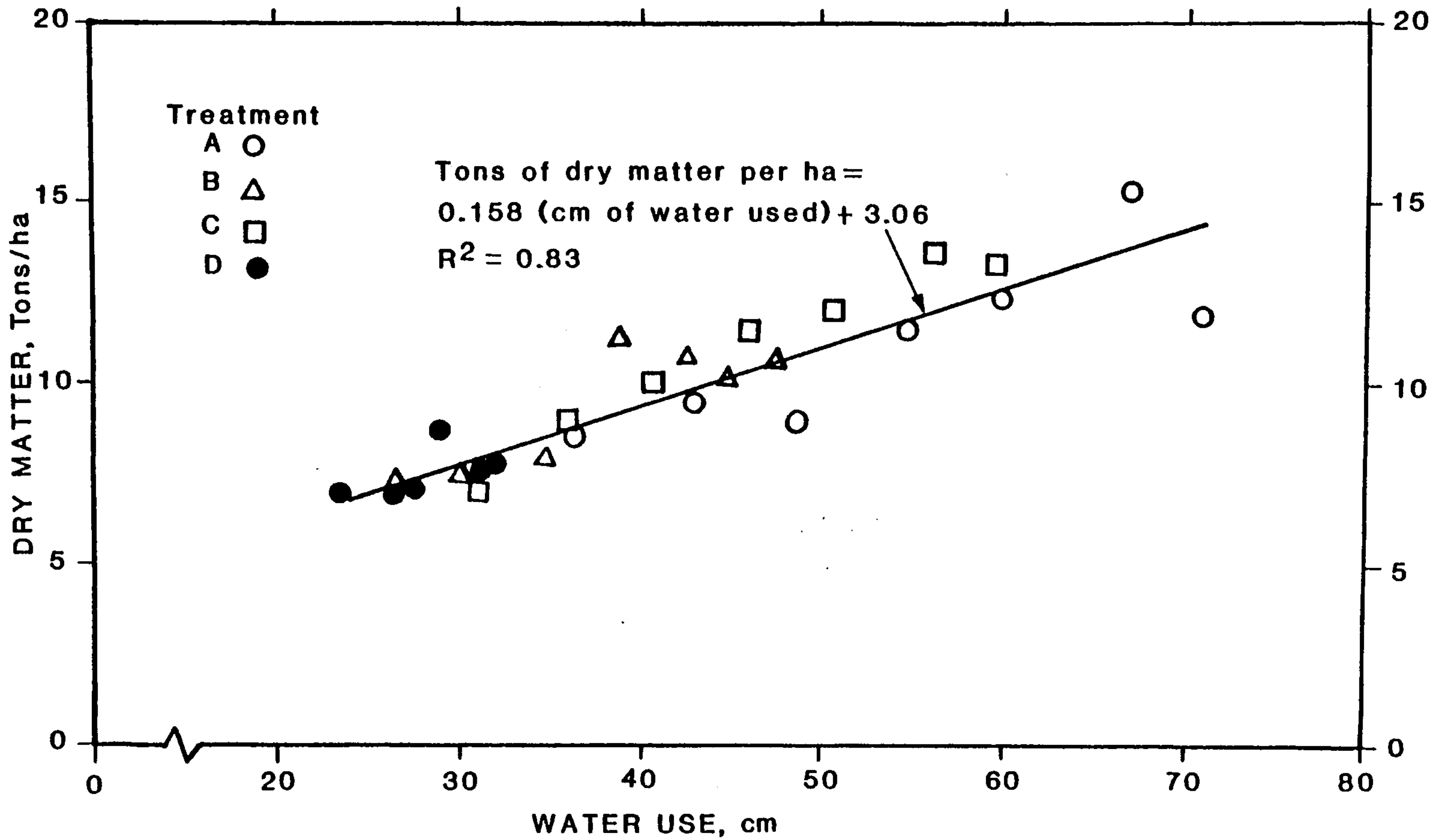

Figure 11. Dry matter production as a function of water use – Palo Alto, *E. lathyris.*

yields of 0.158 per centimeter of water, however no attempt to extrapolate beyond the actually observed values should be made.

Although the wetter treatments produced higher maximum yields than the drier treatments (see Figure 11), in several cases dry matter production for the same quantity of water use was higher for the drier plots than for the wetter treatments. For instance, within the range of 36 to 60 cm of water use, treatment B always produced higher yields than treatment A for the same quantity of water consumed. Care should be exercised because the time factor is also involved in the determination of which treatment will yield the best results. In other words, treatment B would produce higher dry matter yields than treatment A for the same quantity of water use within the common range of observations, but it will take longer for plants in treatment B than in A to use this water and produce these yields (see Figure 7). Similar comparisons can be made for other treatments and ranges of water use and yield.

Biocrude production related to time of harvest. The same four subsamples used to determine percent oven dry matter at each harvest were sent to the laboratory for chemical analysis. Figure 12 gives the results obtained in percent ethyl acetate extract, which represents the oil fraction or biocrude as extracted from *E. lathyris*. As seen in Figure 12, the percent ethyl acetate extract increases from the initial to the last harvests. In general, the average of the three first harvests was about 1.5% lower than the average obtained from the last three harvests. However, due to some variability obtained in the

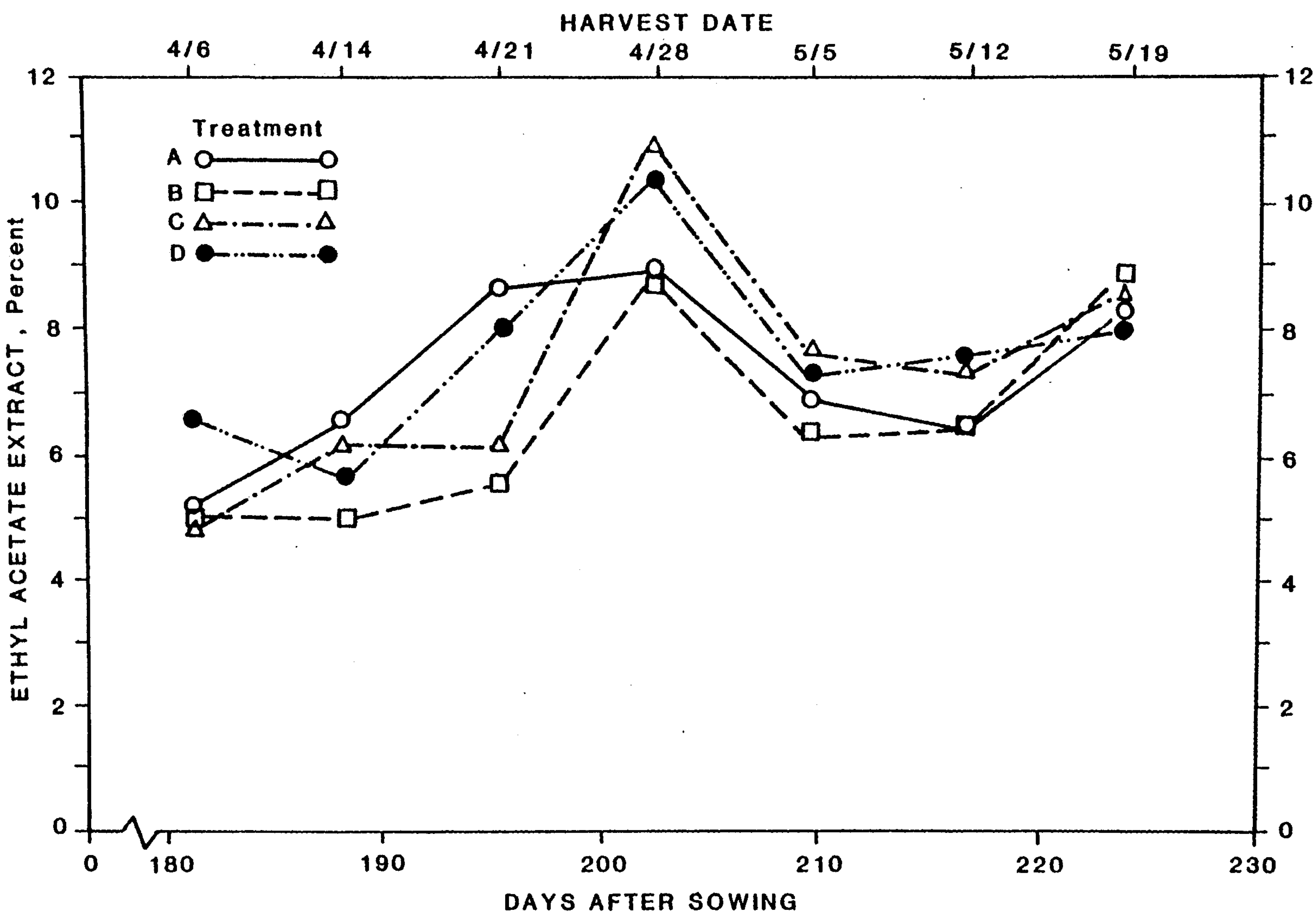

Figure 12. Percent of ethyl acetate extract - Palo Alto, *E. lathyris*

chemical analysis and that only one subsample for each treatment was analyzed, the average treatment is used to compute the biocrude yields. The A, B, C, and D treatments yielded an average of 7.2, 6.6, 7.3, and 7.5 percent ethyl acetate, respectively. These values indicate that there is no clear relationship between soil water availability and percent ethyl acetate extract.

The heat value of one barrel of biocrude is less than the heat value of one barrel of commercial crude oil, but the economic value is similar for both (Peoples, 1980). A barrel of commercial oil weighs 129.4 Kg since commercial oil and biocrude have the same economic value, the above number was used to compute the barrels of biocrude from the Kg of ethyl acetate extract produced. Figure 13 shows the yield of biocrude obtainable from all the harvests and treatments. Analogous to dry matter yield, the biocrude production increased rapidly in the later part of April. Furthermore, a direct relationship was observed between biocrude production and soil water availability through all seven harvests. The average biocrude yields for the last two harvests were 7.5, 6.7, 5.8, and 4.5 bbls/ha, respectively, for treatments A, B, C, and D.

Biocrude production related to water use. Disregarding elapsed time since planting, Figure 14 shows the relationship between biocrude production and water use. Analogous to dry matter yield, the wetter treatments produced higher maximum yields and consumed more water than the drier treatments (see Figure 14). Of particular interest is the fact that, in almost any case the biocrude yields corresponding to

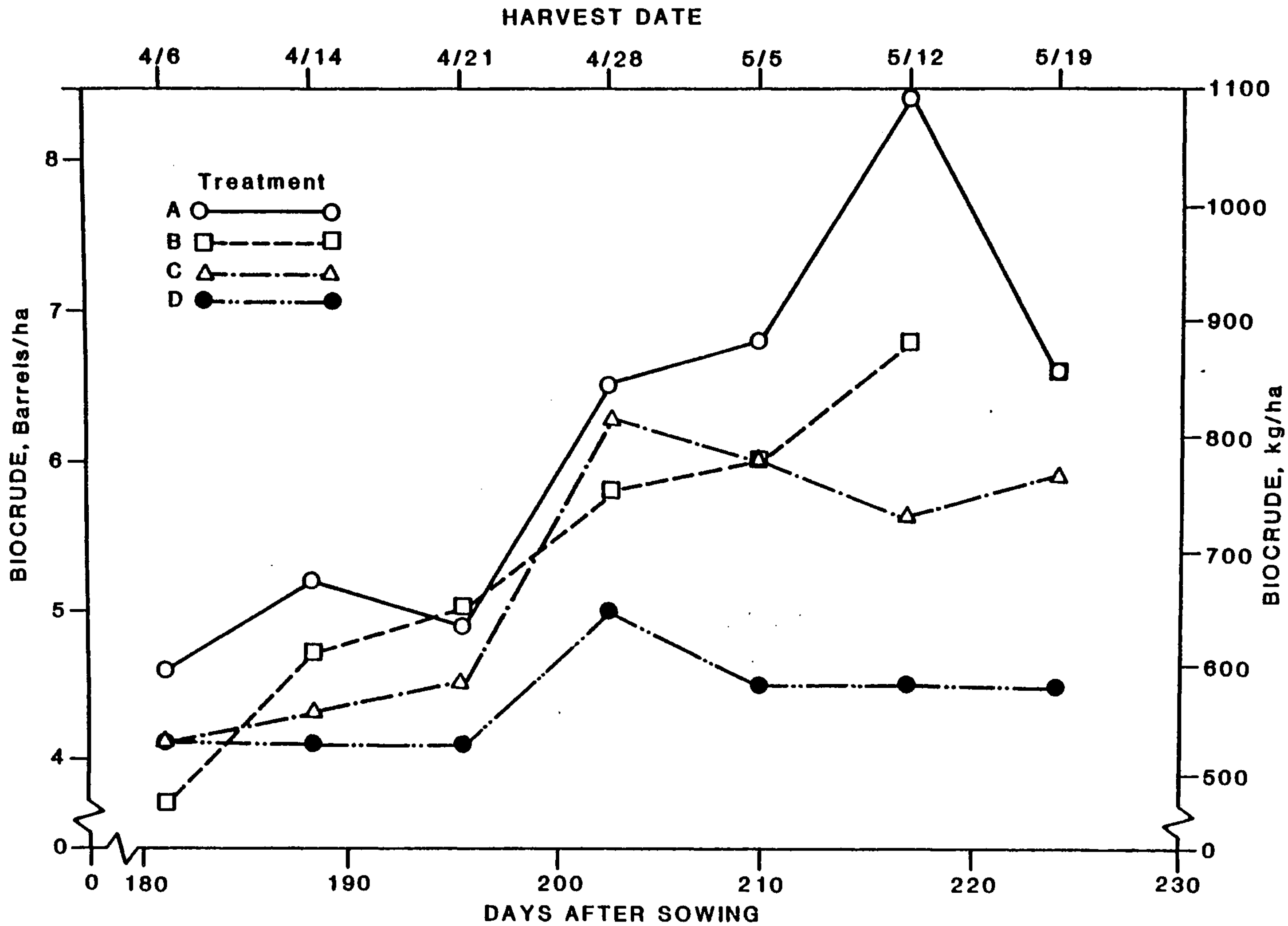

Figure 13. Biocrude production related to time – Palo Alto, *E. lathyris*.

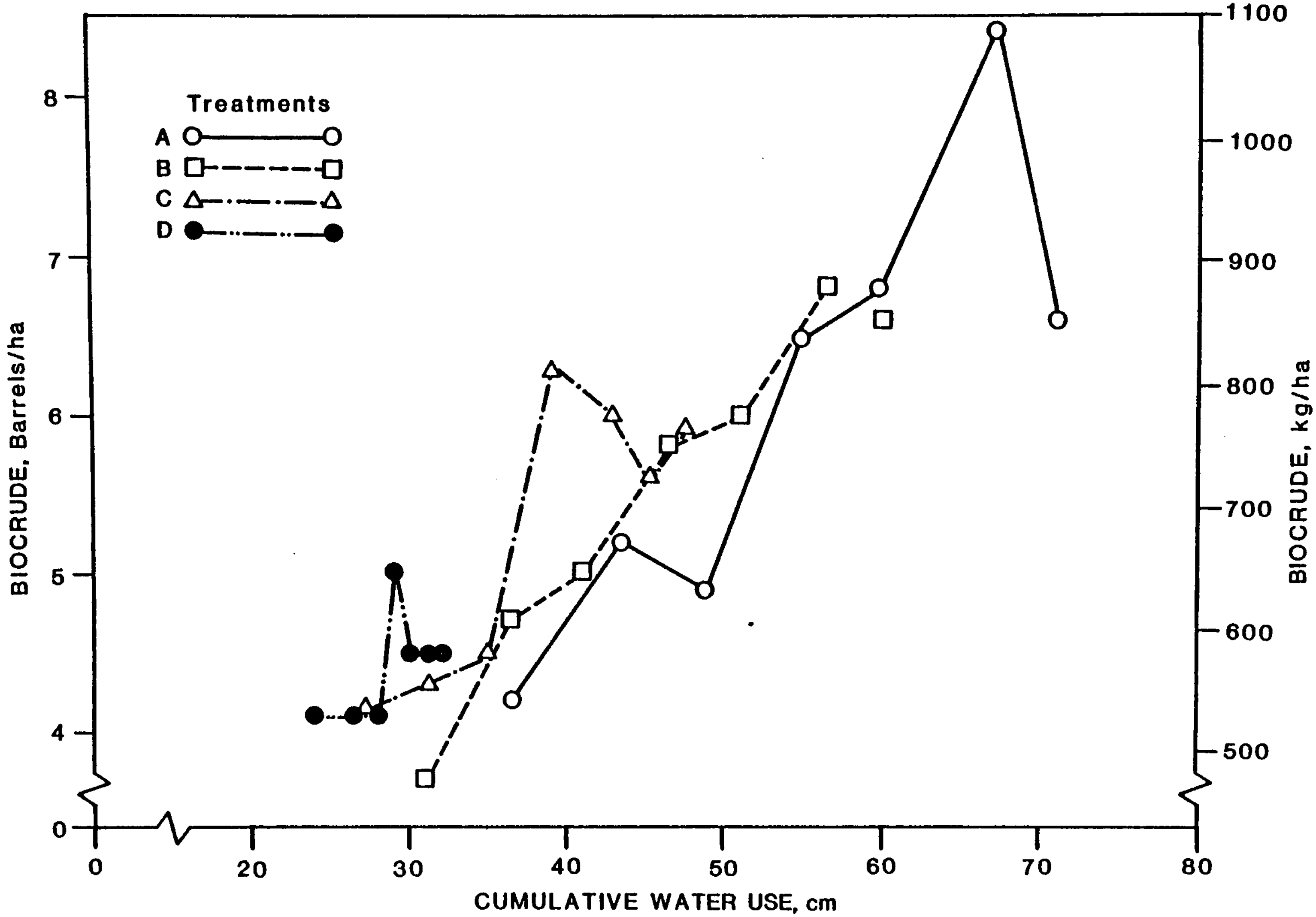

Figure 14. Biocrude production related to cumulative water use – Palo Alto, *E. lathyris*.

the drier treatments are greater than wetter treatment yields for the same quantity of water use. E. lathyris has been suggested for cultivation in regions where availability of water is limited but where vast areas of arid lands are readily available. Hence, treatments which produce lower yields but use less water may be the most desirable. A thorough analysis will depend upon the cost of obtaining additional water.

Chico, E. lathyris

The following discussion will parallel the Palo Alto, E. lathyris discussion. Additionally, relative differences between the two ecotypes of plants will be pointed out.

Water applications. Table 4 shows the dates and quantities of irrigation water applied throughout the growing season. Treatments A, B, C and D were irrigated 10, 8, 6, and 2 times, respectively. The two irrigations in October were to provide uniform soil moisture near field capacity in all test plots. Total irrigation water applied until May 6, 1981 were 61.7, 48.0, 35.3, and 14.2 cm from the wettest to the driest treatments.

No irrigation water was applied to plants in treatment D since October 24, 1980. Therefore, they were under water stress when initial soil moisture in the root zone was depleted. In fact, after April 2 soil moisture in the 30 cm, and 90 cm soil profile were always below the soil moisture corresponding to 15 bars of tension.

Plants in treatment A were irrigated in an attempt to maintain the soil moisture in the root zone close to field capacity. Prior to

Table 4. Irrigation dates and depths. Chico, E. lathyris

Treatment	Water Applied, Centimeters										
	1980			1981							
	10/8	10/24	11/19	2/2	2/18	2/26	3/27	4/8	4/23	5/6	Total
A	6.6	7.62	3.81	3.81	5.33	5.08	6.6	7.62	7.62	7.62	61.71
B	6.6	7.62	--	3.81	5.33	--	6.1	6.90	6.6	5.08	48.04
C	6.6	7.62	--	--	5.33	--	5.08	5.60	5.08	--	35.31
D	6.6	7.62	--	--	--	--	--	--	--	--	14.22

May 15, the soil moisture in the top 30 cm of soil was never lower than 20% by volume. The B and C treatments were then irrigated as a proportion of the water applied in the A plots to provide four distinct irrigated water treatments.

Water use. Similarly to Palo Alto, E. lathyris a soil water balance was computed at the end of the growing season. Based on this balance the crop water use was calculated (Figure 15). No significant changes in soil moisture were measured by the neutron probe meter in the 90 to 120 cm depth indicating no root penetration at this depth.

As shown in Figure 15,during the winter months the rate of water use was approximately 1 mm/day. After February 1981, water use showed a direct correlation with water availability. At the end of the growing season approximately 67, 58, 46, and 24 cm of water had been used in treatments A, B, C, and D, respectively.

The peak water use rate for the 3 wettest treatments occurred in April as indicated by the steep slope of the curves in Figure 15. During this period water use rates were 7.0, 6.3, and 5.2 mm/day, respectively, for treatments A, B, and C. For treatment D the peak rate of 1.7 mm/day occurred in March.

Plant Height. From germination until the third week of November 1980 a growth rate of 8 cm/month was recorded (see Figure 16). Then, from late November to early February growth rate of 1.6 cm/month was measured in treatments B, C, and D, and 2.3 cm/month in treatment A. Thereafter a direct correlation between soil water availability and rate of increase in plant height was observed. In general, plant

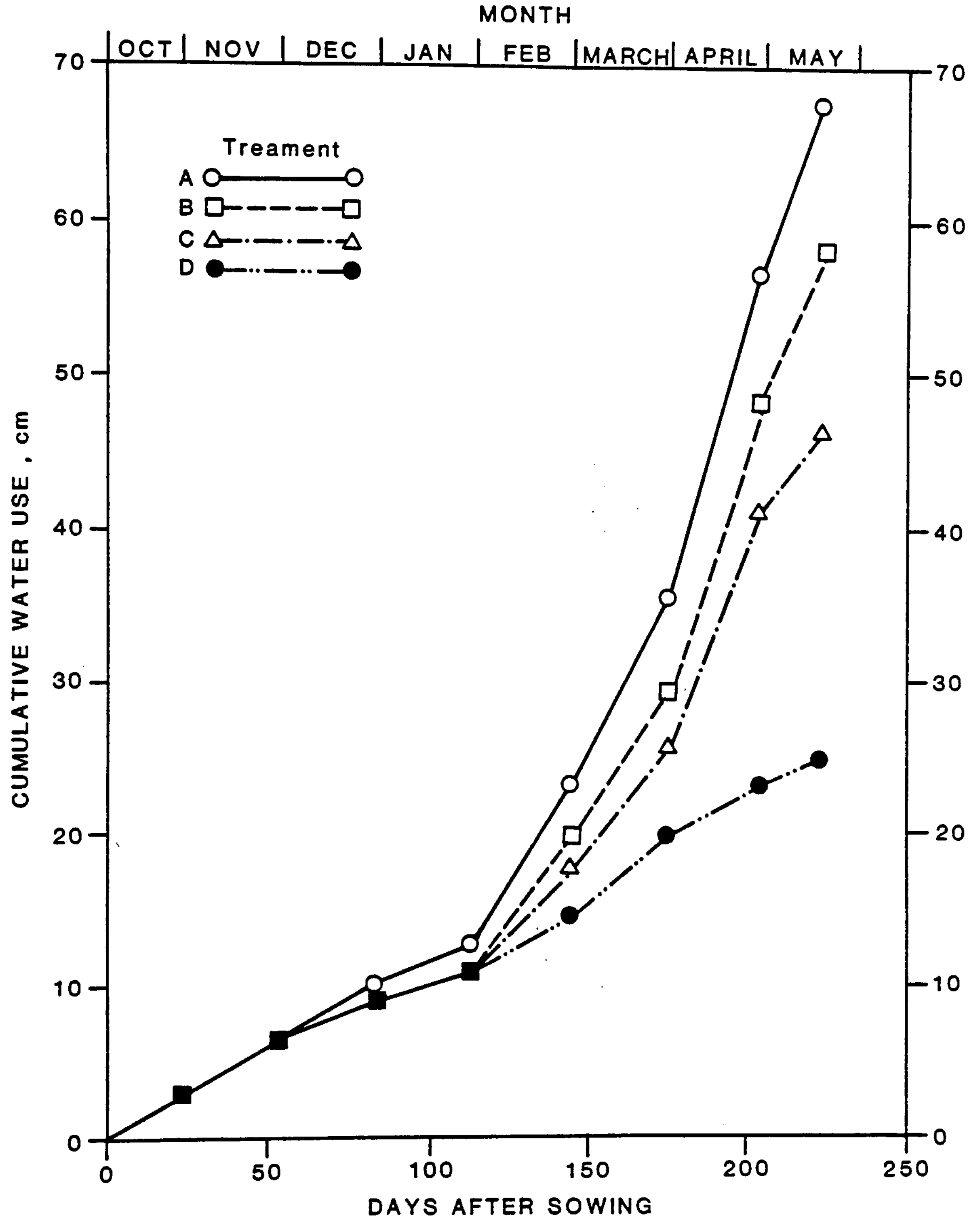

Figure 15. Cumulative water use - Chico, *E. lathyris.*

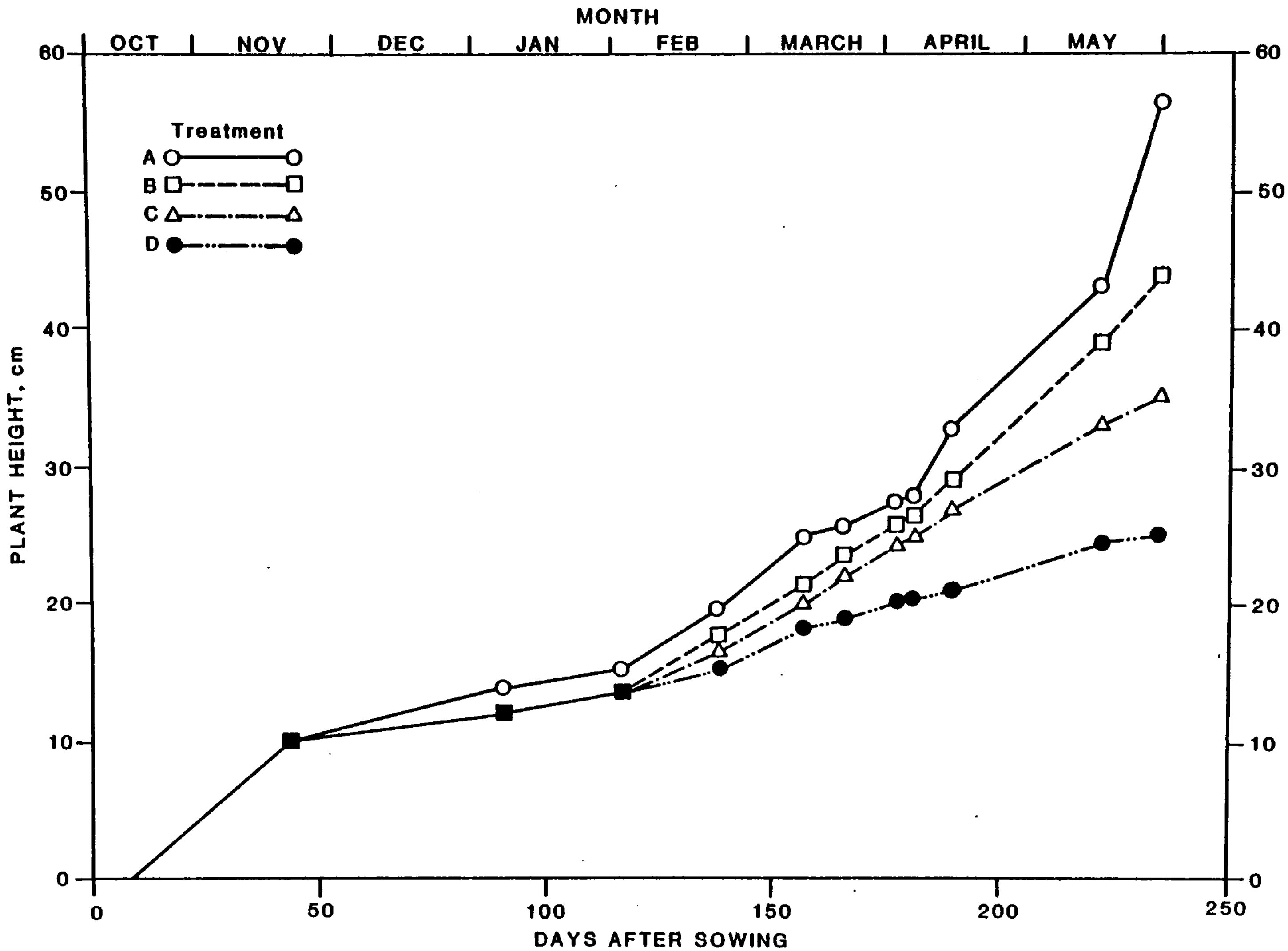

Figure 16. Plant height - Chico, *E. lathyris*.

height in all treatments increased linearly since February showing a growth rate of nearly 7.6, 7.2, 6.0, and 3.4 cm/month for treatments A, B, C, and D, respectively.

Harvest. Harvest dates, number of harvests, methods of harvest, drying of plant material, and calculation of dry matter production were made using the procedure explained previously for Palo Alto, *E. lathyris*. Oven dry matter as a percent of fresh weight is presented in Figure 17 to show the high variability for the three first harvests and the high uniformity for the four last harvests. Analogous to Palo Alto, *E. lathyris*, the data shown in Figure 17 indicate an inverse relationship between water availability and percent oven dry matter. Of particular importance is the fact that Chico, *E. lathyris* had not flowered at the time of the last harvest.

Dry matter production related to time of harvest. Figure 18 shows the variation of dry matter production with time. Similar to Palo Alto, *E. lathyris*, a positive correlation was observed between dry matter production and soil water availability through all seven harvests. Furthermore, the peak rate of increase in dry matter yields occurred in the later part of April. The average dry matter yield for the last two harvests were 9.3, 8.1, 5.6, and 4.2 t/ha for treatments A, B, C, and D, respectively. These values indicate that yields increased 127, 112, 68, and 38%, from the wettest to the driest treatment, with respect to the yield obtained from the initial harvest.

Dry matter production related to water use. Figure 19 shows the average dry matter yield as related to water use for the four

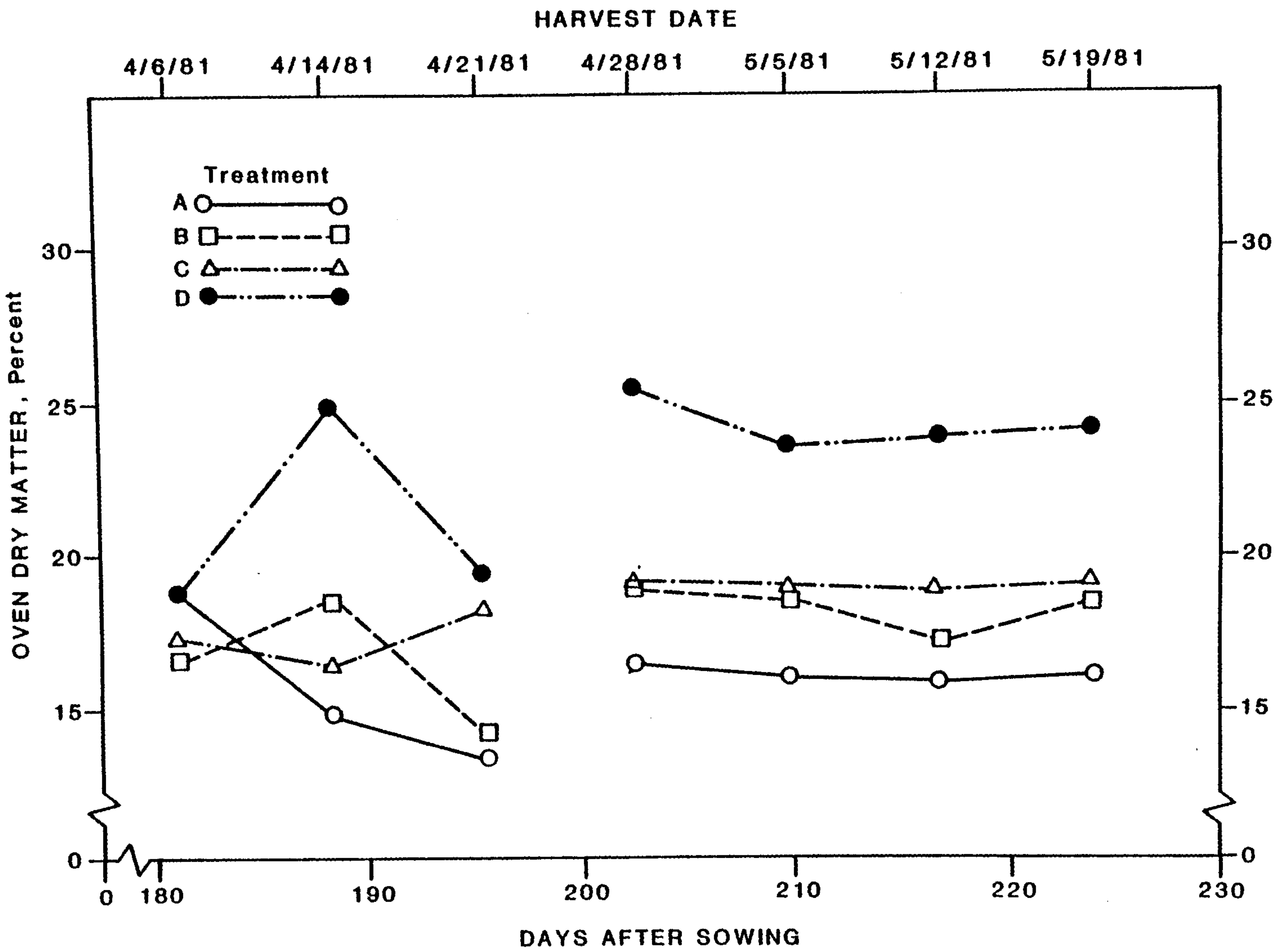

Figure 17. Oven dry matter as a percent of harvested weight – Chico, *E. lathyris*

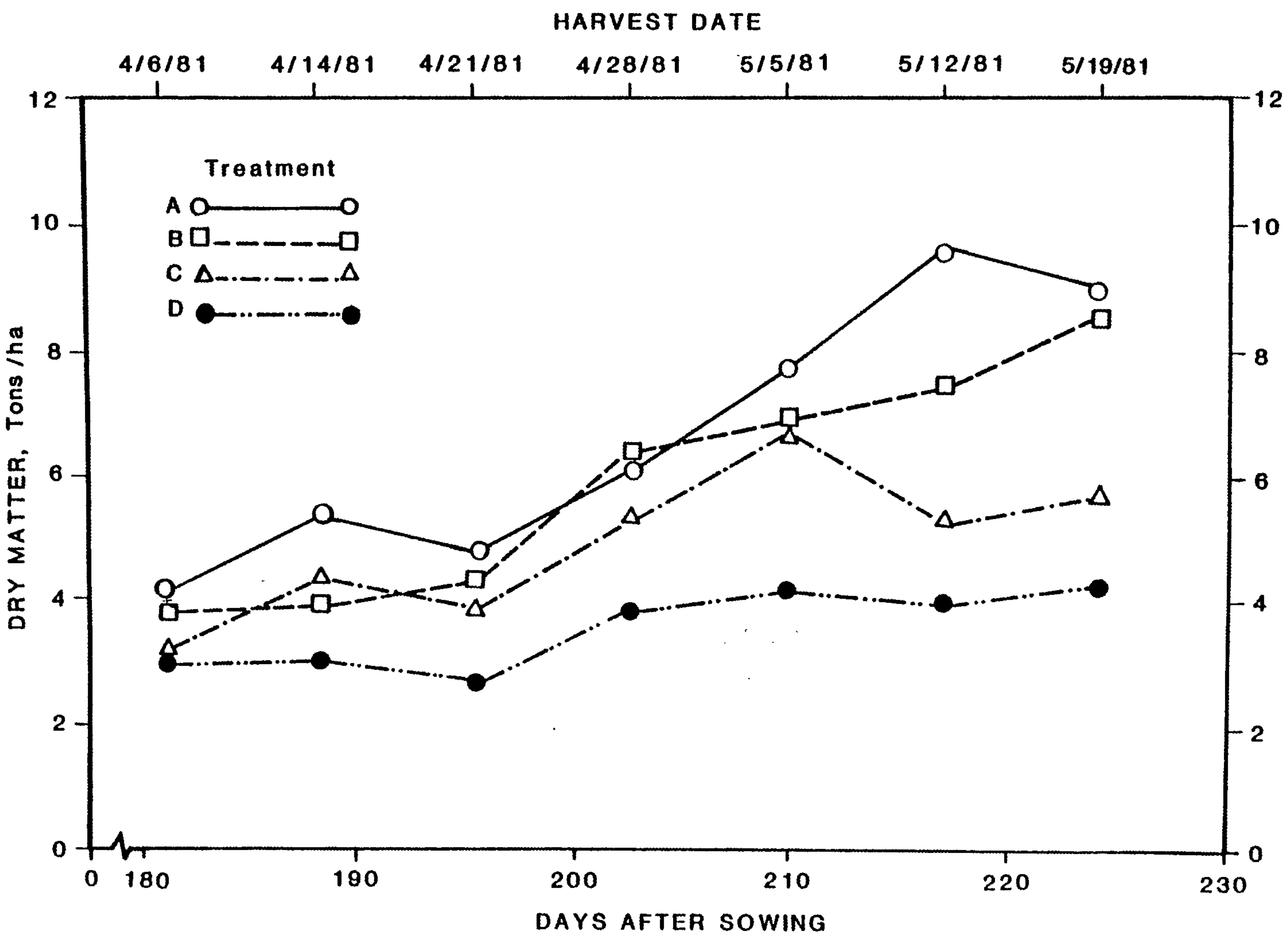

Figure 18. Dry matter production related to time - Chico, *E. lathyris*.

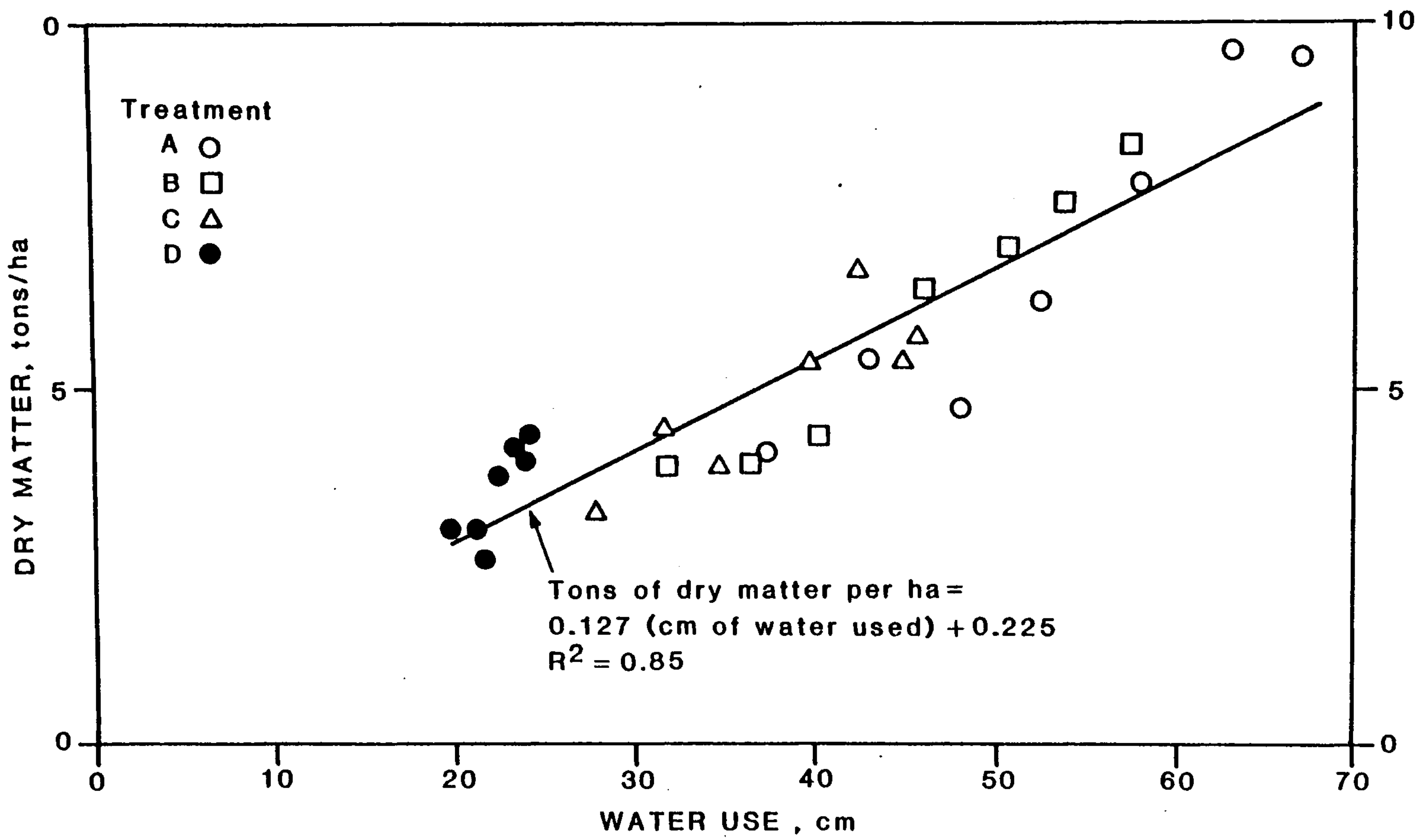

Figure 19. Dry matter production as a function of water use - Chico, *E. lathyris.*

replications and includes a fitted regression line for all treatments lumped together. A general trend of dry matter production increasing linearly with increased water use was observed throughout the harvest period. R^2 and the slope of the lumped regression line are given in Figure 19. Analogous to Palo Alto, E. lathyris, the wetter treatments produced higher maximum yields than the drier treatments. Furthermore, in several cases dry matter production for the same quantity of water use was higher for the drier plots than for the wetter treatments.

Biocrude production related to time of harvest. As can be seen in Figure 20, the percent of ethyl acetate extract increased from the initial to the last harvest. In general, the average of the three first harvests was nearly 1.1% lower than the average obtained from the last three harvests. The average percentages obtained were 7.1, 7.3, 7.2, and 8.3 of ethyl acetate for treatments A, B, C, and D, respectively. These values indicate that the driest treatment produced approximately 1.1% more than the rest of the treatments. Analogous to Palo Alto, E. lathyris, the above averages were used to compute the biocrude production.

Figure 21 shows the yield obtainable from all the harvests for all treatments. Similar to Palo Alto, E. lathyris, a positive correlation was observed between biocrude production and soil water availability through all seven harvests. Furthermore, the peak rate of increase in biocrude production occurred in the later part of April. The average biocrude yields for the last two harvests were 5.1, 4.6, 3.1, and 2.7 bbls/ha for treatments A, B, C, and D, respectively.

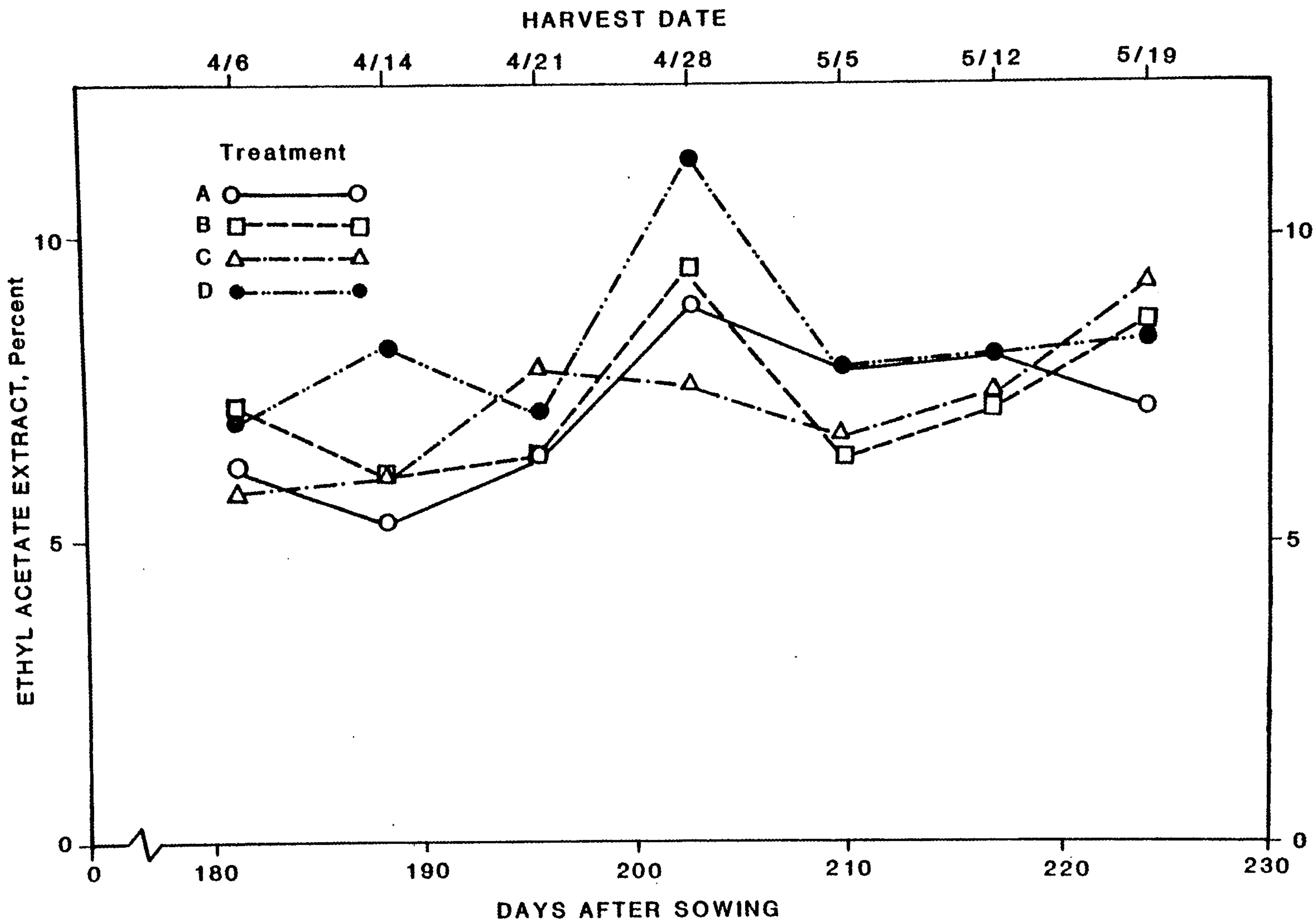

Figure 20. Percent of ethyl acetate extract – Chico, *E. lathyris.*

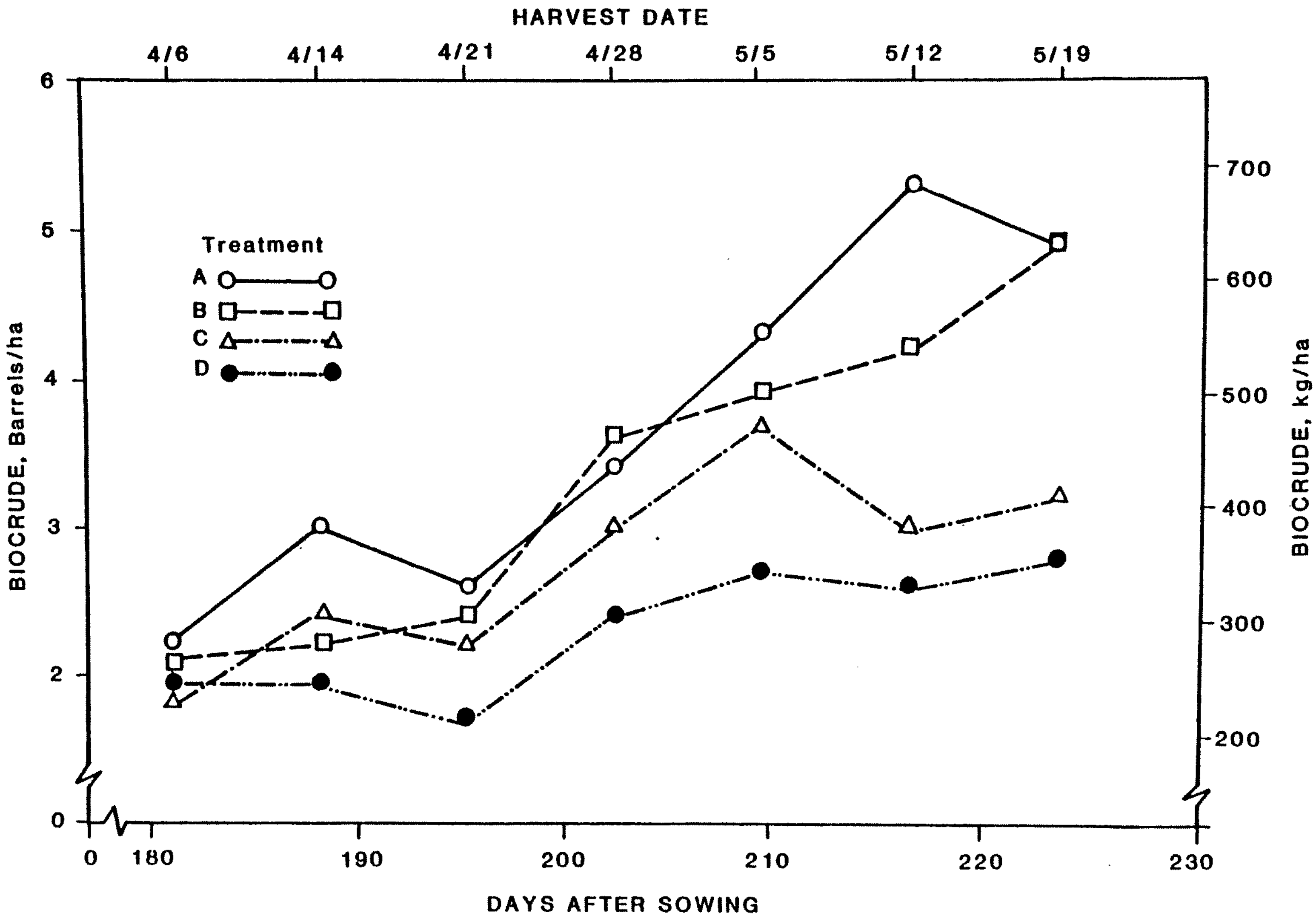

Figure 21. Biocrude production related to time - Chico, *E. lathyris.*

Biocrude production related to water use. Figure 22 shows the biocrude yields related to cumulative water use. The results obtained for Chico, *E. lathyris* follow the same trend as the results obtained for Palo Alto, *E. lathyris*. Thus, the wetter treatments produced higher maximum yields and consumed more water than the drier treatments (see Figure 22). In addition, for most of the cases, the biocrude yields corresponding to the drier treatments are greater than wetter treatment yields for the same quantity of water use.

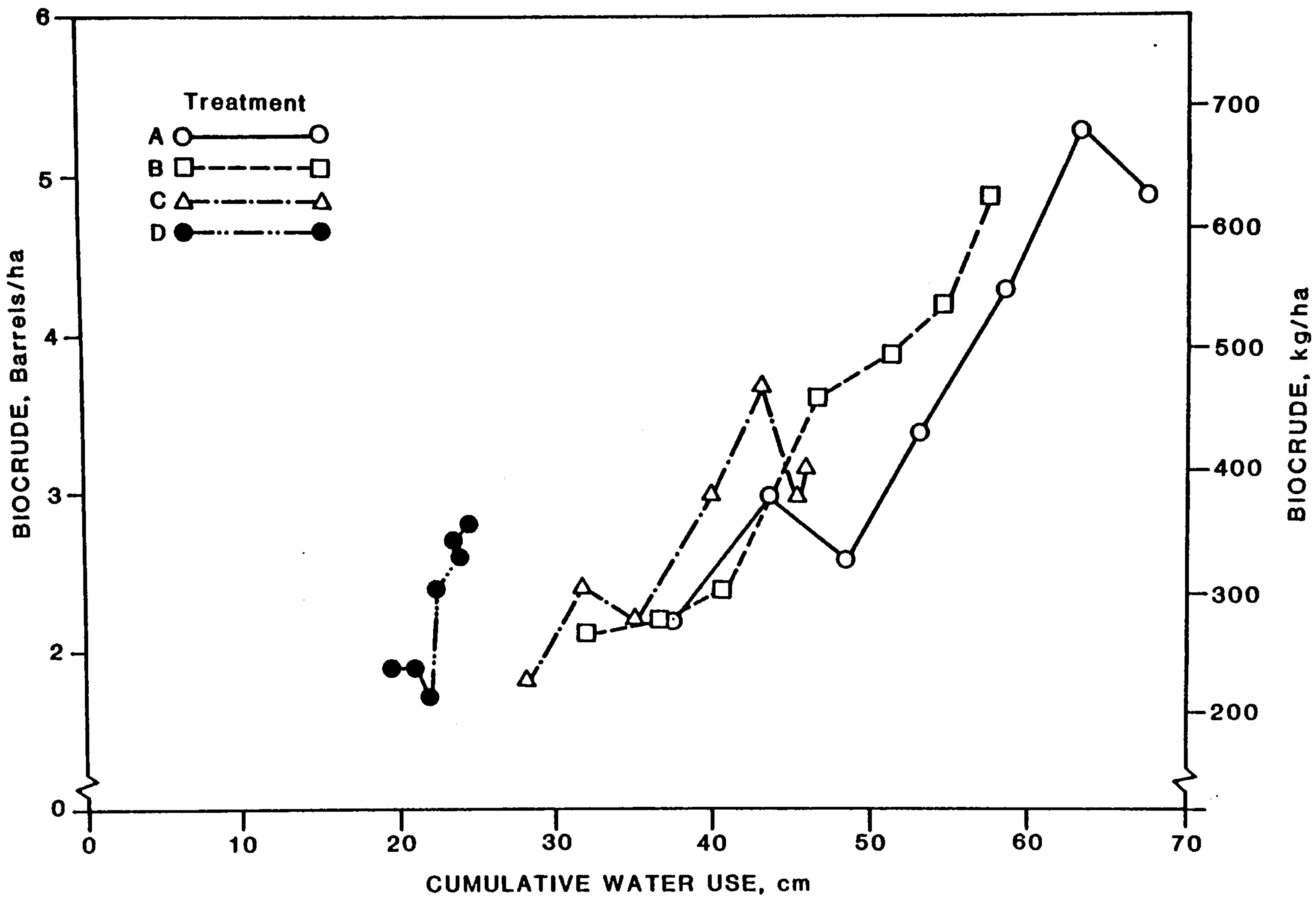

Figure 22. Biocrude production related to cumulative water use – Chico, *E. lathyris.*

SUMMARY AND CONCLUSIONS

Two ecotypes of _Euphorbia lathyris_ were field tested, one from Chico and a second from Palo Alto, California. _E. lathyris_ has been suggested as a plant with a high potential to produce materials which might be substitutes for petroleum. A Spring 1980 planting was hindered by plant disease and did not provide any quantitative results. The Fall 1980 planting, however, provided much useful data. A summary of the most important data collected from seven weekly harvests of the Fall planting is given in Table 5.

As shown in Table 5, the Palo Alto ecotype clearly outperformed the Chico by a factor of approximately 2.5, 1.7, and 1.5 relative to plant height, dry matter yield, and biocrude production, respectively. Similar water use was observed for both ecotypes. Direct relationships were found between soil moisture availability and plant growth, dry matter production, and biocrude production. However, no relationship was observed between percent ethyl acetate extract and soil moisture availability. Furthermore, the percent of ethyl acetate extract increased approximately 1.5% from the initial to the last harvests.

The winter rainfall and post-plant irrigations were sufficient to meet the low water requirement of _E. lathyris_ during the winter months. Therefore, no additional irrigation was needed until mid February when active growth and water use increased. Of particular interest, is the fact that levels of soil moisture in treatment D, the driest treatment, were lower than the equivalent soil moisture at

Table 5. Summary for the Fall 1980 planting.

Plant	Water Treatment	Water Use[1], cm	Maximum plant height[1], cm	Dry Matter production[2], t/ha	Percent ethyl acetate extract[3]	Biocrude production[2], bbls/ha
Palo Alto	A	71	105	13.5	7.2	7.5
	B	60	97	13.2	6.6	6.7
	C	48	80	10.3	7.3	5.8
	D	32	64	7.8	7.5	4.5
Chico	A	67	43	9.3	7.1	5.1
	B	58	39	8.1	7.3	4.6
	C	46	33	5.6	7.2	3.1
	D	24	25	4.2	8.3	2.7

1 As of May 19, 1981.

2 Based on the average of the last two harvests.

3 Average for all harvests.

15 bars of tension for 45 days. Although plants in this treatment showed symptoms of water stress, they continued to grow and the Palo Alto ecotype yielded a maximum of 4.5 bbls/ha of biocrude. This fact indicates that E. lathyris can use water at tensions higher than the commonly assumed permanent wilting point. However, the yields obtained at this moisture level were 10, to over 40 percent lower, respectively, for the initial and final harvest, than the yields obtained from plants grown under the treatment A regime, where water was not limiting.

Palo Alto plants in treatment A used over 70 cm of water and produced the highest yields recorded in this experiment (see Table 5). Optimization of other crop production practices such as fertilization and density of planting would further increase biocrude production. However, the greatest potential for increasing yields lies in the field of genetic improvement and search for new germ plasm to find plants with a higher percentage of hydrocarbon-like material, higher biomass production, disease resistance, and lower water requirements.

REFERENCES

Calvin, M. 1977. Energy and materials via photosynthesis. In Living systems as energy converters, R. Buret, M. J. Allen, and J. P. Massure (eds.). North Holland Publishing Company, New York. pp. 231-259.

Calvin, M. 1978a. Green factories. Chemical and Engineering News. Vol. 56, No. 12. March 20. pp. 30-36.

Calvin, M. 1978b. Petroleum plantations. Paper presented to the Agricultural Chemical Society of Japan, Nagoya, Japan, April 1, 1978. p. 37.

Coelho, M. A. 1974. Spatial variability of water related soil physical properties. Ph.D. thesis at the University of Arizona, Tucson.

Congressional Research Service, Library of Congress. 1980. The energy factbook. U.S. Government Printing Office, Washington, D.C. p. 809.

Dickey, E., L. Schwankl. 1978. Soil moisture monitoring using the neutron probe. USDA Soil Conservation Service. Davis, California. p. 57.

Goodin, J. R., and D. K. Northington. 1979. Arid land plant resources. In Proceedings of the International Arid Lands Conference on Plant Resources. International Center for Arid and Semiarid Land Studies. Texas Tech. University. Lubbock, Texas. p. 724.

Hammond, A. L., W. D. Metz, and T. H. Maugh. 1973. Energy and the future. American Association for the Advancement of Science, Washington, D.C. p. 184.

Israelson, O. W., and V. Hansen. 1962. Irrigation principles and practices. Third Edition. John Wiley and Sons, Inc. New York. p. 447.

Lawrence Berkeley Laboratory. 1981. Hydrocarbons and energy from plants. Lawrence Berkeley Laboratory Annual Report: 1980. University of California, Berkeley, California. Chemical Biodynamics Division. March 10. p. 16.

McMullan, J. T., R. Morgan, and R. B. Murray. 1977. Energy resources. Edward Arnold Ltd., London, Great Britain. p. 177.

Meador, R. 1974. Future energies. Ann Arbon Science Publishers, Inc., Michigan. p. 63.

The National Atlas of the United States of America. 1970. United States Department of the Interior Geological Survey. Washington, D.C. p. 417.

Nemethy, E. K., J. W. Otvos, M. Calvin, and R. Sachs. 1978. Hydrocarbons and energy from plants. Lawrence Berkeley Laboratory Report 8596, November 1978. To be published in proceedings of Workshop on "Biomass Energy and Technology", Electric Power Research Institute, Palo Alto, California. p. 13.

Peoples, T. R., and J. D. Johnson. 1980. Crop alternatives in semiarid regions. Presented at CONACYT and CONAZA Conference on Natural Resources and Regional Development the case of the Semiarid Region. Cuautla, Morelas, Mexico. October 6-8. p. 17.

Peoples, T. R. 1980. Personal communication. Assistant Professor, Department of Plant Sciences, University of Arizona, College of Agriculture, Tucson, Arizona.

Peoples, T. R. 1981. Gopher Plant in Arizona. Department of Plant Sciences Information Series 81-11. The University of Arizona, Tucson, Arizona. p. 2.

Peoples, T. R. et al. 1981. Euphorbia lathyris L.: A future source of extractable liquid fuels. University of Arizona Ag. Exp. Stn. Technical Paper No. 3416. To be published in Biosources Digest, Vol. 3, No. 3. p. 8.

Sachs, R. M., C. B. Low, J. D. MacDonald, and A. R. Awad. 1981. Terpene hydrocarbon yields from Euphorbia lathyris. To appear in Proceedings of "Energy from Biomass and Wastes V", Sponsored by Institute Gas Tech. January 26-30. p. 15.

Sellers, D. S., and R. H. Hill (eds.). 1974. Arizona climate 1931-1972. 2nd Edition. The University of Arizona Press. Tucson, Arizona. p. 616.

U.S. Department of Energy. 1981. Monthly energy review. Energy Information Administration, U.S. Government Printing Office, Washington, D.C. March. p. 103.