IRRIGATION EVALUATIONS AND IMPROVEMENTS IN NEW MEXICO TO CONSERVE WATER AND ENERGY

by

Robert B. Hulsman
Principal Investigator
Agricultural Engineering Department

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ABSTRACT

Sixteen on-farm, closed border, surface irrigation systems were evaluated over a three-year period in Dona Ana County, New Mexico. One hundred forty-one individual and 16 seasonal irrigation efficiencies were calculated along with 378 distribution uniformities and the same number of coefficients of uniformity. Wide variations in individual efficiencies (1.24 to 232.5 percent), seasonal efficiencies (22.61 to 124.77 percent), distribution uniformities (20.3 to 96.37 percent), and coefficients of uniformity (55 to 98 percent) indicate the potential for considerable savings in water and energy resources. These savings have been presented in tabular form for water, energy, and cost resources.

Keywords: irrigation efficiency, water distribution, uniformity coefficient, surface irrigation, water, energy.

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Introduction

The total agricultural acreage in the state of New Mexico exceeds 1.0 million hectares (2.5 million acres [Lansford, et al. 1980]), of which 57 percent is irrigated. Sixty percent of the irrigated acreage comes from pumped ground water. As a result of large-scale pumping, extreme declines in water levels have been experienced and surface flows have been diminished in areas where surface and ground supplies are interconnected (U. S. Department of the Interior 1976). The problems of ground water mining are becoming especially acute in the Texas-Gulf and Pecos River basins (U. S. Department of the Interior 1976).

The question of how long the present water resources will last is very much a function of how efficiently the water is used. The timely application of precise amounts of water will assure that adequate quantities are provided for crop consumptive-use without excessive run-off, deep percolation, or conveyance losses. Because of the difficulty in making the needed measurements, very little data are available in the state of New Mexico that indicate general levels of water application efficiencies achieved by farmers. Available data indicate that the water application efficiency computed on a typical farm located in the extreme south-central areas of the state average about 65 percent on a seasonal basis, ranging from 35 to more than 100 percent depending on the field (Lansford et al. 1977). These values were estimated by measuring the applied water and computing the consumptive-use from current information on evapotranspiration under nonlimiting moisture conditions. These estimates may or may not be accurate depending upon the yields achieved because the yield is a direct function of evapotranspiration.

In Utah, Willardson (1972) reported application efficiencies ranging from 24 to 77 percent with an average of 46 percent on the same field throughout the season. The application efficiency between irrigations had as large a variance as the variance in seasonal efficiencies between fields.

"Irrigation evaluations and improvements in New Mexico to conserve water and energy" was a federally funded project undertaken by the author in the Department of Agricultural Engineering, New Mexico State University. The duration of the project was from June 1979, with extensions, through May 1983. The purpose of the study was to evaluate irrigation practices associated with surface flooding of closed borders to determine: water application efficiencies for individual and seasonal irrigations, distribution and coefficients of uniformities, and methods and practices for improved efficiencies and uniformities. Potential water and energy resource savings are also evaluated based upon current management practices.

Procedures

The Dona Ana County extension service agent was consulted relative to the selection of local cooperative farmers. Seven farmers were selected who were fairly well distributed around the county and who were raising typical state crops of barley, alfalfa, cotton, onions and chile. Other crops were added as the project progressed due to changes made by the farmers in their cropping patterns and the economic situation. These crops were lettuce, cucumbers, wheat and pecans. Other factors entering into the selection of cooperating farmers was the distance from the university, the distances between farms, and the ability of the researcher to travel from one farm to another gathering data.

The chosen border, approved by the farmer for the crop to be monitored, was identified and surveyed. A careful log of field dimensions and slope (table 1) was maintained. The slopes measured were very shallow. Four of the 16 fields sloped very gently in the direction of the head of the border. Because the slopes were so slight, and the fields had been freshly cultivated when the measurements were taken, the observed slopes were believed to be within measurement error and therefore of little or no consequence. In-line totalizing water meters were installed at the turnout to each border. Multiple meters were installed at borders with more than one turnout. The flow meters were calibrated prior to installation each year using a rectangular weir. Water application for each irrigation was recorded as was the total water applied during the irrigation season.

Infiltration characteristics were investigated using buffered infiltrometers. At least five locations were tested on each border. Infiltration functions were plotted for each test and adjusted as explained by Merriam, et al (1978) and based upon intake opportunity times derived from advance/recession (A/R) curves using the standard depth of infiltration equation and the depth of irrigation equation for flood irrigations as follows:

$$d = kT^a \qquad (1)$$

$$DA = 28QT \qquad (2)$$

Table 1. Border strip dimensions for closed borders of various observed crops including root zone depths.

CROP YEAR	SLOPE (m/100 m)	LENGTH (m)	WIDTH (m)	ZONE (m)
ALFALFA80	0.0543	201.0	13.7	1.45
ALFALFA81	0.0543	201.0	13.7	1.52
BARLEY80	0.0444	536.4	18.9	0.38
CHILE801	0.0788	193.2	17.7	0.53
CHILE802	0.0252	108.8	12.2	0.53
CHILE81	0.0264	261.2	15.1	0.61
CHILE82	-0.0143	201.0	15.2	0.61
COTTON80	0.0625	148.4	10.1	1.14
COTTON81	-0.0143	204.2	16.6	1.22
CUCUMBERS82	0.0142	259.1	13.7	0.30
LETTUCE821	-0.0143	160.6	8.2	0.30
LETTUCE822	0.0214	427.6	9.3	0.30
ONIONS80	-0.0357	192.0	15.1	0.38
ONIONS81	0.0380	155.4	10.4	0.46
PECANS81	0.0063	246.9	27.1	1.45
WHEAT81	0.1288	117.3	35.7	0.46

The depth infiltrated is "d" in centimeters; "a" is an exponent taken from the infiltration curves of figures 1 and 2; "T" the opportunity time of infiltration, in minutes; "D" is the depth of irrigation, in centimeters; "t" is the time in hours to irrigate a border; "A" is the area flooded, in hectares; "Q" is the flow rate into the border, in l/s; and "k" is a coefficient averaged over the total number of A/R tests for the border in question.

Advance/recession data were collected for each border at least once and, in some cases, two and three times during the irrigation season. These data are plotted in figures 20 through 46. The depth of infiltration was calculated for each station down the border using the intake opportunity times shown, in total minutes, between the advance and recession curves in the figures. Distribution uniformities (DU) were then calculated using the ratio of the average low quarter infiltrated to the average water infiltrated over the entire border (Merriam, et al 1978). Coefficients of uniformity (CU) were calculated from the A/R curves using the equation derived by Christiansen (1942). Values for DU and CU were also calculated using data obtained from neutron probe measurements.

Neutron access tubes were installed in two, and in some cases three, rows spaced 6 to 9 m (20 to 30 ft.) apart, depending on border width, down each border at 30.5 m (100 ft.) intervals. The 5.1 cm (2.0 in.) diameter aluminum tubes were set at a depth of 1.83 m (6.0 ft.). Soil profiles were logged at each access tube location as they were being installed. These data were used to determine classification and layering of the soils which are classified as Glendale-Harkey deep, nearly level,

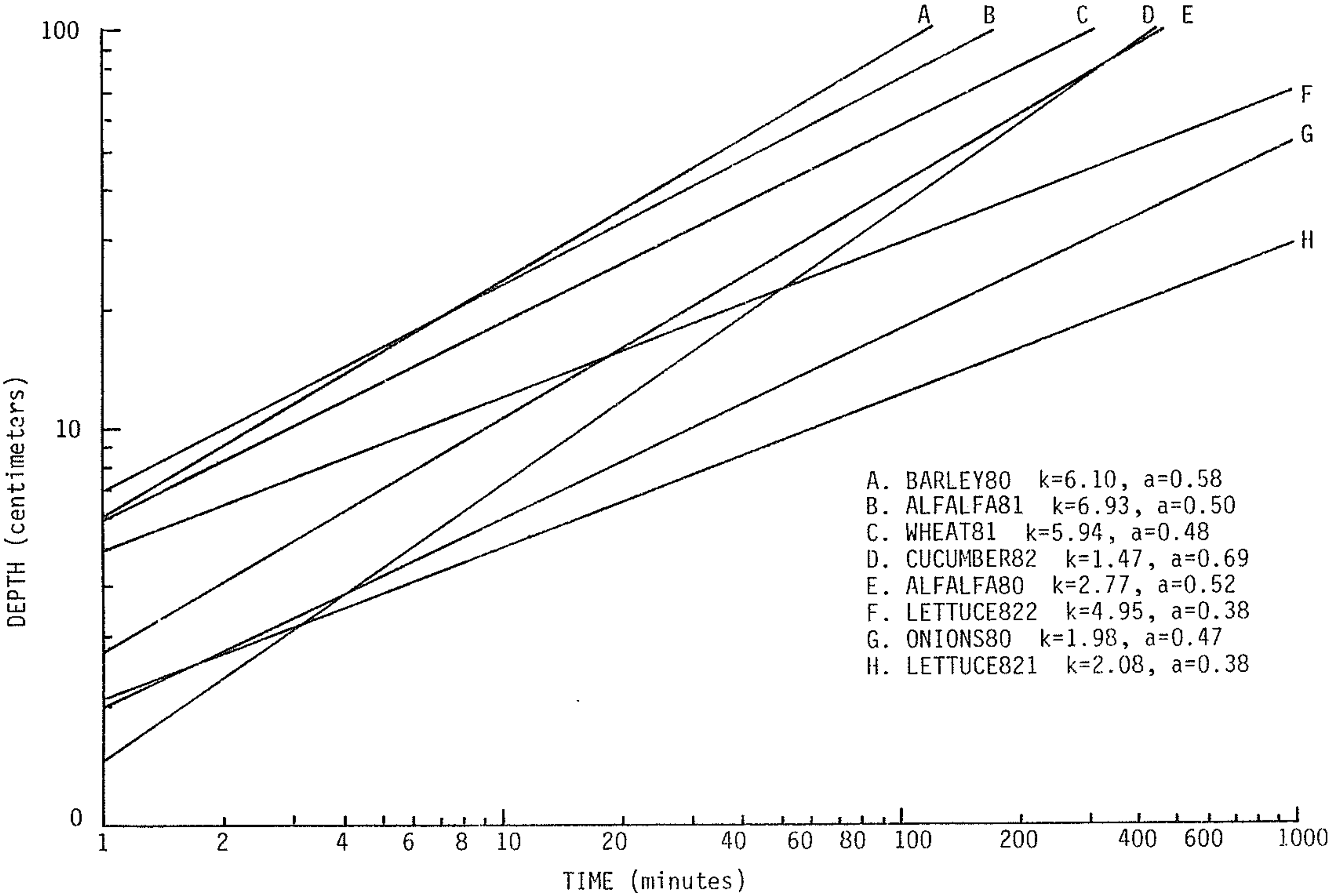

Figure 1. Infiltration functions for crops as noted. Crop names are given along with the year of season. Values of k and a, are constants to be used in the infiltration equations.

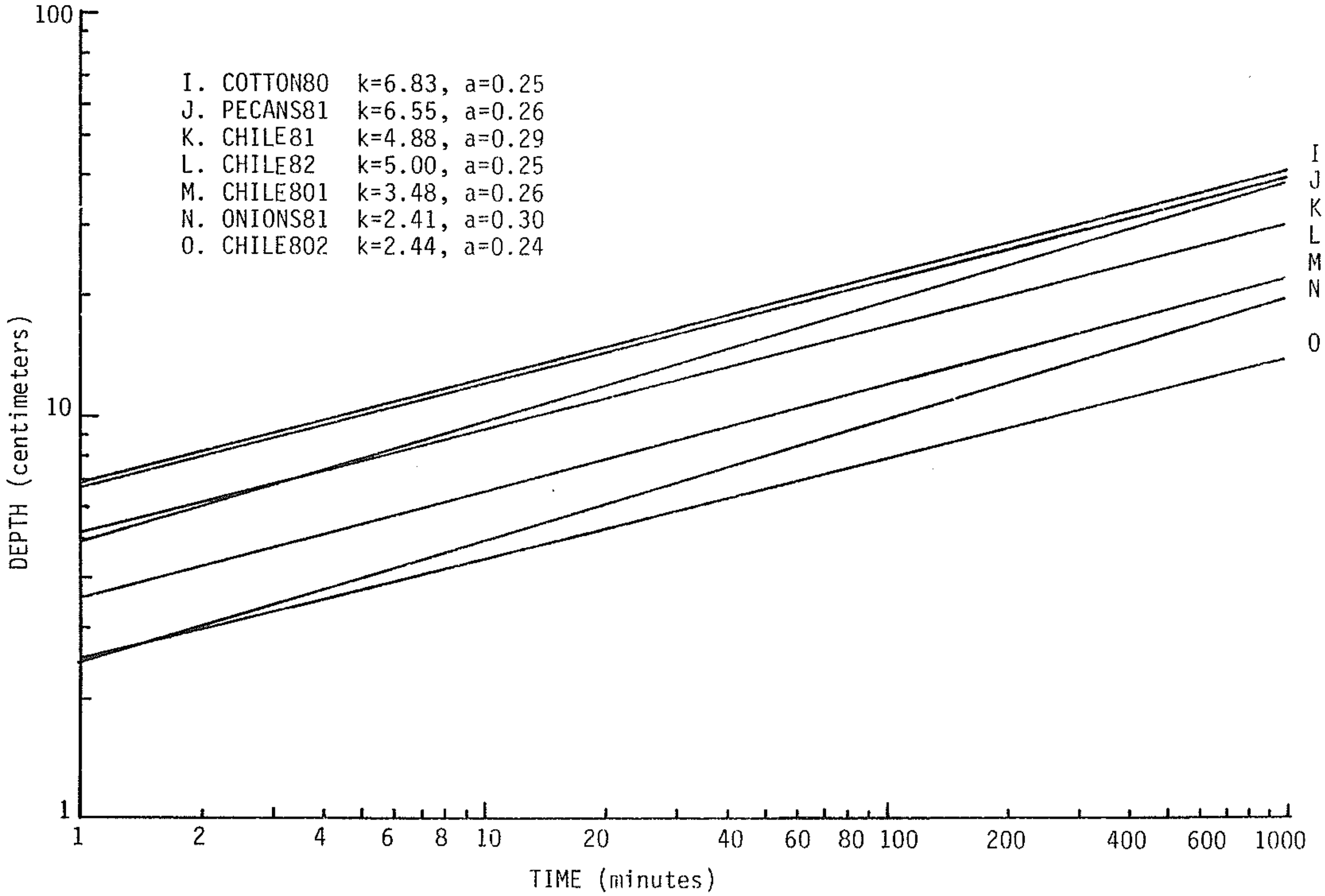

Figure 2. Infiltration functions for crops as noted. Crop names are given along with the year of season. Values of k and a, are constants to be used in the infiltration equations.

well drained soils that formed in alluvium (USDA 1980). Field capacity (FC), permanent wilting point (PWP), and available soil moisture (AW) were calculated using physical properties of soils from Hansen (1979). Soil moisture measurements were taken every other week when possible and as soon after an irrigation as one could get onto the field. A neutron scattering probe, Troxler Model 104, was used to make these measurements.

The values shown in figure 3 for FC and PWP were calculated using soil logging data when the neutron access tubes were installed as explained earlier. These data are tabulated in table 2 for each crop along with the AW, average soil moisture (AV), and the percentage of soil moisture depletion. Available soil moisture is the difference between FC and PWP. The AV is the average of the neutron probe readings over the season and is indicated by the dashed line in the figure and by the value shown in table 2 under column 5. The total seasonal average soil moisture depletion, table 2, column 6, was calculated as the ratio of the amount depleted to the available water as follows:

$$\text{PERCENTAGE DEPLETED} = 100\ (\ FC - AV\ )\ /\ AW \qquad (3)$$

All variables are as previously defined. Crop names in the table denote both the name of the crop and the year the data were collected. In the event that more than one crop of the same type was observed during the same year, an additional numeric value was added to the name. For example, CHILE801 and CHILE802 represent two chile crops, numbers 1 and 2, grown in the 1980 season.

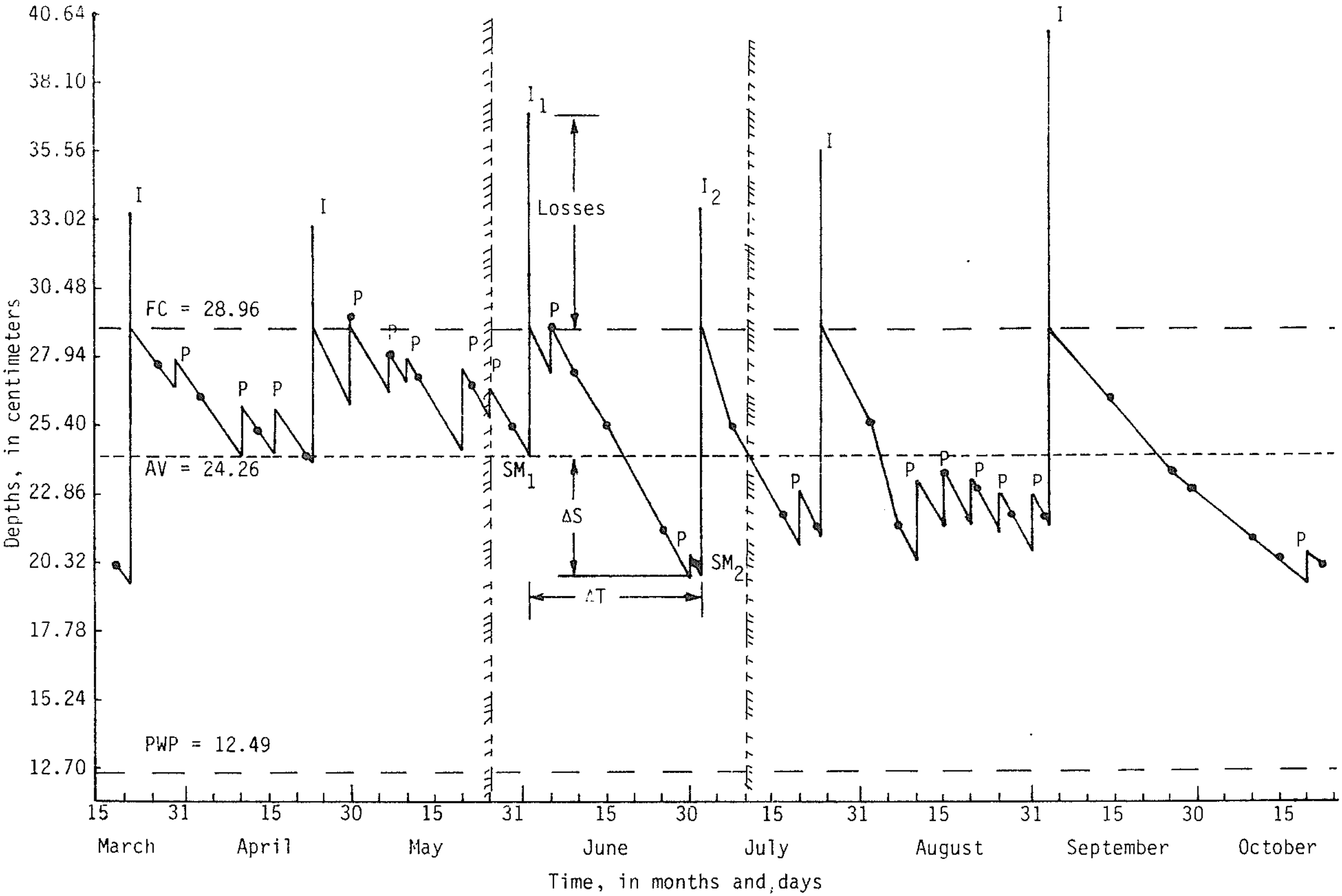

Figure 3. Soil moisture changes with time for PECANS81. I_1 and I_2 are two different irrigation events, SM_1 and SM_2 are two soil moisture amounts, ΔS, is the change in soil moisture during ΔT, the change in time between irrigations.

Table 2. Field capacities, permanent wilting points, average soil water as derived from neutron probe data, and percent water depletion over the season.

CROP/YEAR	FIELD CAPACITY (cm)	PERMANENT WILTING POINT (cm)	AVAILABLE WATER (cm)	AVERAGE WATER (cm)	DEPL (%)
ALFALFA80	26.24	11.30	14.94	17.81	56.43
ALFALFA81	26.24	11.30	14.94	16.48	65.33
BARLEY80	15.37	6.38	8.54	14.45	10.77
CHILE801	15.95	7.63	8.33	14.05	23.81
CHILE802	17.62	8.49	9.13	14.81	30.78
CHILE81	20.45	9.85	10.60	18.64	17.08
CHILE82	18.23	8.72	9.51	13.34	51.42
COTTON80	31.83	14.96	16.89	24.33	44.40
COTTON81	26.76	12.13	14.63	19.84	47.30
CUCUMBERS82	12.29	5.94	6.35	11.96	5.20
LETTUCE821	9.11	4.36	4.75	7.21	40.00
LETTUCE822	10.70	5.15	5.55	9.86	15.14
ONIONS80	11.38	5.45	5.94	8.71	45.12
ONIONS81	13.67	6.54	7.13	12.07	22.44
PECANS81	28.96	12.49	16.47	24.26	28.54
WHEAT81	18.43	8.92	9.51	11.99	67.72

Results

The research findings establish a basis upon which to generalize events at the farm level. The application of water onto a field is the basis upon which most irrigation evaluations may be made. Table 3 is a tabulation of the individual applied irrigations, in centimeters of water; total seasonal applied water, in centimeters; and the total seasonal evapotranspiration (ET), by crop name. The table shows considerable variability in the depth of water applied to these crops. Although some variability is necessary, as when adjusting applied water with increasing demand by the crop, the variability shown here does not reflect this. The applied amounts are scattered throughout the season with no apparent regard for changes in ET. There also appears to be considerable disparity between the required irrigation amount and the amount actually applied. For example, with CHILE801 and COTTON80, the quantity applied was just half the quantity required to meet crop water needs. With LETTUCE821 and ONIONS81, the water applied was double the amount actually needed. Other irrigation depths fall between these two extremes.

Figure 3 describes soil moisture variations using neutron probe and ET information. The time period in 1981 from May 25 through July 10 has been highlighted to illustrate the soil moisture profile during the period between two irrigation events. The amount of moisture in the soil, SM_1, is calculated before irrigation event one, I_1, occurs. Reading this value to be 24.18 cm (9.52 in.) an irrigation of 12.76 cm (4.99 in.), I_1, would raise the soil moisture level to 36.94 cm (14.54 in.). Assuming further that the field capacity for this soil

Table 3. Applied water at each irrigation, total seasonal water used, and evapotranspiration (ET) noted below crop and year.

CROP YEAR ET (cm)	IRRIGATION DEPTHS (cm)	CROP YEAR ET (cm)	IRRIGATION DEPTHS (cm)	CROP YEAR ET (cm)	IRRIGATION DEPTHS (cm)	CROP YEAR ET (cm)	IRRIGATION DEPTHS (cm)	CROP YEAR ET (cm)	IRRIGATION DEPTHS (cm)
ALFALFA80	11.61		5.44		7.72	LETTUCE821	15.34		2.79
93.25	11.61		3.45		5.54	27.76	9.25		1.52
	11.61		0.91		5.49		5.15		5.08
	11.43		43.28		2.11		4.24		3.07
	8.56				3.05		5.18		3.02
	11.48	CHILE802	8.15		2.97		4.52		4.57
	21.41	71.20	3.15		6.02		4.62		3.91
	9.12		3.00		3.61		4.06		4.14
	7.62		8.08		4.95		2.49		4.50
	104.50		8.08		79.40		54.89		5.82
			8.28						5.54
ALFALFA81	8.76		4.04	COTTON80	8.33	LETTUCE822	11.36		7.37
104.94	6.35		11.58	60.35	8.33	28.19	9.17		5.23
	6.60		13.89		8.15		4.17		5.13
	26.77		12.85		4.95		1.55		6.60
	15.45		12.09		3.71		3.05		11.25
	8.46		5.74		5.77		29.57		6.12
	10.57		107.57		39.24				103.46
	16.61					ONIONS80	5.11		
	10.54	CHILE81	9.93	COTTON81	19.81	34.04	5.11	PECANS81	13.44
	110.41	82.63	4.19	68.30	9.40		7.70	90.42	8.74
			13.34		7.19		6.15		12.83
BARLEY80	20.85		11.05		7.11		5.54		13.59
43.43	20.85		11.05		7.32		5.59		14.48
	7.85		12.37		50.85		3.86		18.36
	35.03		13.16				5.23		81.41
	21.46		4.27	CUCUMBER82	5.44		2.57		
	19.33		6.71	27.66	6.53		3.94	WHEAT81	10.80
	125.35		86.06		8.92		50.77	46.60	12.24
					6.20				11.07
CHILE801	10.92	CHILE82	9.35		5.69	ONIONS81	4.39		10.01
86.74	3.99	71.20	8.18		5.74	52.02	3.89		14.51
	7.49		6.86		38.23		4.19		58.62
	5.38		6.50				2.51		
	4.85		7.06				2.87		

is 28.96 cm (11.4 in.), all water applied in access of 4.78 cm (1.88 in.) is lost to deep percolation, evaporation, and/or runoff. This is represented by the vertical line extending upward from the line marked field capacity (FC). The period between I_1 and I_2 would see a steady decline in soil moisture, except for an occasional small increase due to a rainfall event (P). Soil moisture, SM_2, of 19.81 cm (7.8 in.) is the ending soil moisture for the period. The difference between SM_1 and SM_2 represents the change in soil during this time. The total moisture consumptively used by the crop, then, would be this change in soil moisture plus ET. The Blaney/Criddle equation (USDA 1967) was used to calculate ET with sunshine and daylight percentage for New Mexico (U. S. Department of the Interior 1976) and is shown in the figure by the sloping lines between irrigation events. This technique may be similarly used to describe events between all irrigations for each crop observed. The solid circles located on the curve are the soil moisture amounts measured by the neutron probe. Graphic depictions of soil moisture for each crop are found in figures 4 through 19 in the appendix.

Table 4 lists the total number of irrigations applied during the season, including pre-irrigations; individual irrigation efficiencies by percentages; and the overall annual efficiencies for each crop. Irrigation efficiencies as used here relate only to the water applied to an individual border strip and how well it was used on that strip. It is recognized that water lost from one border onto an adjoining border may not be "lost" water, because it still may be efficiently used. It was, however, inefficiently used on the intended border strip. Irrigation efficiencies were calculated from Jensen (1969) as follows:

Table 4. Individual and seasonal irrigation efficiencies by crop name and year with number of irrigations noted below crop name.

CROP YEAR	IRRIGATION EFFICIENCY (%)	CROP YEAR	IRRIGATION EFFICIENCY (%)	CROP YEAR	IRRIGATION EFFICIENCY (%)
ALFALFA80	115.11	CHILE81	26.29	LETTUCE822	91.97
(9)	98.25	(9)	44.14	(5)	51.22
	79.56		56.55		75.41
	47.18		42.30		68.33
	36.95		51.35		
	44.96		73.81	ONIONS80	88.56
	177.55		98.86	(10)	31.35
	18.21				1.24
		CHILE82	62.11		61.93
ALFALFA81	165.60	(14)	154.67		23.18
(9)	97.31		66.41		43.42
	12.81		47.84		32.52
	92.26		42.76		139.60
	71.39		55.05		29.03
	54.79		29.17		
	73.01		119.28	ONIONS81	3.92
			65.83	(22)	2.42
BARLEY80	21.56		97.44		5.05
(6)	68.93		62.87		2.73
	12.26		65.49		8.33
	15.56		63.08		4.00
	15.11				89.26
		COTTON80	96.65		118.49
CHILE801	124.51	(6)	61.99		138.33
(8)	75.44		89.23		87.66
	53.93		138.36		49.08
	88.79		69.60		37.85
	125.74				27.51
	27.59	COTTON81	103.18		38.07
		(5)	58.93		13.45
CHILE802	30.77		20.83		47.09
(12)	232.50				46.53
	69.44	CUCUMBERS82	16.82		14.23
	128.70	(6)	48.64		19.19
	167.57		38.46		30.71
	83.78		10.66		
	203.70		18.75	PECANS81	121.22
	36.13		35.51	(6)	48.91
	96.24				34.77
	115.12	LETTUCE821	38.24		62.74
	119.75	(9)	20.96		67.22
	224.67		17.16		
			64.04	WHEAT81	67.84
			101.65	(5)	37.16
			55.13		44.67
			85.71		18.21

$$E_i = 100 (ET + LF - P + \Delta S) / W_i \qquad (4)$$

The percentage of irrigation efficiency is E_i; ET is evapotranspiration; LF is any specified leaching fraction; P is effective precipitation; ΔS is the change in soil moisture storage between irrigations; and W_i is the applied irrigation; all in centimeters.

Precipitation data was obtained from weather records at the offical weather station at New Mexico State University for 1980 and 1981, and from rain gauge data for 1982. The general storm patterns for southern New Mexico are characterized by small moving weather cells that produce very localized rainfall. Some areas in the valley may receive moderate rainfall while others receive none. Rainfall amounts for 1980 and 1981 have been adjusted in some cases to reflect this phenomenon and to better fit the neutron scatter data. All precipitation falling within a given border remains in that border and is therefore considered to be effective rainfall. The values used to indicate rainfall amounts in figures 4 through 19 also incorporate additional water applied to some borders from adjacent borders. This unmeasured water is the result of broken border ridges, some of which were washed out, while others were deliberately broken by the irrigator, or from slide gates that were inadvertently left open since the last irrigation. It was not possible to measure this flow because of the randomness associated with the opening of the border ridges. A tabulation of the parameters used to solve equation 4 is in table 5.

Soil and irrigation water salinity were not considered a problem and the farmers were not applying extra water to control any salt conditions, therefore LF was taken to be zero in all efficiency calculations.

Table 5. The parameters which equate annual water use efficiency to precipitation, P; ground water storage, ΔS; and irrigation amounts for 16 crops in New Mexico.

CROP YEAR	CONSUMPTIVE USE (cm)	RAINFALL AMOUNT (cm)	CHANGE IN STORAGE (cm)	IRRIGATION AMOUNT (cm)	EFFICIENCY %
ALFALFA80	93.55	29.34	2.67	104.50	64.00
ALFALFA81	104.93	19.56	3.81	110.41	80.77
BARLEY80	43.43	15.21	0.13	125.35	22.61
CHILE801	86.74	24.92	-7.82	43.28	124.77
CHILE802	71.20	24.77	-3.15	36.60	118.25
CHILE81	82.63	20.47	-3.12	86.06	68.60
CHILE82	73.94	12.45	-3.45	79.40	73.13
COTTON80	60.35	21.72	-4.85	39.22	86.14
COTTON81	68.30	29.46	-4.78	50.85	67.34
CUCUMBERS82	27.66	4.98	-0.15	38.23	58.94
LETTUCE821	27.76	7.65	-1.78	54.89	33.41
LETTUCE822	28.19	8.84	-0.58	29.57	63.49
ONIONS80	34.04	15.80	0.00	50.77	35.92
ONIONS81	52.02	8.36	-6.04	103.56	36.33
PECANS81	90.42	26.04	0.64	81.41	79.87
WHEAT81	46.63	12.19	-0.13	58.63	58.54

Irrigation efficiencies varied from a low of 1.24 percent to a high of 232.50 percent for individual irrigations. The lower efficiency was due to a condition that allowed the stored soil moisture to satisfy most of the consumptive needs of the crop. This irrigation interval saw an ET requirement of 4.06 cm (1.60 in.) and a decrease in soil moisture of 2.79 cm (1.10 in.). Precipitation provided only 1.19 cm (0.47 in.) and the irrigation amount was 6.15 cm (2.42 in.) which yields an efficiency of 1.24 percent. Much of the applied irrigation water was lost to adjacent borders due to the destruction of the border in several places along the length of the run. The higher efficiency of 232.50 percent was from one of 12 irrigations of the season. Seven of the 12 achieved efficiencies in excess of 100 percent, and three were in excess of 200 percent. These values are the result of under-irrigations. In each case, the irrigator attempted to irrigate with less than 2.80 cm (1.11 in.) of water when the crop needs were greater.

An efficiency of 22.61 percent was the lowest obtained on a seasonal basis. This crop was located along the Rio Grande and had a permanent water table located at a depth of 30 to 60 cm (11.8 to 23.6 in.) most of the season. The barley crop was irrigated excessively with 125.35 cm (49.35 in.) of water applied to meet the ET requirements of 43.43 cm (17.1 in.). The higher seasonal irrigation efficiency of 124.77 percent was attributed to the small amount of irrigation water applied to the CHILE801 crop. This was also true with CHILE802. The remaining efficiency levels are fairly well spread out over the spectrum between these two extremes, yielding an average annual efficiency of 68.53 percent.

Irrigation efficiencies describe how well the applied water was used relative to the water requirement. Irrigation efficiencies do not describe how evenly the applied water was spread across the field and thus infiltrated for greater accessibility by the crop roots. Distribution uniformity (DU) and coefficient of uniformity (CU) are used to explain how well the applied water was distributed. As with irrigation efficiencies, the values obtained for uniformities are widely scattered. Table 6 is a tabulation of high and low uniformities by crop name. Also listed is the total number of measurements made as well as the seasonal values for both DU and CU. A total of 378 measurements were conducted which produced a high DU of 96.37 percent and a low DU of 20.30 percent. Likewise, the high CU resulting from these calculations was 97.67 percent with a low of 55.05 percent. It should be noted that the values for CU are higher than those of DU. The reason for this is that the DU values were derived using a low quarter average, while the values for CU were derived by using a statistical relationship which is more nearly associated with a 50 percent average. The closer these two values are, the more evenly is the applied water distributed over the border area. In the table, LETTUCE821 has a DU of 94.34 percent and a CU of 96.58 percent. These are the best values attained for the crops tested. The closeness of the two values would indicate that this particular border was very well managed with good uniform distribution of the applied water over the border during the growing season.

The uniformities described above were calculated using neutron probe data and a computer program. In contrast, additional uniformity data were calculated using advance/recession curves. The depth of

Table 6. Distribution and coefficients of uniformity, by crop, depicting high, low, and yearly values derived from neutron probe data.

CROP/YEAR	NO. TESTS	DISTRIBUTION UNIFORMITY			DISTRIBUTION UNIFORMITY		
		HIGH (%)	LOW (%)	YEARLY (%)	HIGH (%)	LOW (%)	YEARLY (%)
ALFALFA80	30	85.11	40.82	72.73	88.54	59.22	77.38
ALFALFA81	32	82.21	43.66	77.35	83.47	68.63	81.44
BARLEY80	8	85.54	81.92	86.30	92.26	90.03	92.35
CHILE801	21	83.00	70.67	79.52	86.40	77.87	83.45
CHILE802	21	82.86	56.11	80.51	87.92	73.24	86.22
CHILE81	25	93.01	58.79	90.91	96.33	78.88	94.70
CHILE82	30	84.34	68.04	79.49	89.49	76.00	84.52
COTTON80	23	86.61	69.35	79.49	90.25	71.07	83.19
COTTON811	27	81.21	36.78	73.09	86.61	62.91	84.74
COTTON812	26	93.31	67.95	88.28	95.76	82.16	95.54
CUCUMBERS82	9	96.37	44.41	93.36	97.47	70.00	96.03
LETTUCE821	13	95.66	68.72	94.34	97.67	83.33	96.58
LETTUCE822	13	87.13	78.86	82.82	91.55	87.39	90.00
ONIONS80	10	89.14	81.86	87.21	92.78	88.61	91.57
ONIONS81	24	89.75	27.07	83.89	93.57	63.53	90.52
PECANS80	16	82.25	70.24	75.32	86.85	76.74	80.83
PECANS81	30	77.89	43.50	68.50	80.64	63.94	71.30
WHEAT81	20	81.63	20.30	69.39	87.75	55.05	79.24

moisture in the soil was determined at 30.5 meter (100 ft.) intervals along the border using the intake opportunity times found on the A/R curves in figures 20 through 46. Table 7 is a tabulation of these uniformities. It should be noted that the values listed in Table 7 are much higher than those obtained by using neutron probe data. Advance/recession curves are typically plotted from data that had been obtained under better than usual conditions. For example, the borders are never broken, eliminating the possibility of irrigation water running out of or into the border, and water is usually turned off at the prescribed time. The values thus obtained are representative of the near ideal conditions associated with A/R testing. In other words, the values did not truly depict actual uniformities along the border under normal management conditions. Looking again at the A/R curves in figures 20 through 46, it can be seen that the intake opportunity times are quite large. Most of the fields observed were overlain with a clay loam soil. This layer of soil varies in depth from the surface from 0.9 to 1.2 meters (3.5 to 4.0 ft.) and is primarily responsible for the variations in the DU and CU tabulations found in tables 5 and 6. Subsurface soils vary from fine sand to sandy gravel.

The effects that efficiency and uniformity have on yield are directly related and become apparent when the data of table 8 are compared with the efficiency data in table 5. The data for alfalfa indicate that average yields can be produced with average efficiencies. The yield was noticeably increased as the efficiency was increased from 67.04 to 97.55 percent. This is not the case for BARLEY80, however. The yields here were quite a bit higher than the county average (Berger,

Table 7. Distribution and coefficients of uniformity derived from advance/recession data on selected fields.

CROP/YEAR	DISTRIBUTION UNIFORMITY (%)	COEFFICIENT OF UNIFORMITY (%)
ALFALFA80	94.17	94.01
ALFALFA80	98.07	98.65
ALFALFA81	86.44	93.22
BARLEY80	96.20	97.85
BARLEY80	95.26	96.88
CHILE801	91.94	92.03
CHILE801	89.77	92.69
CHILE802	97.80	98.53
CHILE81	95.88	97.60
CHILE81	95.41	97.67
CHILE82	94.74	97.37
CHILE82	95.79	97.53
CHILE82	93.70	96.89
CHILE82	85.76	92.87
COTTON80	92.96	96.09
CUCUMBERS82	91.80	94.60
CUCUMBERS82	78.65	85.90
LETTUCE821	83.59	91.00
LETTUCE821	86.70	92.92
LETTUCE822	94.93	97.24
ONIONS80	97.64	98.62
ONIONS80	97.57	98.45
ONIONS81	97.31	98.03
ONIONS81	98.70	99.13
ONIONS81	98.19	98.75
PECANS81	94.73	97.23
WHEAT81	81.23	90.18

Table 8. Crop types and yields achieved per season as compared with average county yields.

CROP/YEAR	ACTUAL YIELD	COUNTY AVERAGE
ALFALFA80	10.33 t/ha (4.61 T/ac)	10.93 t/ha (4.88 T/ac)
ALFALFA81	13.84 t/ha (6.18 T/ac)	10.93 t/ha (4.88 T/ac)
BARLEY80	8.62 cu m/ha (95.8 bu/ac)	5.83 cu m/ha (64.8 by/ac)
CHILE801	17.92 t/ha (8.0 T/ac)	26.9-33.6 t/ha (12-15 T/ac)
CHILE802	13.44 t/ha (6.0 T/ac)	26.9-33.6 t/ha (12-15 T/ac)
CHILE81	3.92 t/ha (1.75 T/ac)	26.9-33.6 t/ha (12-15 T/ac)
COTTON80	1354.00 kgm/ha (1209 #/ac)	666.4 kgm/ha (595 #/ac)
COTTON81	1383.00 kgm/ha (1235 #/ac)	666.4 kgm/ha (595 #/ac)
CUCUMBER82	See note 1	
LETTUCE821	447.5 kgm/ha (339.5 cwt/ac)	234.1 kgm/ha (209 cwt/ac)
LETTUCE822	368.5 kgm/ha (329.0 cwt/ac)	234.1 kgm/ha (209 cwt/ac)
ONIONS80	34.3 Mgm/ha (306 cwt/ac)	36.0 Mgm/ha (321.7 cwt/ac)
PECANS81	See note 2	
WHEAT81	9.05 cu m/ha (100.5 bu/ac)	6.25 cu m/ha (69.4 bu/ac)

Notes:

1. Cucumbers were washed out at harvest time due to heavy rains.
2. Pecan trees were very young and nonbearing at time of study.

et al. 1981) although the efficiency was extremely low. This was a well drained sandy loam soil that permitted good soil aeration in spite of the field being overirrigated. Most of the chile crops achieved lower than average yields although two of the four crops had very good irrigation efficiencies. A 73.13 percent efficiency for CHILE82 had the best yield. The CHILE81 crop, with near average efficiency, had the worst yield, while the two crops with efficiencies above 100 percent produced half the county average. The cotton crops both achieved yields of twice the average for the county, one with average efficiency and the other with a higher efficiency. The CUCUMBERS82 crop was growing quite well until near harvest time. Locally persistent rains flooded the field, however, making the crop unsalvageable. The PECANS81 crop was harvested from a relatively young orchard and did not produce a harvestable crop. Young pecan trees typically do not produce until they are at least eight years old, these trees were six years old. Studying the yields further and comparing these data with the percentage of depletion data found in table 2 shows that there was no apparent correlation between yield and the percentage of water depletion. Of the 16 crops studied, only six maintained an average soil moisture depletion of less than 25 percent. Six of the crops maintained an average soil moisture depeletion between 25 and 50 percent and four averaged greater than 50 percent. Those crops whose soil moisture was maintained between 20 and 40 percent generally produced higher yields than did the others.

The water savings that could be realized with an irrigation efficiency of 90 percent is shown in table 9. The table compares

Table 9. Crop type, actual irrigation efficiency, actual water use, water use at 90 percent efficiency, and the potential water resource savings at 90 percent efficiency.

CROP/YEAR	ACTUAL EFFICIENCY (%)	ACTUAL WATER USE (cm)	WATER USE 90% EFFICIENCY (%)	POTENTIAL WATER SAVINGS (cm)
ALFALFA80	64.00	104.50	74.31	30.19
ALFALFA81	80.77	110.41	99.09	11.32
BARLEY80	22.61	125.35	28.17	97.18
CHILE801	124.77	43.28	N.A.*	0.0
CHILE802	118.25	36.60	N.A.*	0.0
CHILE81	68.60	86.06	65.58	20.47
CHILE82	73.13	79.40	64.49	14.91
COTTON80	86.14	39.22	37.53	1.69
COTTON81	67.34	50.85	37.84	13.01
CUCUMBERS82	58.94	38.23	25.04	13.18
LETTUCE821	33.41	54.89	20.37	34.52
LETTUCE822	63.49	29.57	20.86	8.71
ONIONS80	35.92	50.77	20.27	30.51
ONIONS81	36.33	103.56	41.81	61.75
PECANS81	87.74	81.41	72.24	9.17
WHEAT81	58.54	58.63	34.14	24.49

*N.A. = Not Applicable

present water use with that used at the 90 percent efficiency level. The potential water resource savings is presented by crop name. Two of the crops listed in the table already had achieved better than 90 percent efficiency, therefore, the potential water resource savings for these crops is listed as zero. A total water savings of 371.1 ha-cm/ha (12.17 ac-ft/ac) was realized. This value indicates that there is a potential for saving this amount of water per irrigation season. This translates to 23.19 ha-cm/ha (0.76 ac-ft/ac) on the average over the borders tested. Dona Ana County, New Mexico, is currently irrigating 38,742 ha (95,730 ac) of agricultural land. Therefore, a potential annual water savings of 901,746 ha-cm (73,075 ac-ft) exists.

Table 10 extends this further to show the potential savings in energy resources if the water resource savings were all pumped water. The energy savings shown here are for the county only but may easily be transferred to any land area. The energy resources noted in the table were derived by assuming the entire water resource savings were pumped with each of the energy resources. These energy resource savings are further tabulated in table 11 to show the dollar amount, in U. S. dollars, that the farmer would realize through better water management practices. The total dollar amount returned to the farmer would be 901,746 ha=cm (73,075 ac-ft) times $1.99/ha-cm ($24.50/ac-ft), the current cost of water from the irrigation district, or $1,794,475 per season for this county alone. The figures used to calculate the values shown in table 10 are as follows: 529.5 cu m/ha-cm (1.52 mcf/ac-ft) for natural gas; 1,919.6 kwh/ha-cm (155.56 kwh/ac-ft) for

Table 10. Potential energy resource savings per crop season for various energy sources.

RESOURCE TYPE	QUANTITY (per units shown)
Natural gas	3,135,619 cu m (111,074 mcf)
Electricity	11,367,601 kwh (11,367,601 kwh)
Diesel fuel	2,411,866 liters (637,217 U. S. gallons)
Propane	3,896,162 liters (1,028,170 U. S. gallons)

Table 11. Potential cost savings in U. S. dollars for energy resources per crop season.

RESOURCE TYPE	AMOUNT (U. S. dollars)
Natural gas	266,579
Electricity	568,380
Diesel fuel	637,217
Propane	483,240

diesel fuel; and 309.2 l/ha-cm (14.07 gal/ac-ft) for propane. The cost figures used to calculate the values shown in table 11 were derived from the following: $2.40/mcf for natural gas; $0.05/kwh for electricity; $0.71/gallon for diesel fuel; and $0.47/gallon for propane.

Additional savings are possible, if not assured, through water and energy resources conservation. The use of better water management results in better leaching management with a resulting savings in fertilizers and pesticides. The value placed on these two savings will depend upon the individual situation and the amount of these products customarily used. Operation and maintenance costs of equipment will be reduced because farm machinery will be reduced proportionally with less applications of fertilizers and pesticides. Wear and tear on pumping equipment also will be less, resulting in longer service life and lower repair costs.

Conclusions and Recommendations

On-farm water management is an integral part of the overall administration of a farm. Irrigation water must be scheduled and applied to the crop in a timely fashion and in the amounts needed to meet the evapotranspiration requirements of the plants. For this to be done efficiently, the farmer must not only know of his crop water needs, but he must also be aware of his soil types and their water holding capacities. Layered soils present different problems than do non-layered soils. The former presents the possibility of perched water tables while the later may introduce problems associated with available water quantities. The Glendale-Harkey soils found in the test area are characteristically layered with clay-loam overlaying a sandy substrata. The depths of the layers vary considerably over the valley.

Irrigation efficiencies were only slightly different from those found by Lansford et al. (1977), who reported an average annual efficiency of 65 percent, and Willardson (1972), who reported individual efficiencies ranging from 24 to 77 percent. Distribution uniformities and coefficients of uniformity indicate that there are areas in many fields that are under-irrigated and others that are over-irrigated. This is also borne out by the wide range of application efficiencies for these same fields. While under-irrigating will always produce higher application efficiencies, it will not necessarily yield correspondingly high DU and CU values. Soil layering, particularly with a clayey loam overlaying a sandy sublayer, can have a dramatic affect on DU and CU results. Not much can be done about this in most cases but if the wide range of DU and CU values is not due to soil stratification it is most probable that improvements in irrigation efficiencies will also alter DU and CU as well.

Considerable resource savings may be realized by increasing application efficiencies from the present values to 90 percent. Many of the fields observed were already quite close to this level. These farmers could materially raise their application efficiencies by closing the spread between the high and low values which currently exists for individual irrigations. The training of good irrigation operators is one way to close this gap. It is just as important to have well trained ditch operators as it is to decide how much water to apply and when to apply it. No amount of excellent upper level management will offset the effects created by uneducated ditch operators. The operator must know what he is expected to do, how he is to do it, and why it must be done in that fashion.

The training of irrigators may not always be a practical or desirable solution. Automation of surface irrigation systems is a viable alternative to training people. In some instances this may be the only way to achieve the application efficiencies necessary to obtain meaningful savings in water resources. New advances in surface irrigation techniques will allow the irrigator to routinely achieve efficiencies in the nineties. One such system is called "surge flow" irrigation. This new and exciting technique has been the subject of on-going research at several of the western universities for the past five years. Water is applied to a field in surges, that is, on/off cycles rather than continuously. The timing of the cycles is dependent, in part, on soil texture. Results thus far have shown that water can be placed onto a field in much less time, and in much smaller quantities, than with a comparable system using a continuous water inflow. The application of water onto a field in a shorter time results in far superior distribution uniformities and higher irrigation efficiencies. The end result is greater yields, water and pumping energy conservation and higher profits to the farmer. Past research efforts have been directed toward applying this technique to furrow irrigation. The Department of Agricultural Engineering at New Mexico State University is currently undertaking a study to evaluate the concepts of surge flow to closed border flood irrigations.

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APPENDIX

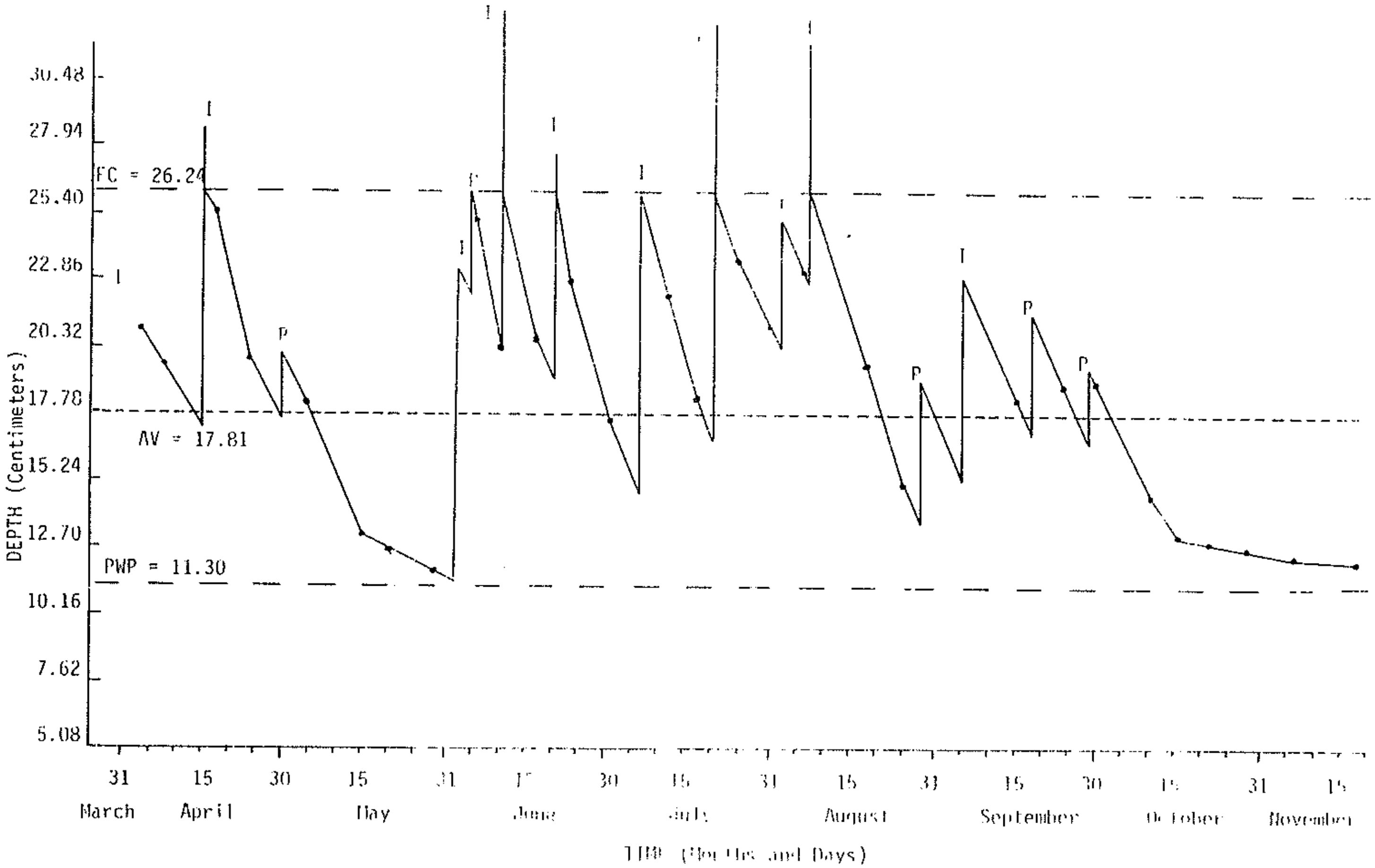

Figure 4. Soil moisture changes with time for ALFALFA80. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indiciated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

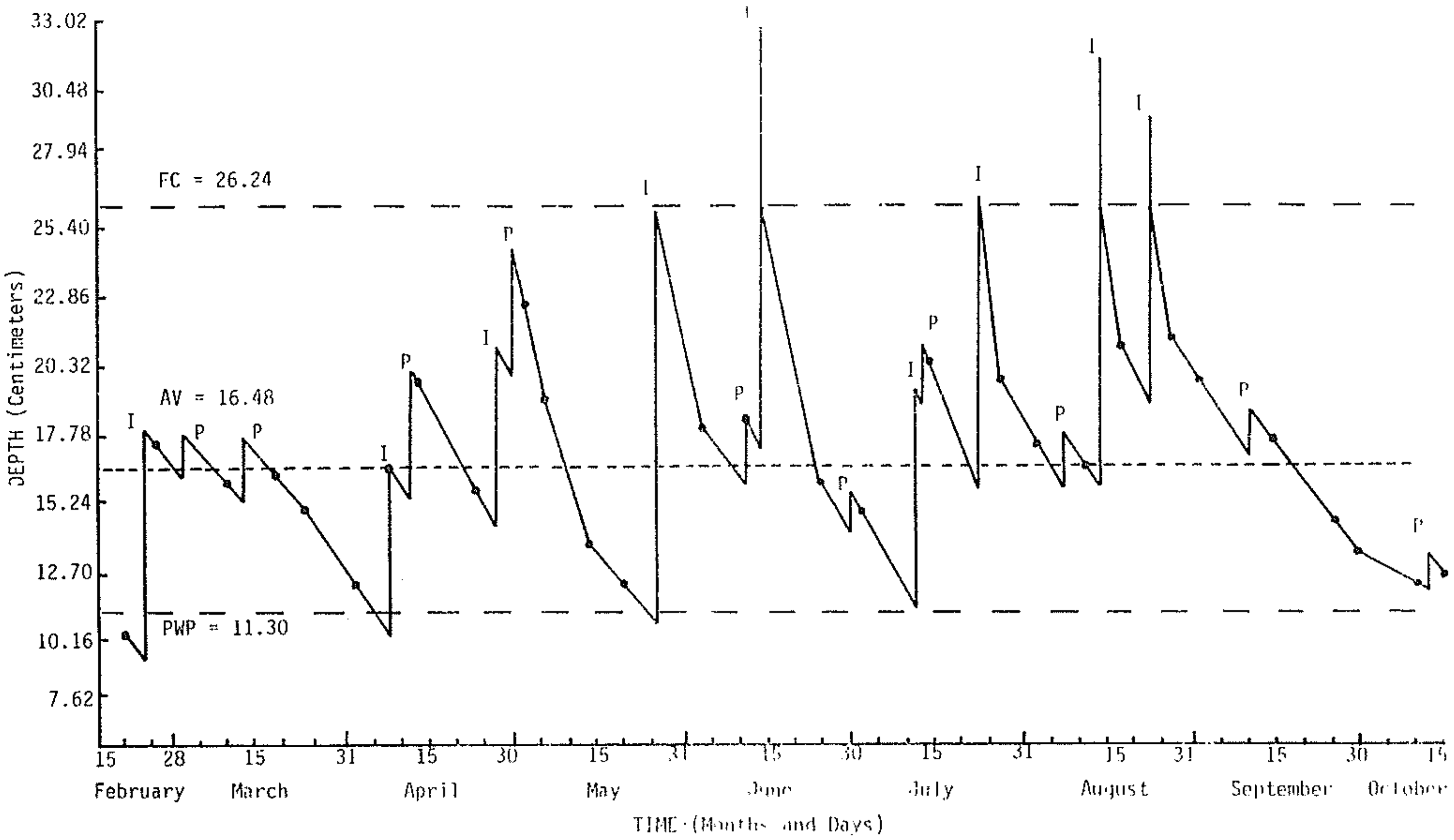

Figure 5. Soil moisture changes with time for ALFALFA81. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

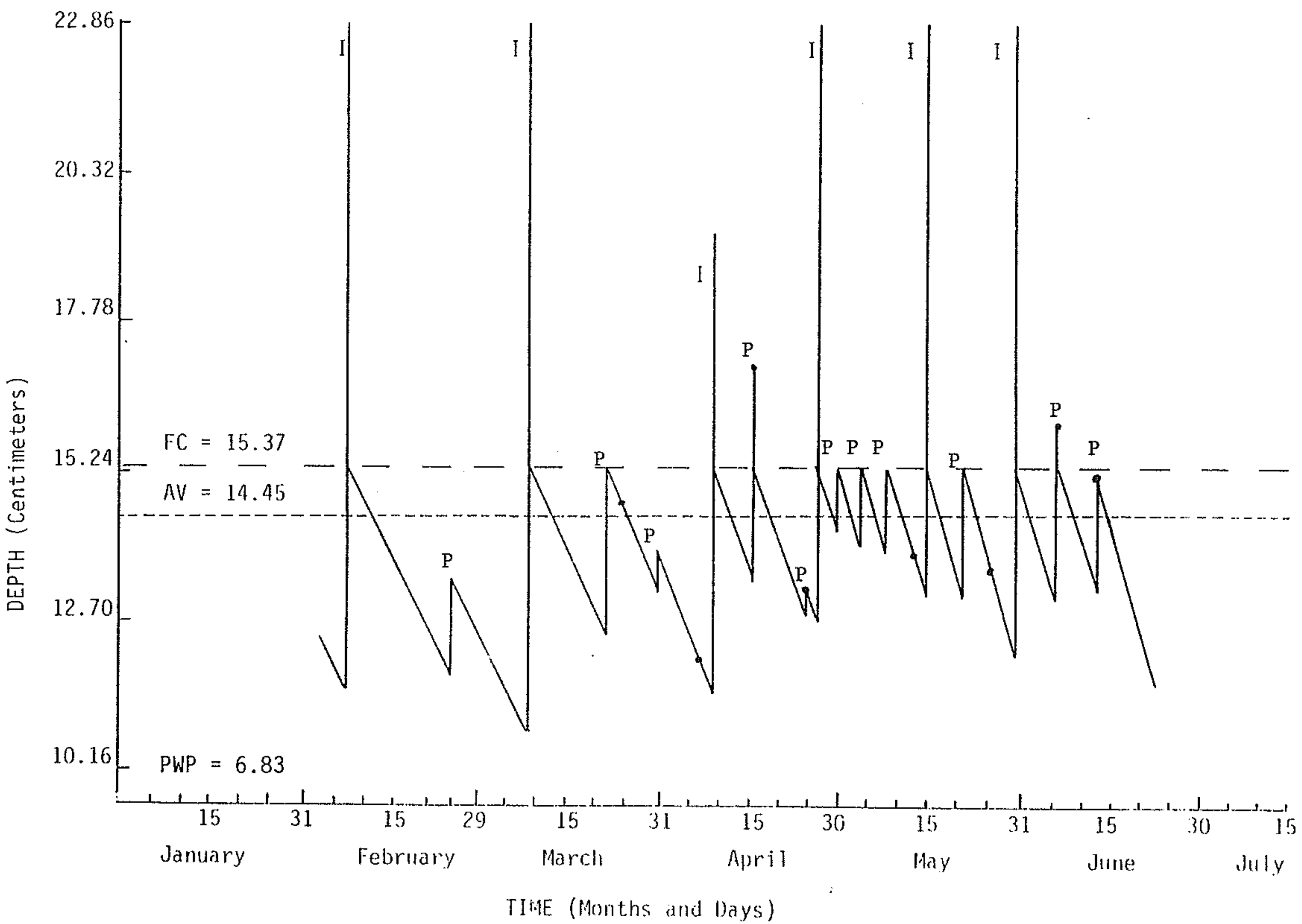

Figure 6. Soil moisture changes with time for BARLEY80. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

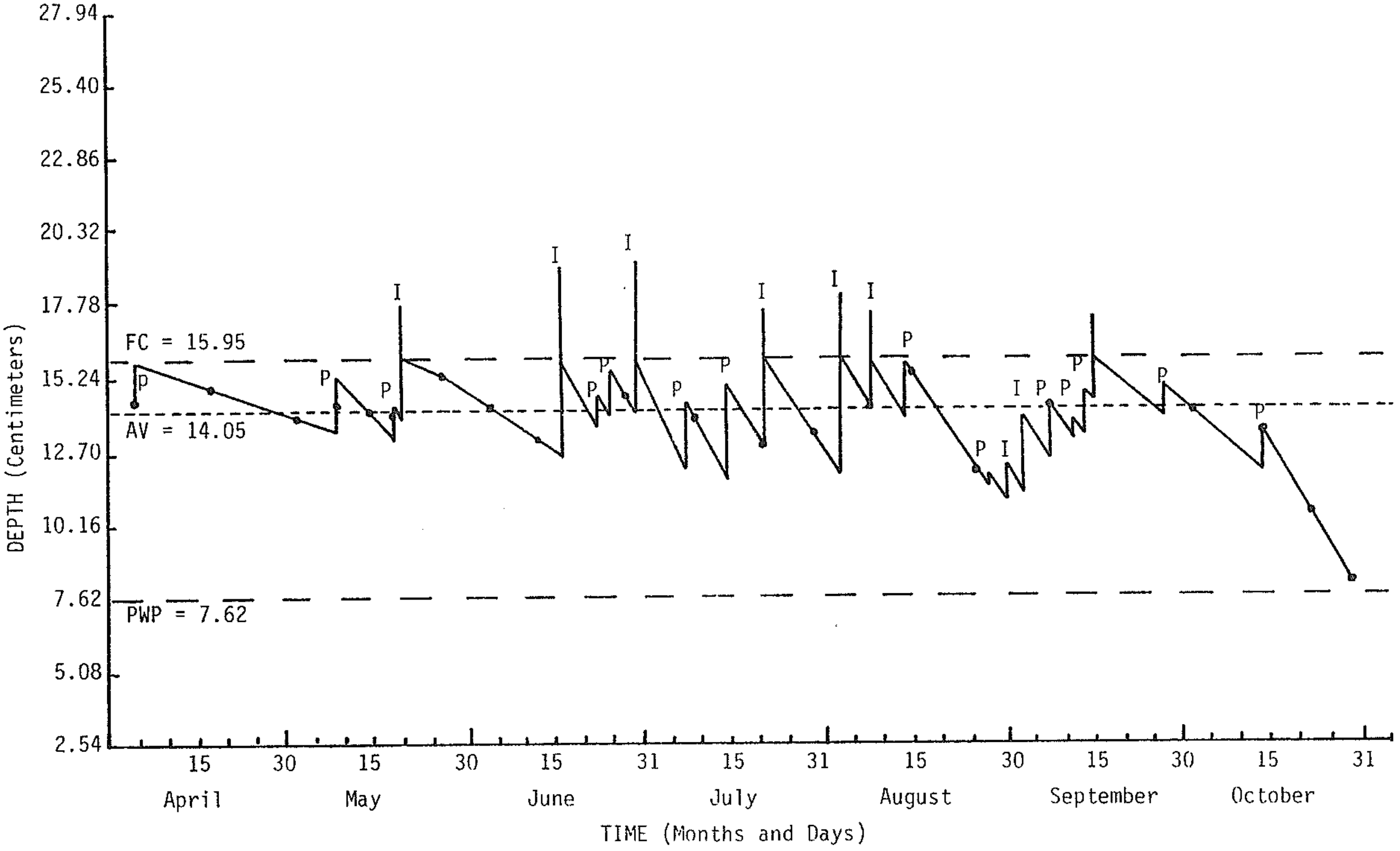

Figure 7. Soil moisture changes with time for CHILE801. Field capacity (FC), permanent wilting percent (PWP), and average aoil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

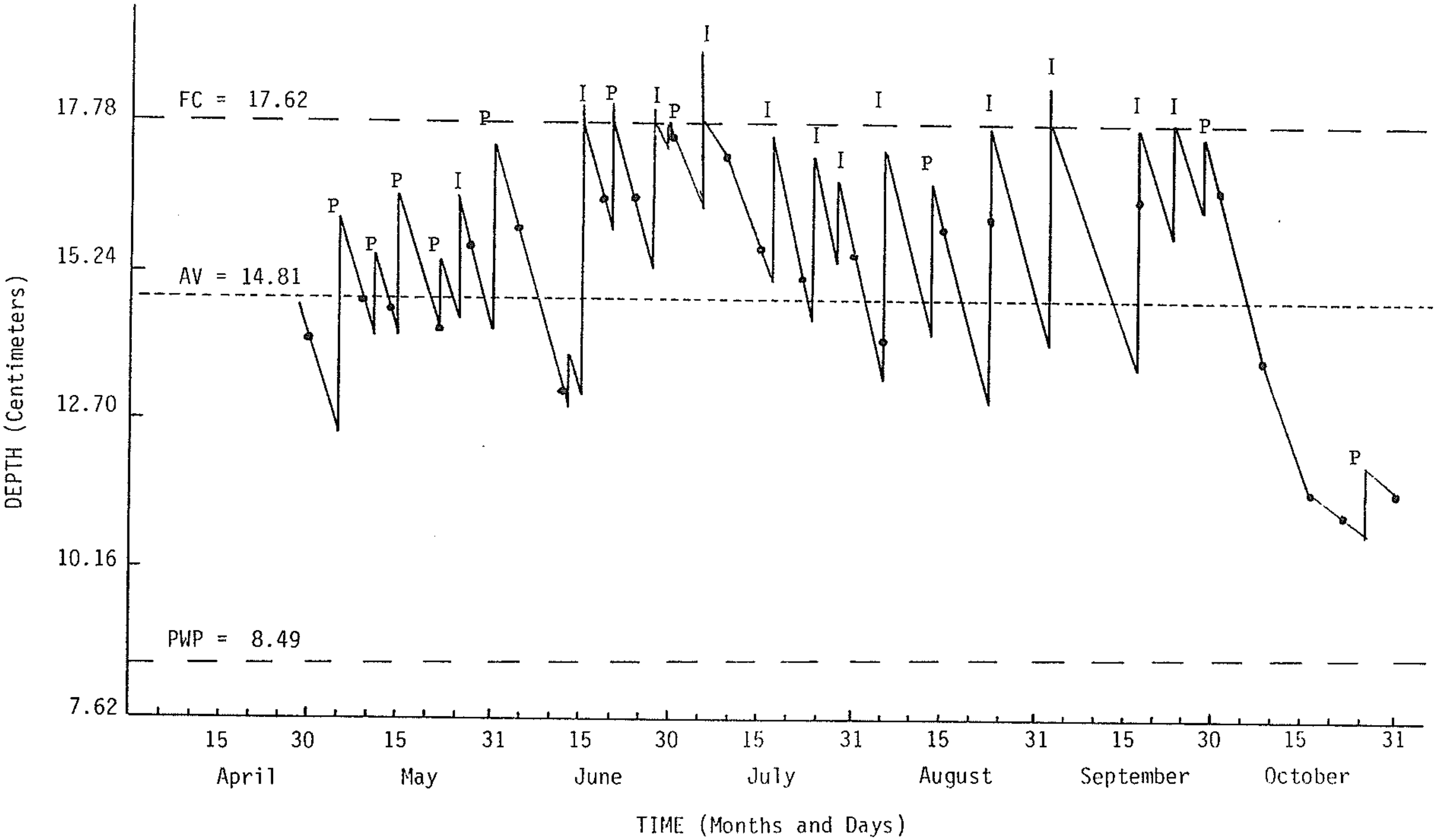

Figure 8. Soil moisture changes with time for CHILE802. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

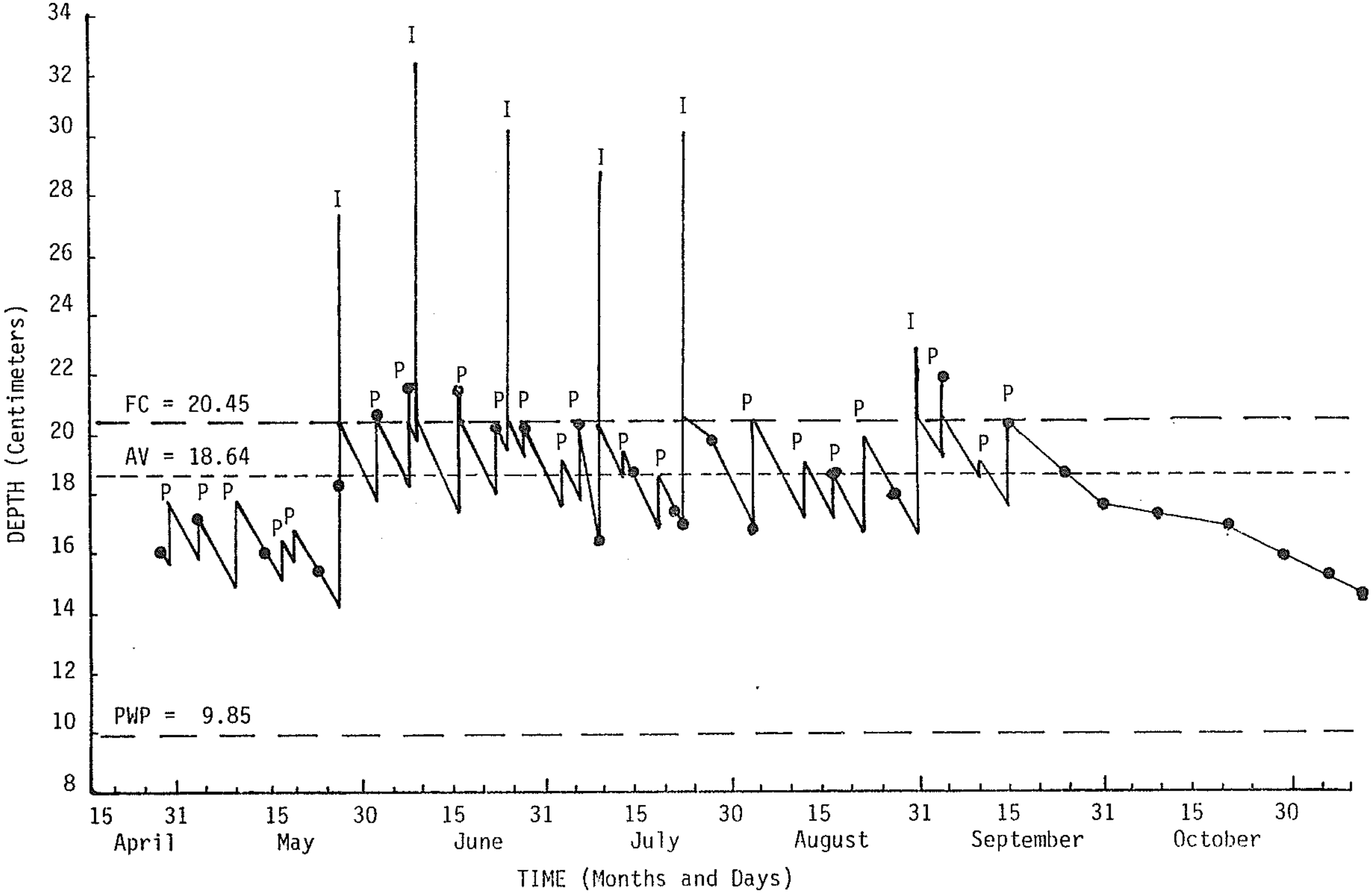

Figure 9. Soil moisture changes with time for CHILE81., Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

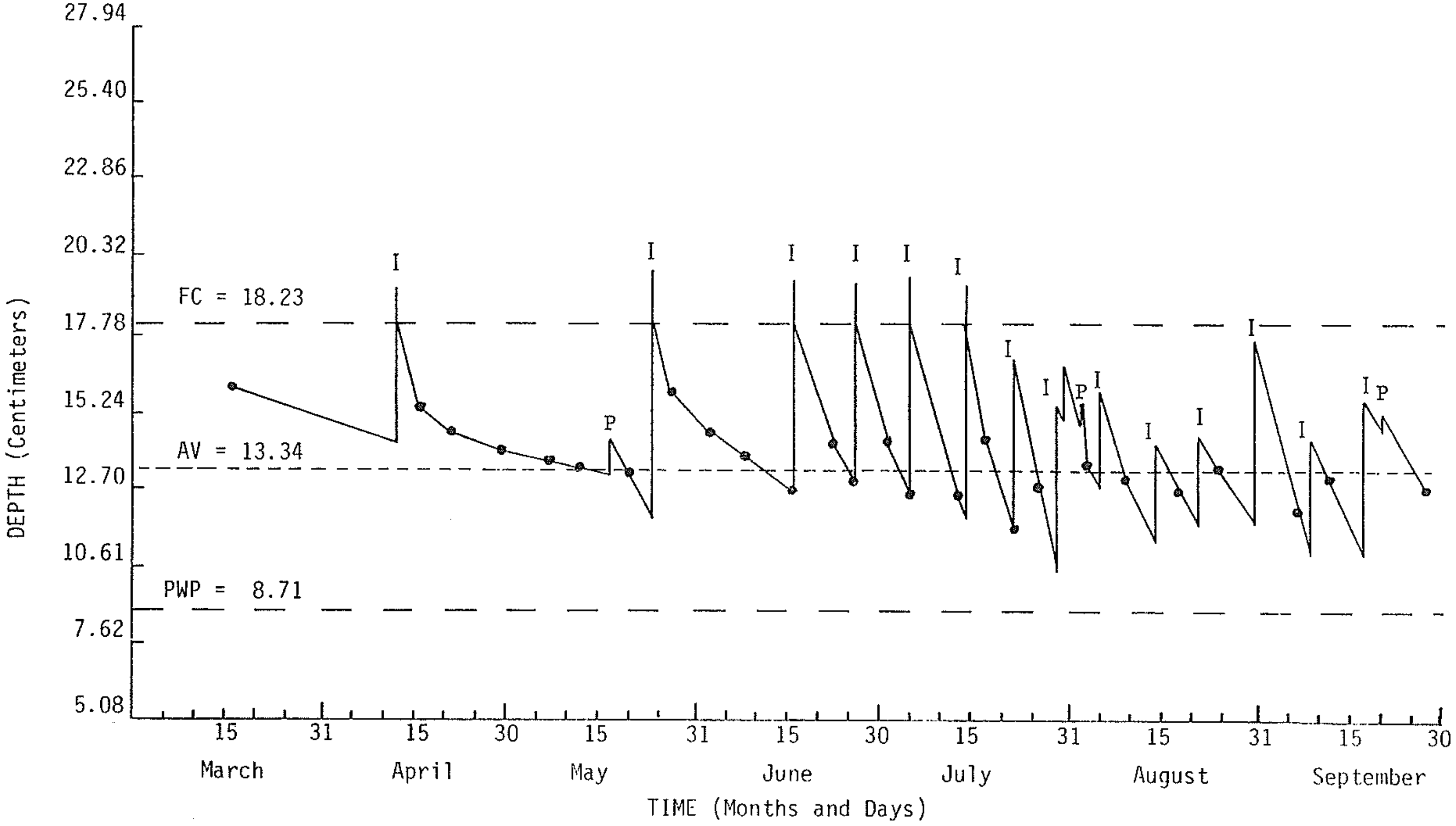

Figure 10. Soil moisture changes with time for CHILE82. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

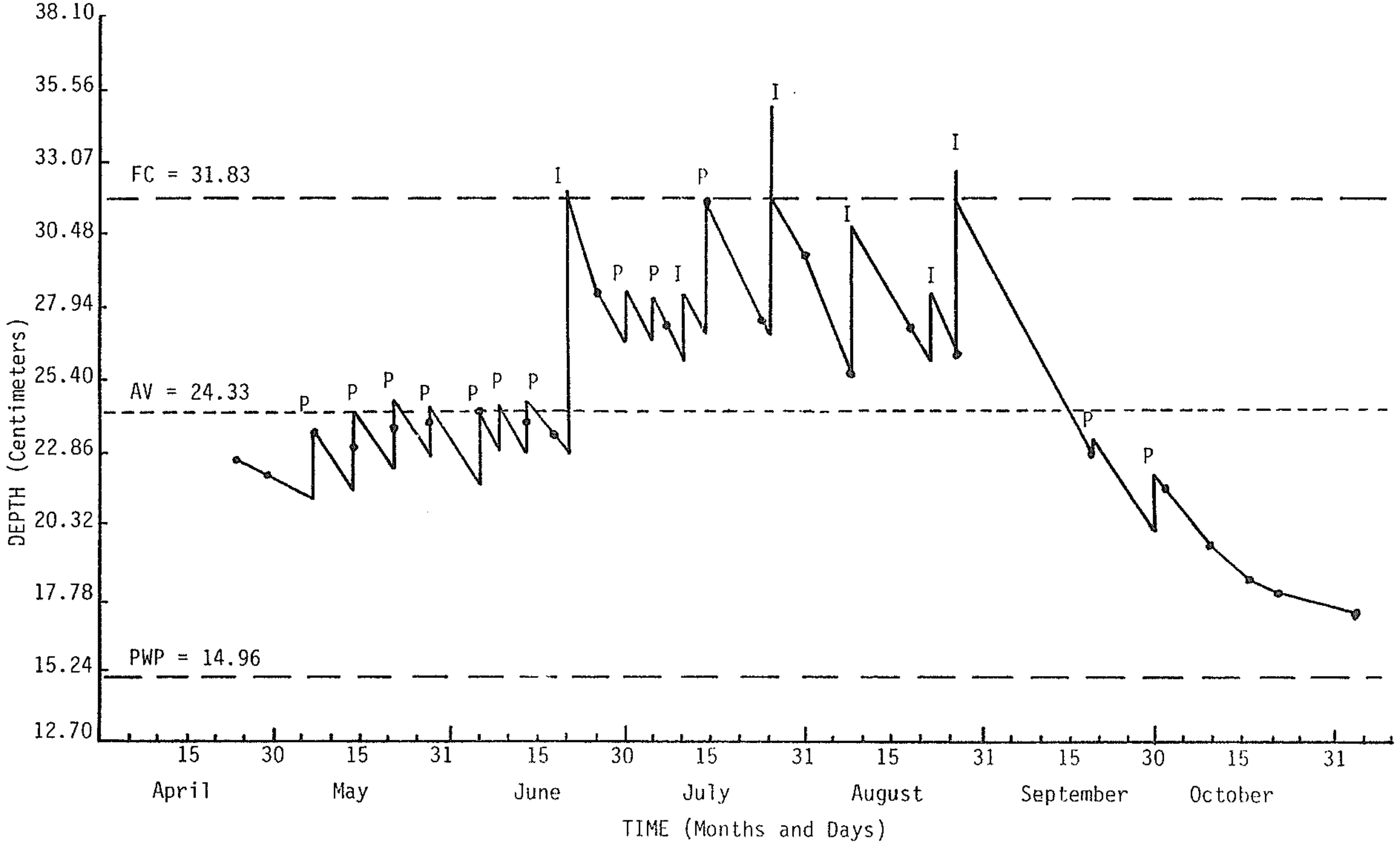

Figure 11. Soil moisture changes with time for COTTON80. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

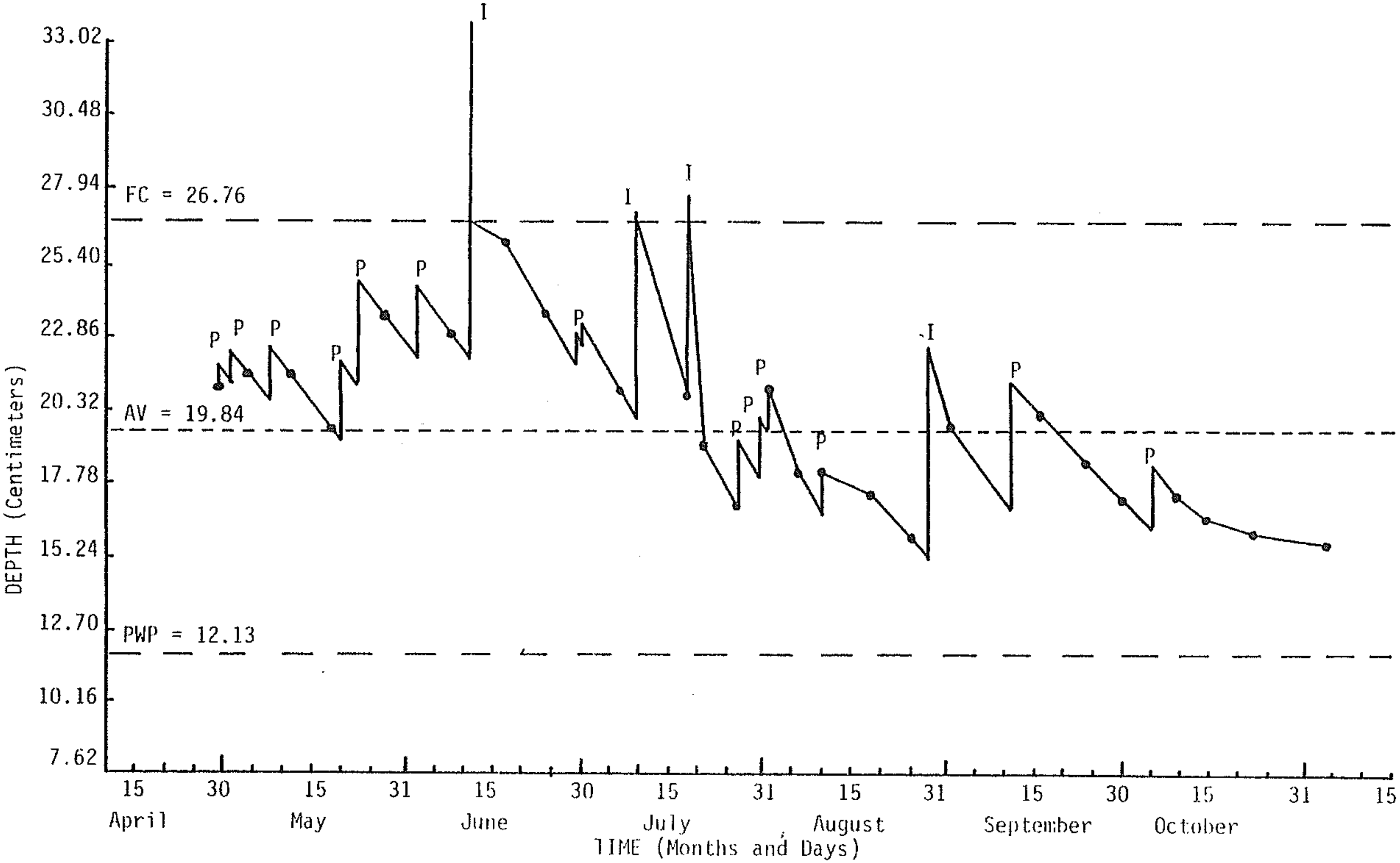

Figure 12. Soil moisture changes with time for COTTON81. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

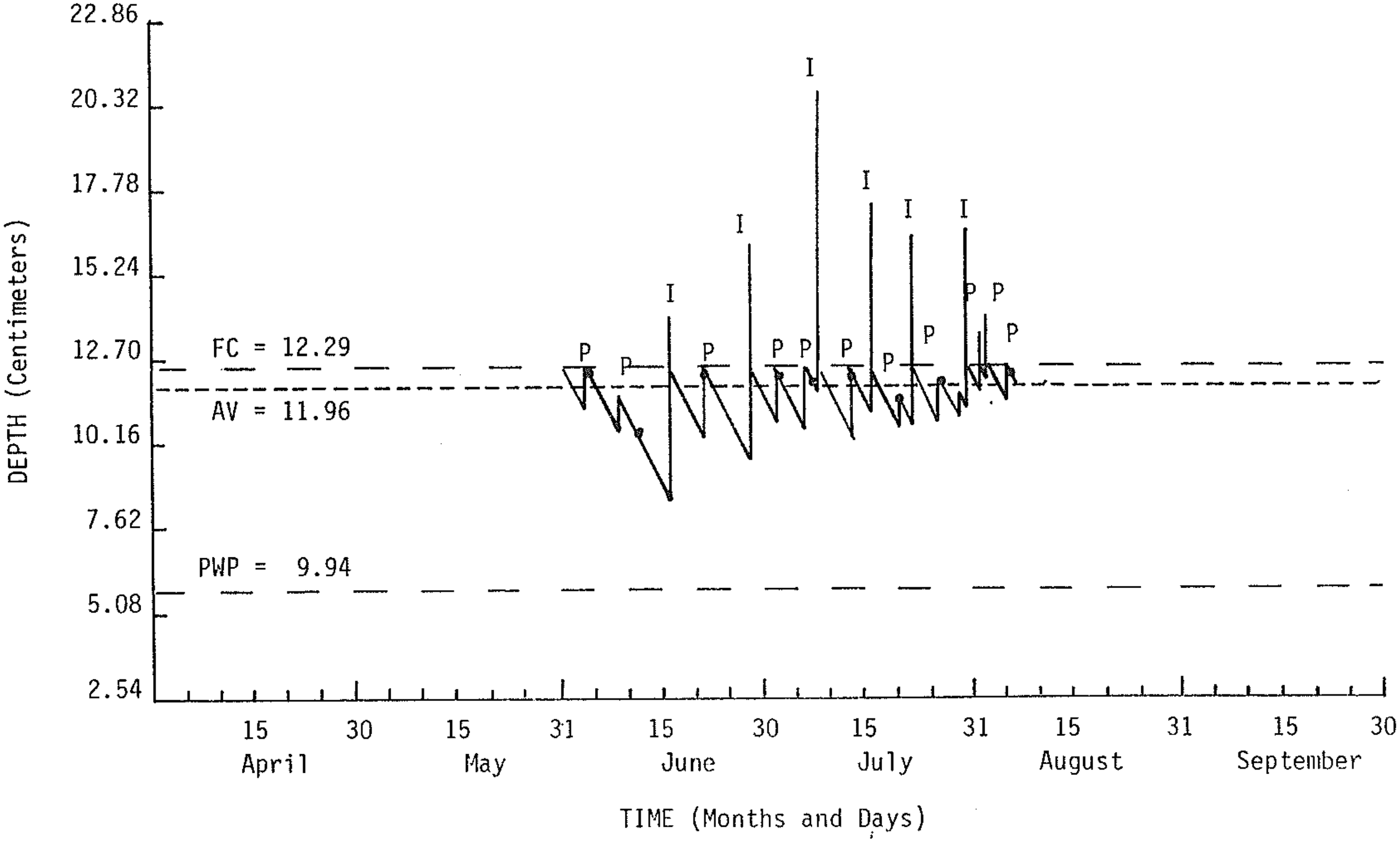

Figure 13. Soil moisture changes with time for CUCUMBERS82. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

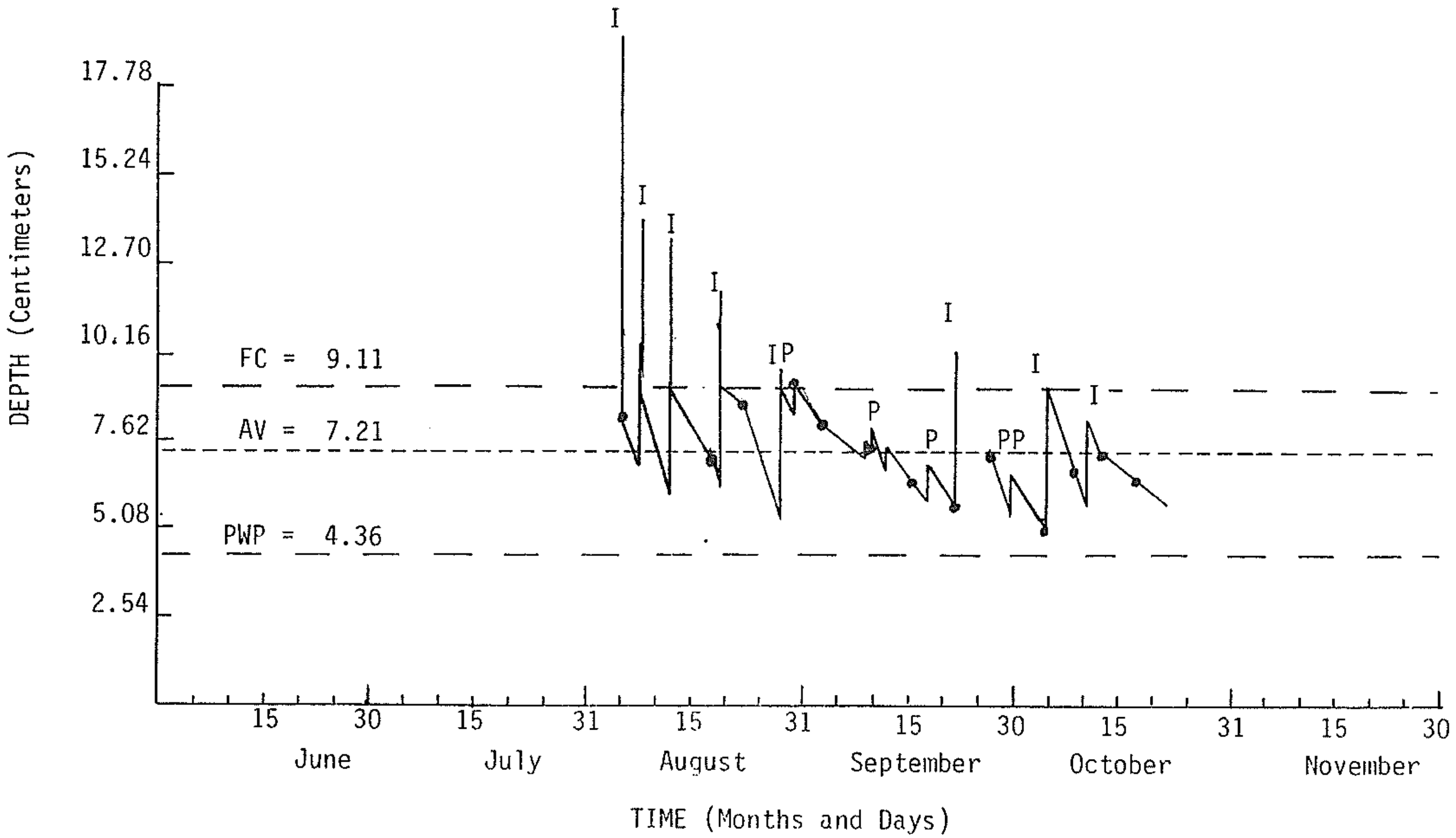

Figure 14. Soil moisture changes with time for LETTUCE821. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

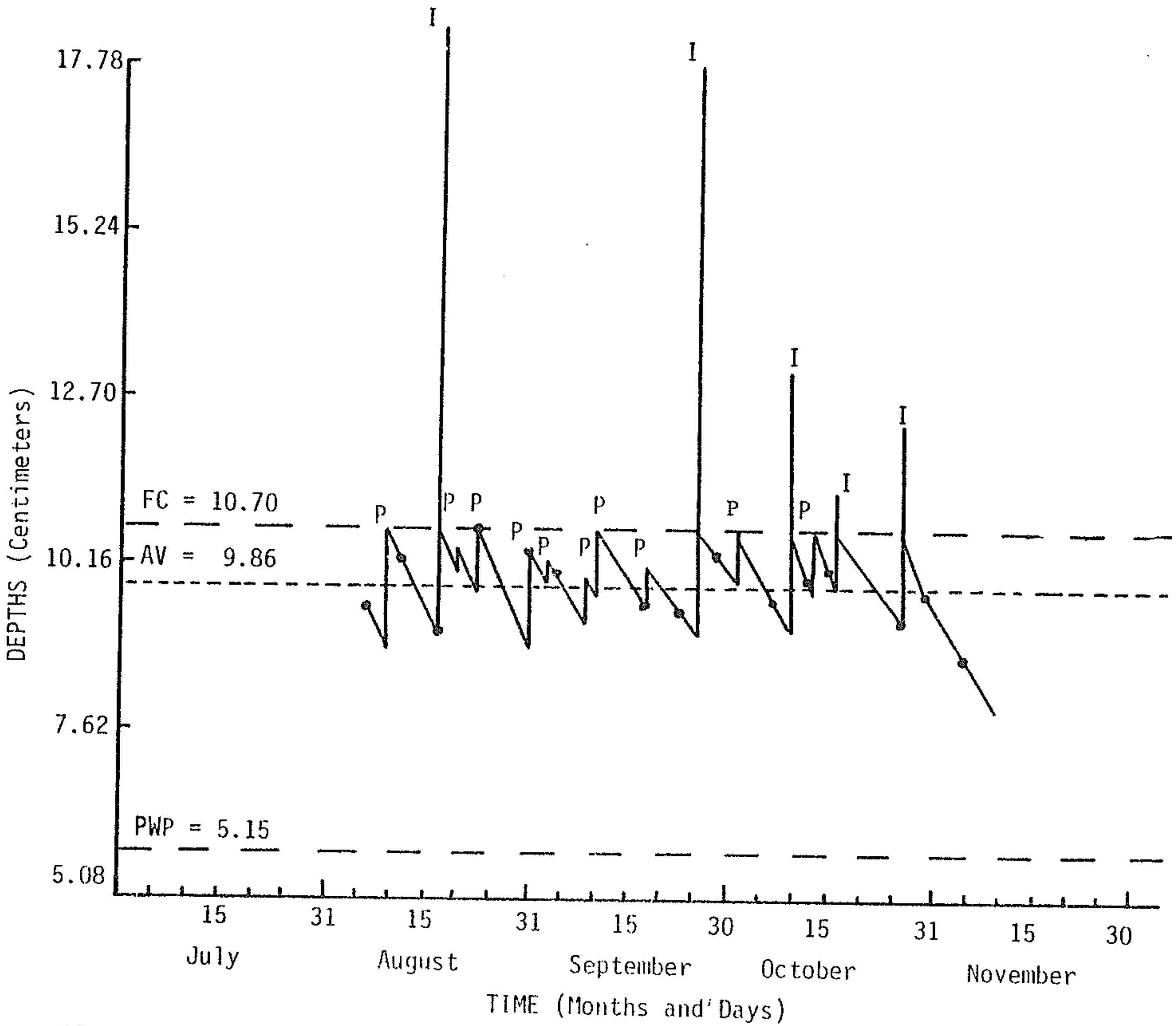

Figure 15. Soil moisture changes with time for LETTUCE822. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

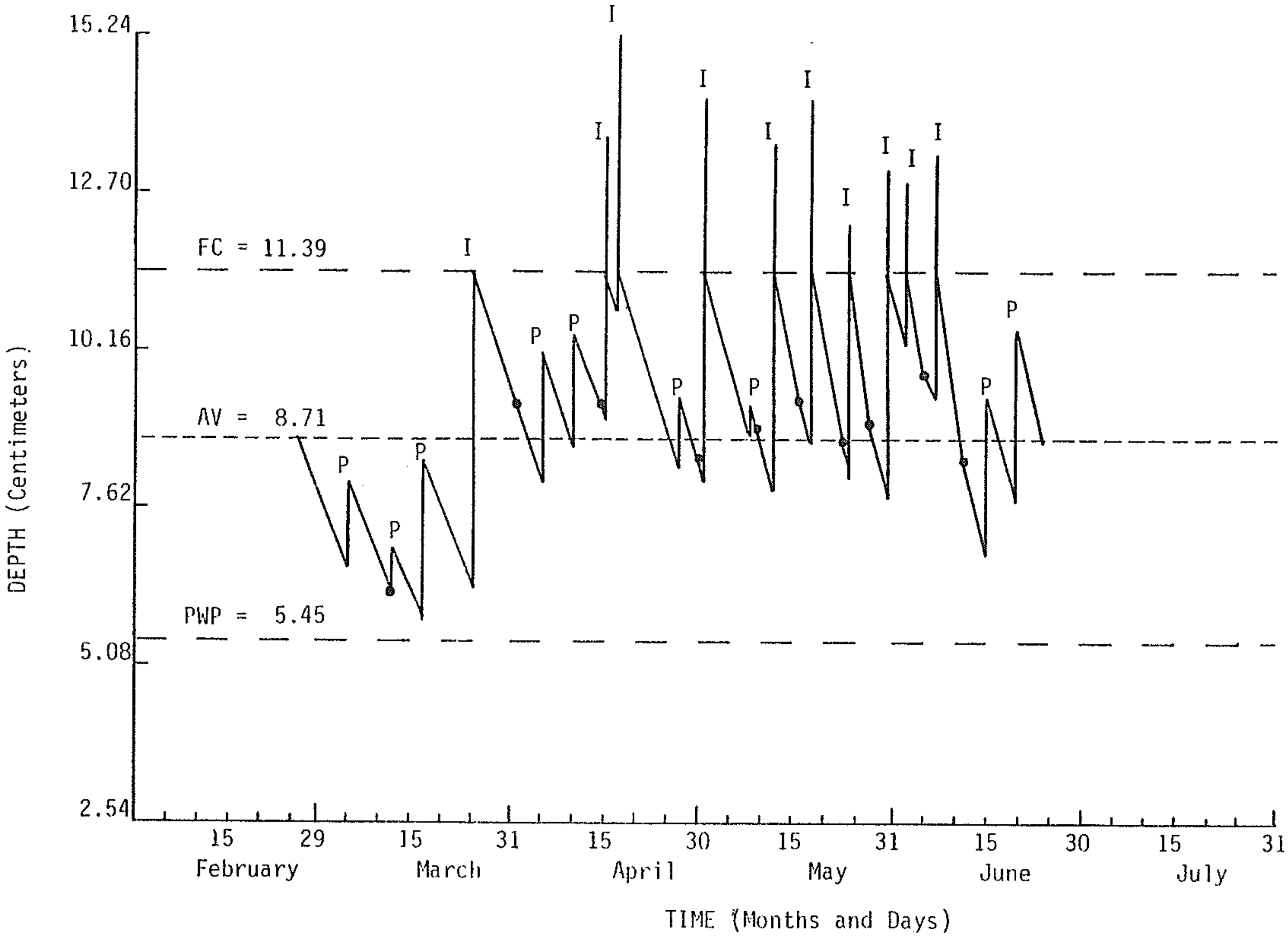

Figure 16. Soil moisture changes with time for ONIONS80. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

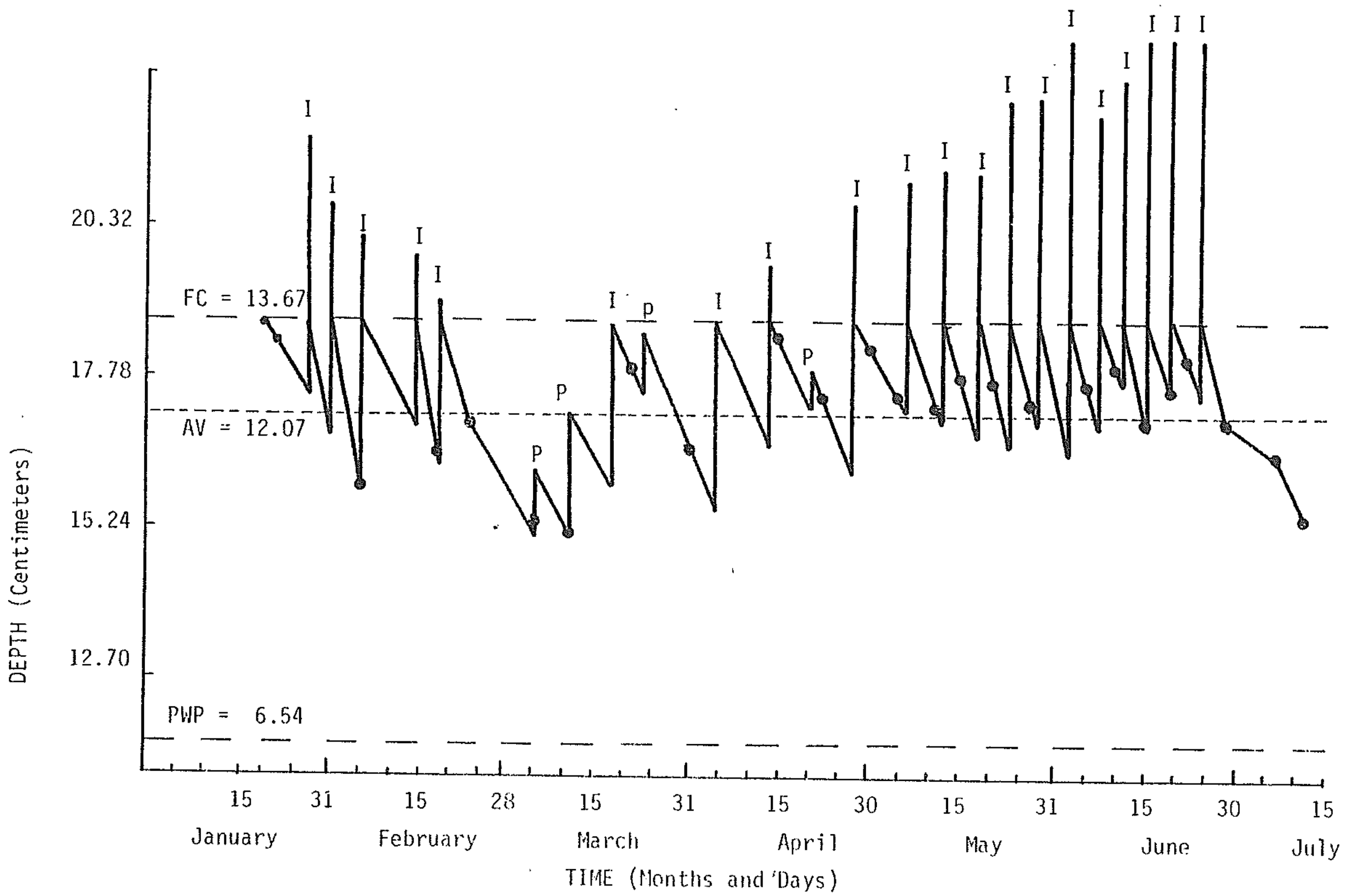

Figure 17. Soil moisture changes with time for ONIONS81. Field capacity (FC), permanent wilting perc (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moist amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at e occurrence.

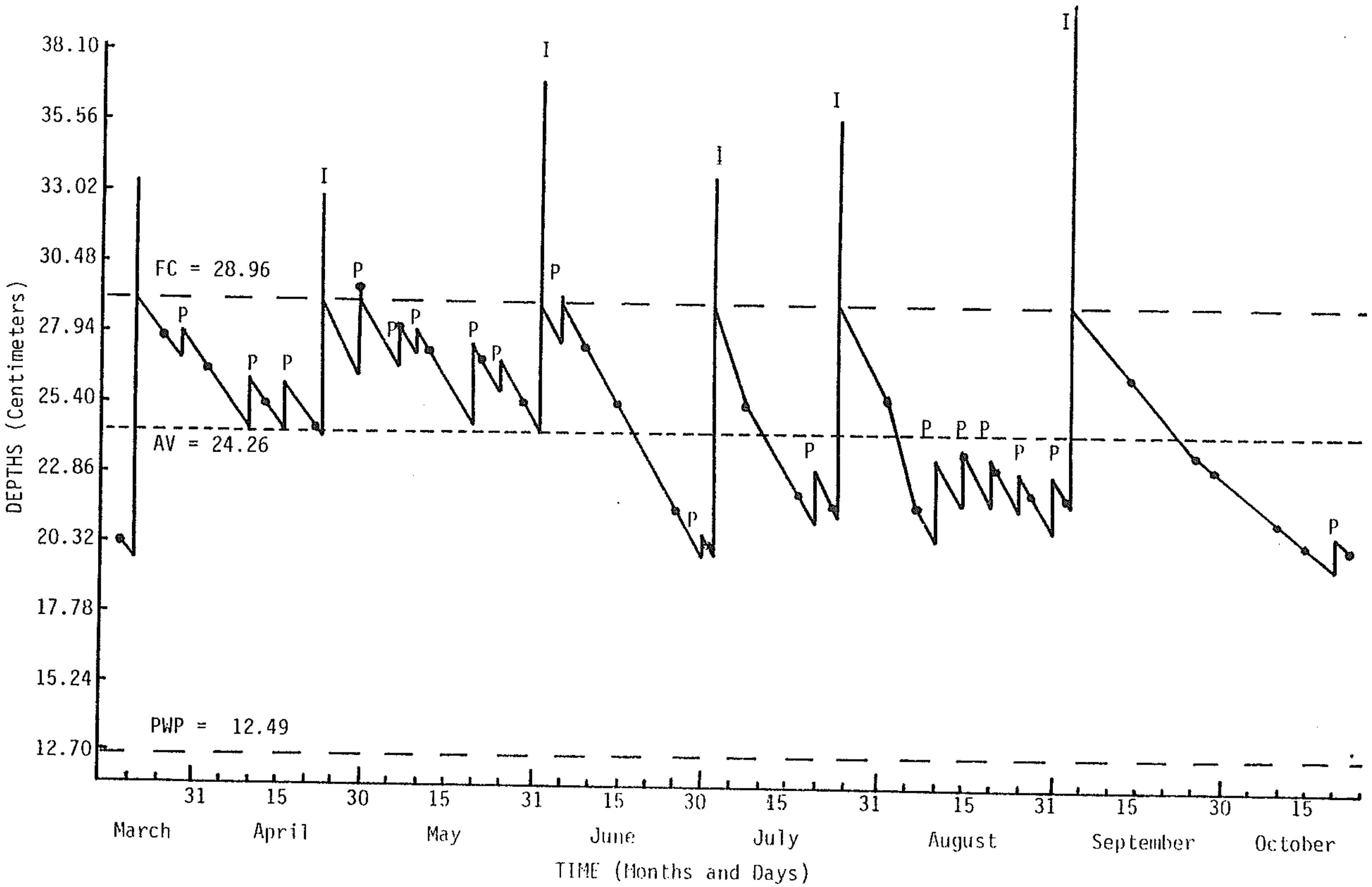

Figure 18. Soil moisture changes with time for PECANS81. Field capacity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

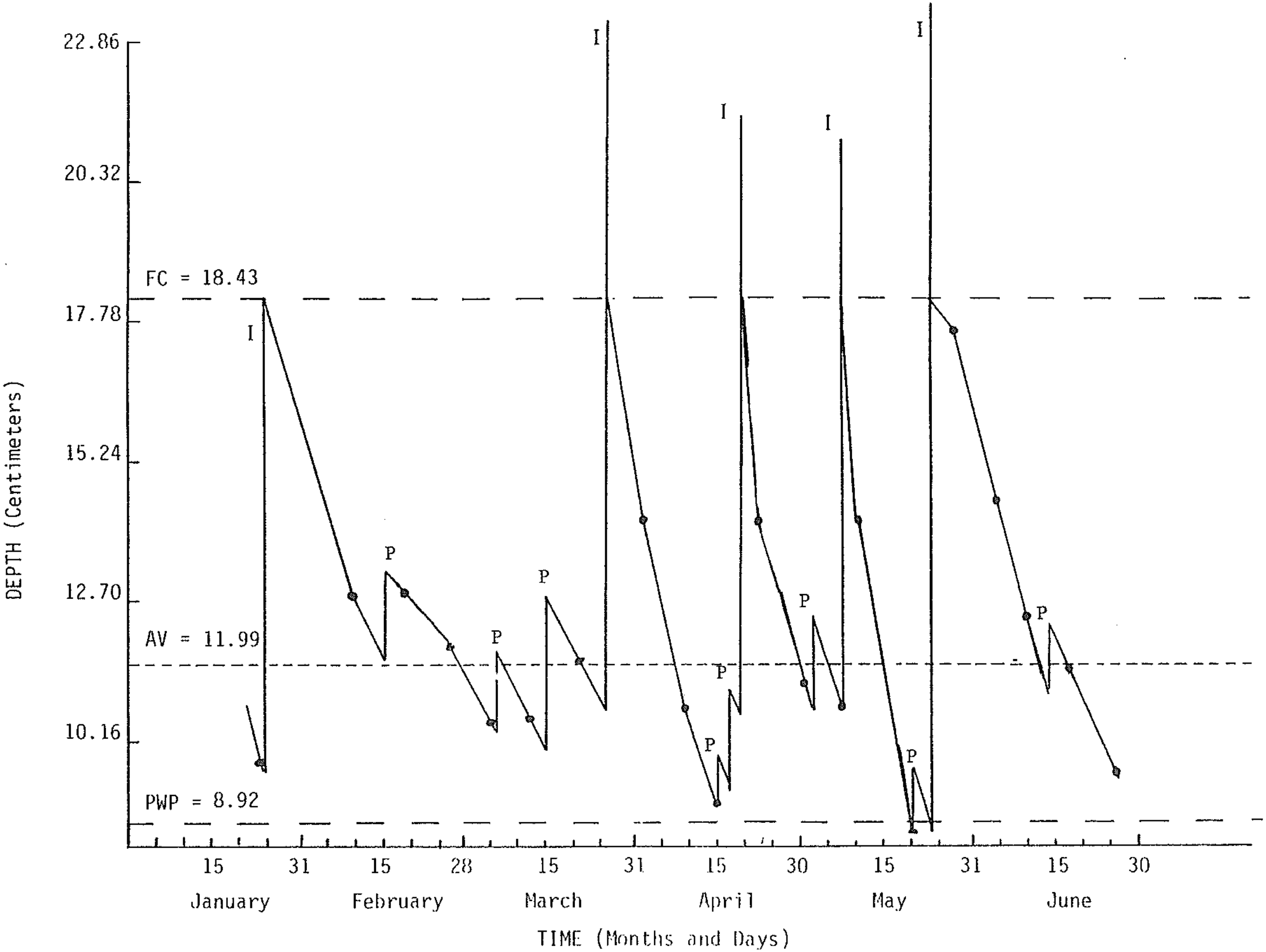

Figure 19. Soil moisture changes with time for WHEAT81. Field capapcity (FC), permanent wilting percent (PWP), and average soil moisture (AV), are noted. Solid dots are neutron probe soil moisture amounts for the dates indicated. Irrigations (I) and precipitation (P) are also noted at each occurrence.

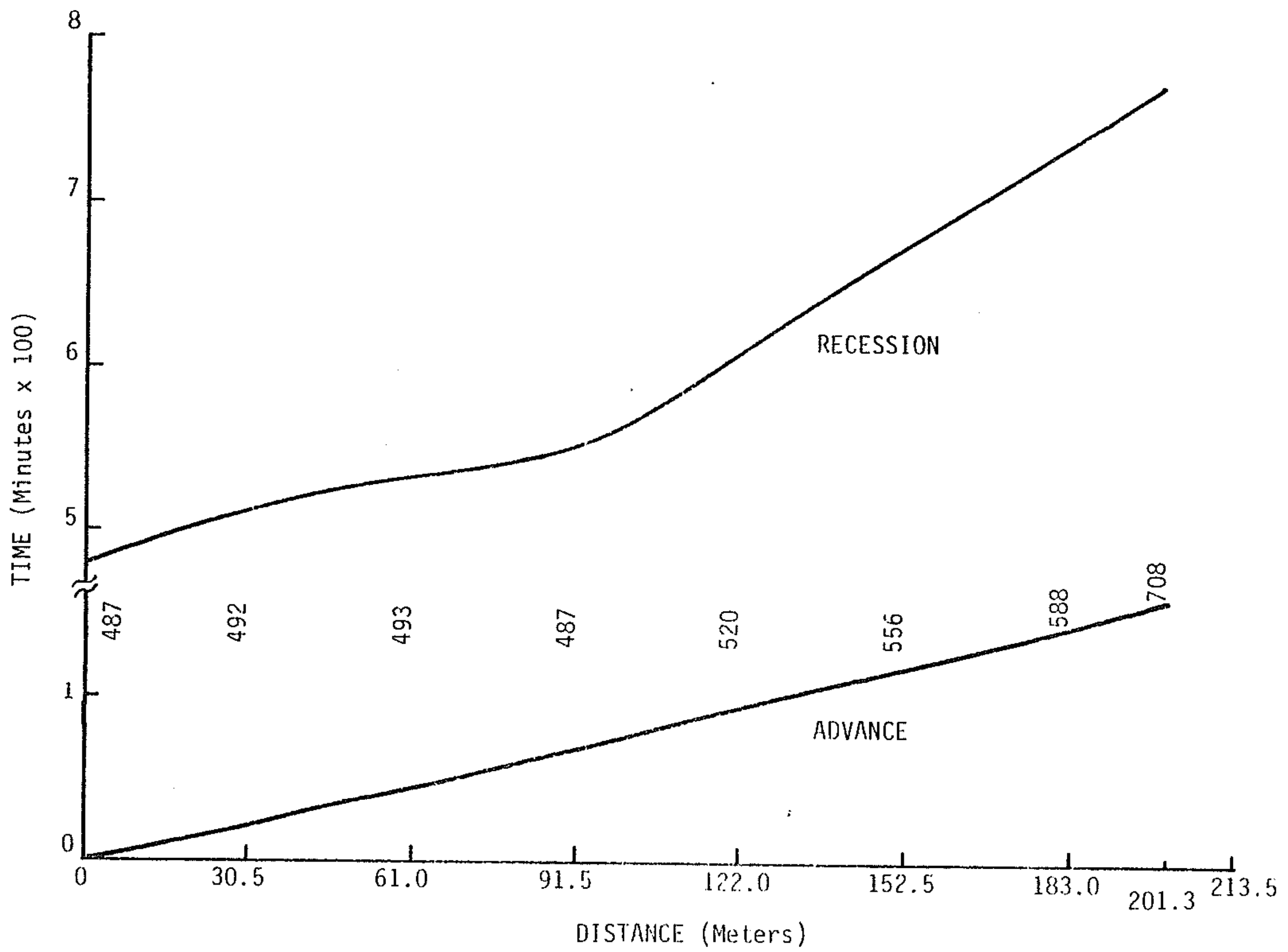

Figure 20. Advance/recession curves for ALFALFA80. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

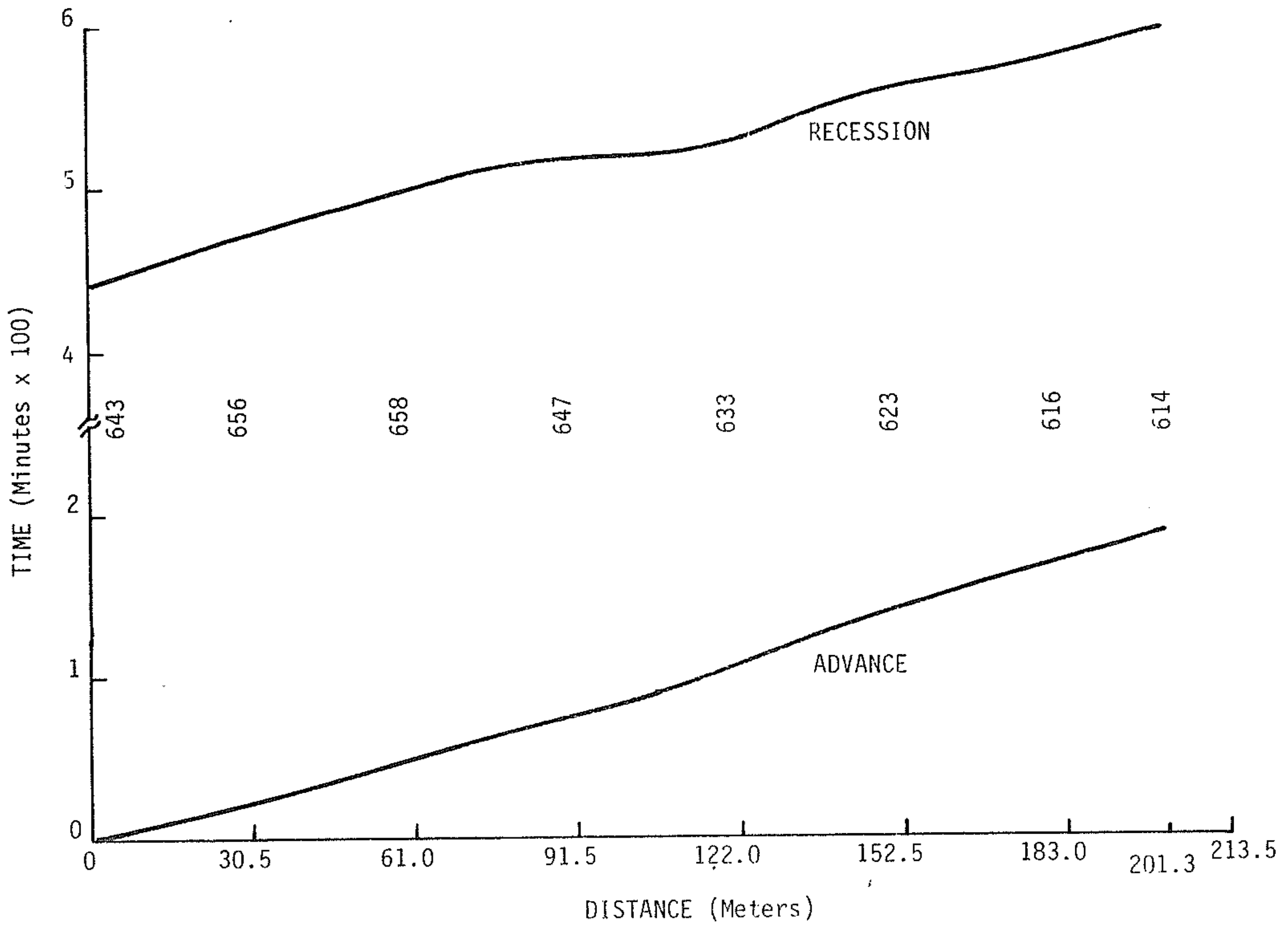

Figure 21. Advance/recession curves for ALFALFA80. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

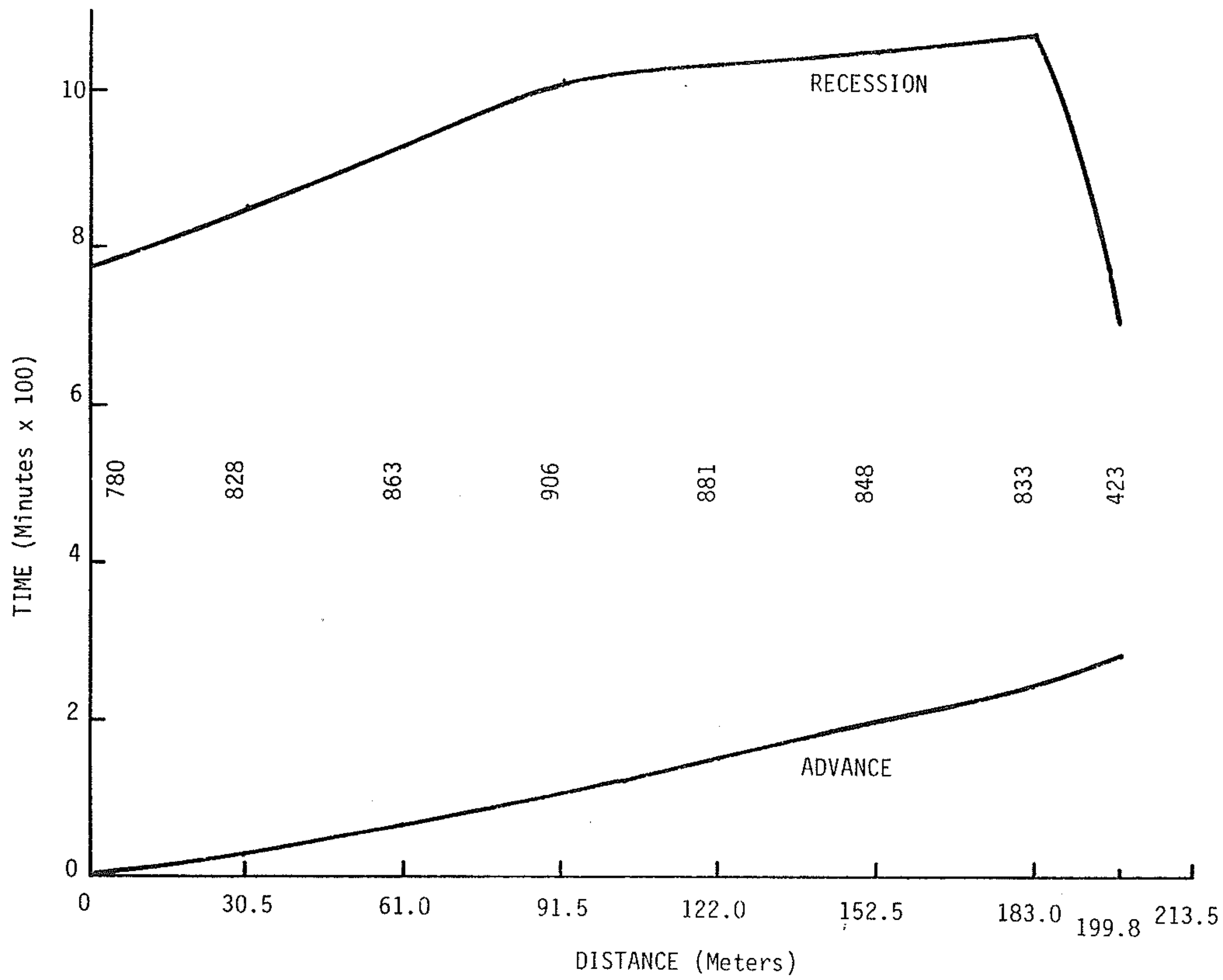

Figure 22. Advance/recession curves for ALFALFA81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

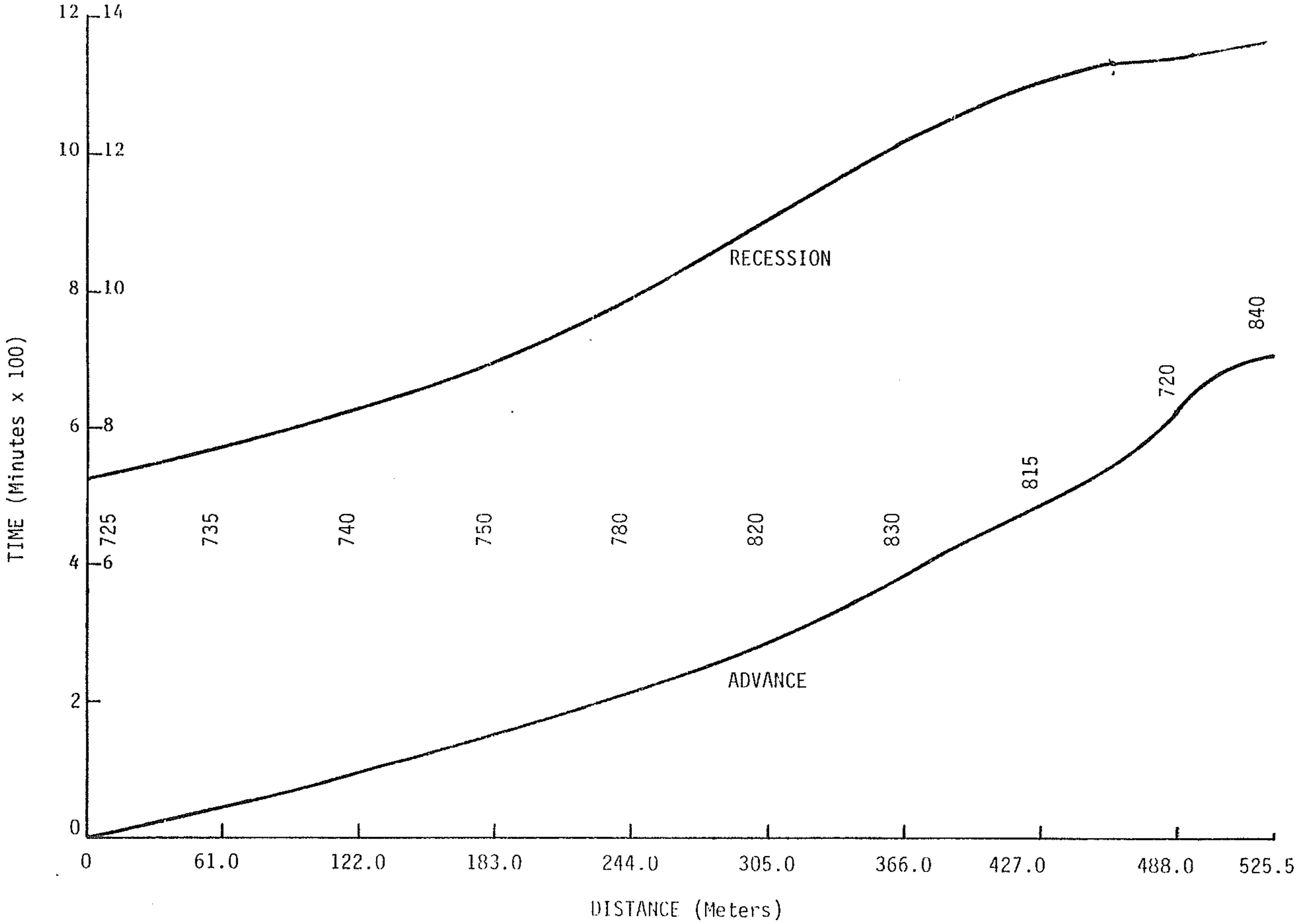

Figure 23. Advance/recession curves for BARLEY80. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

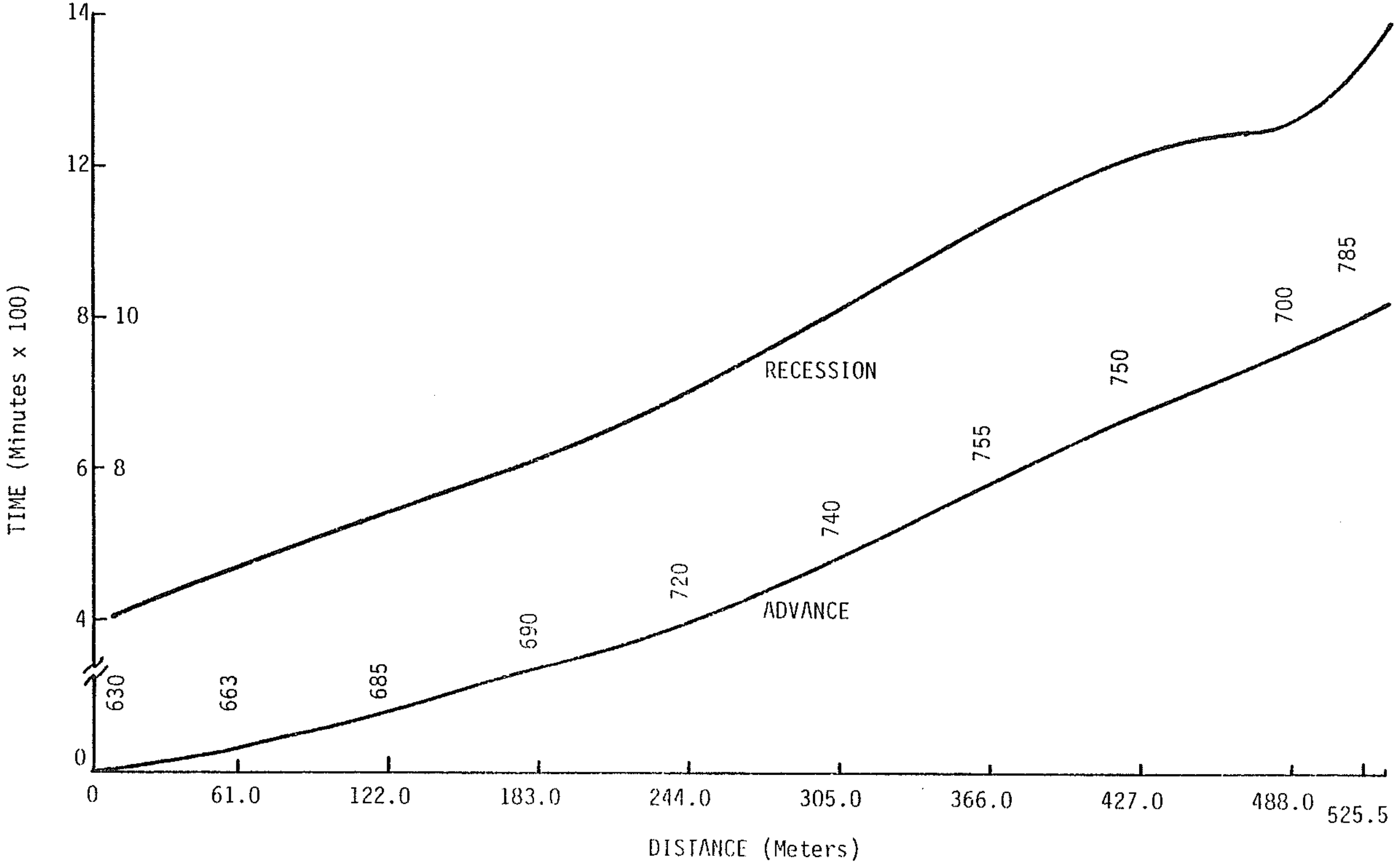

Figure 24. Advance/recession curves for BARLEY80. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

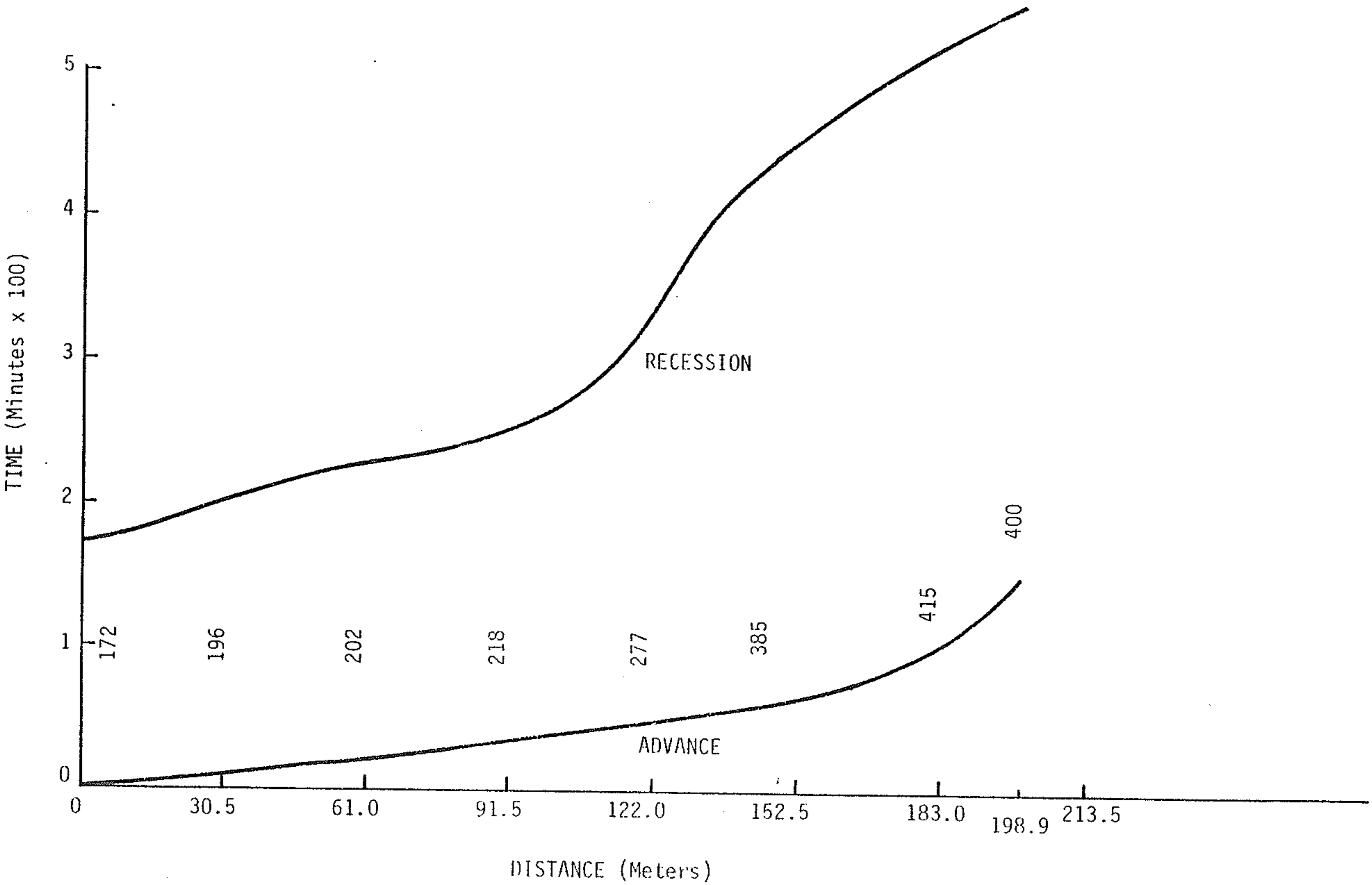

Figure 25. Advance/recession curves for CHILE801. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

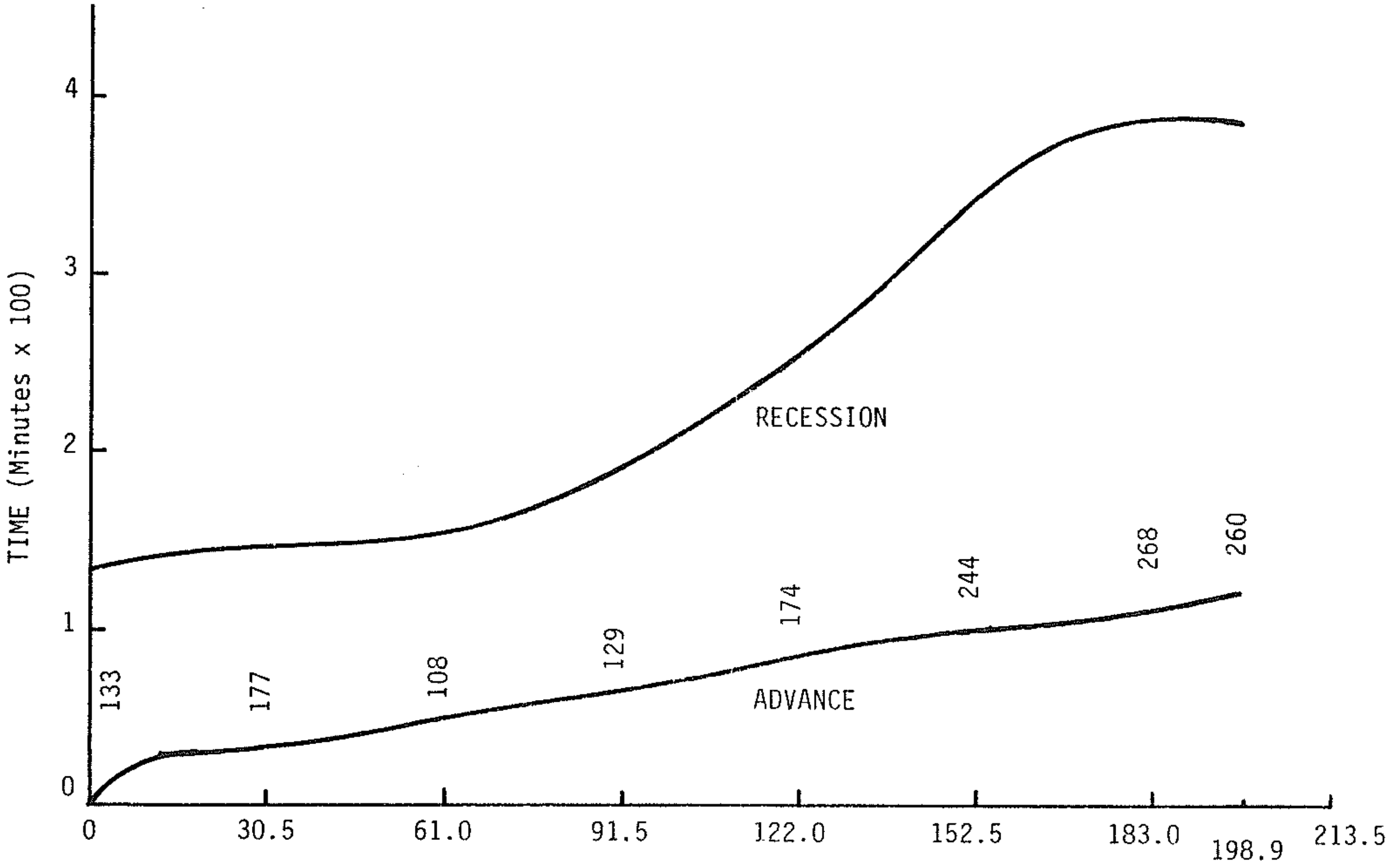

Figure 26. Advance/recession curves for CHILE801. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

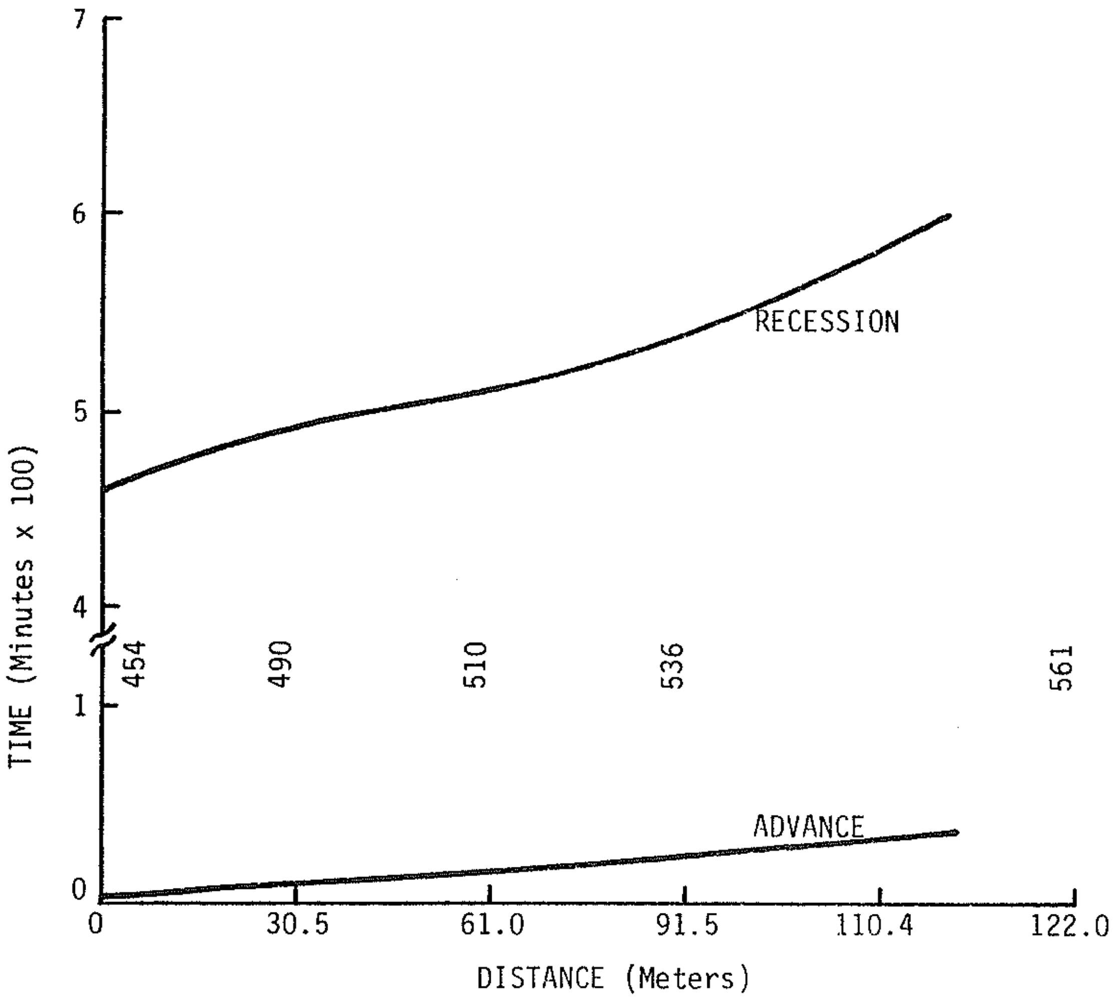

Figure 27. Advance/recession curves for CHILE802. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

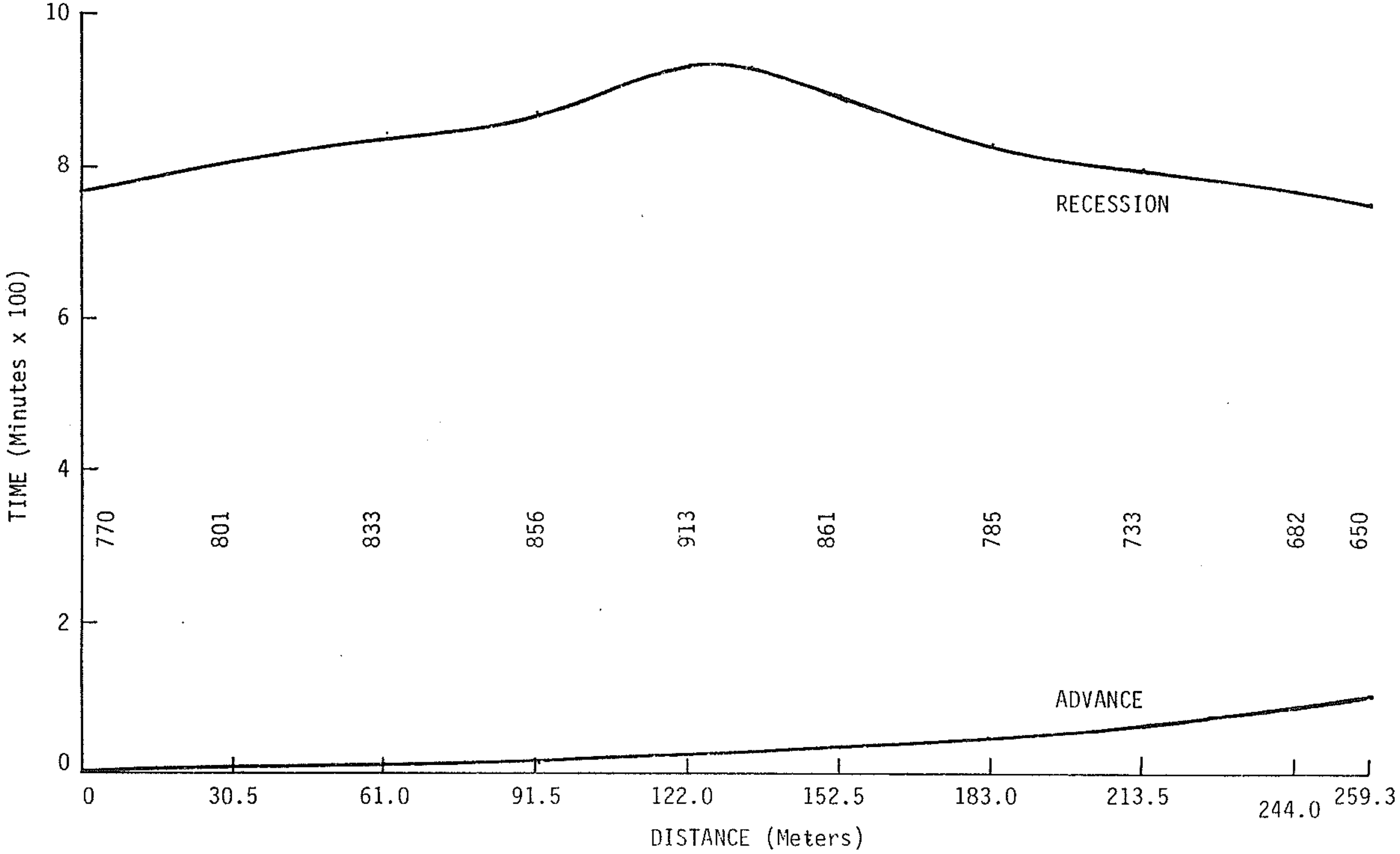

Figure 28. Advance/recession curves for CHILE81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

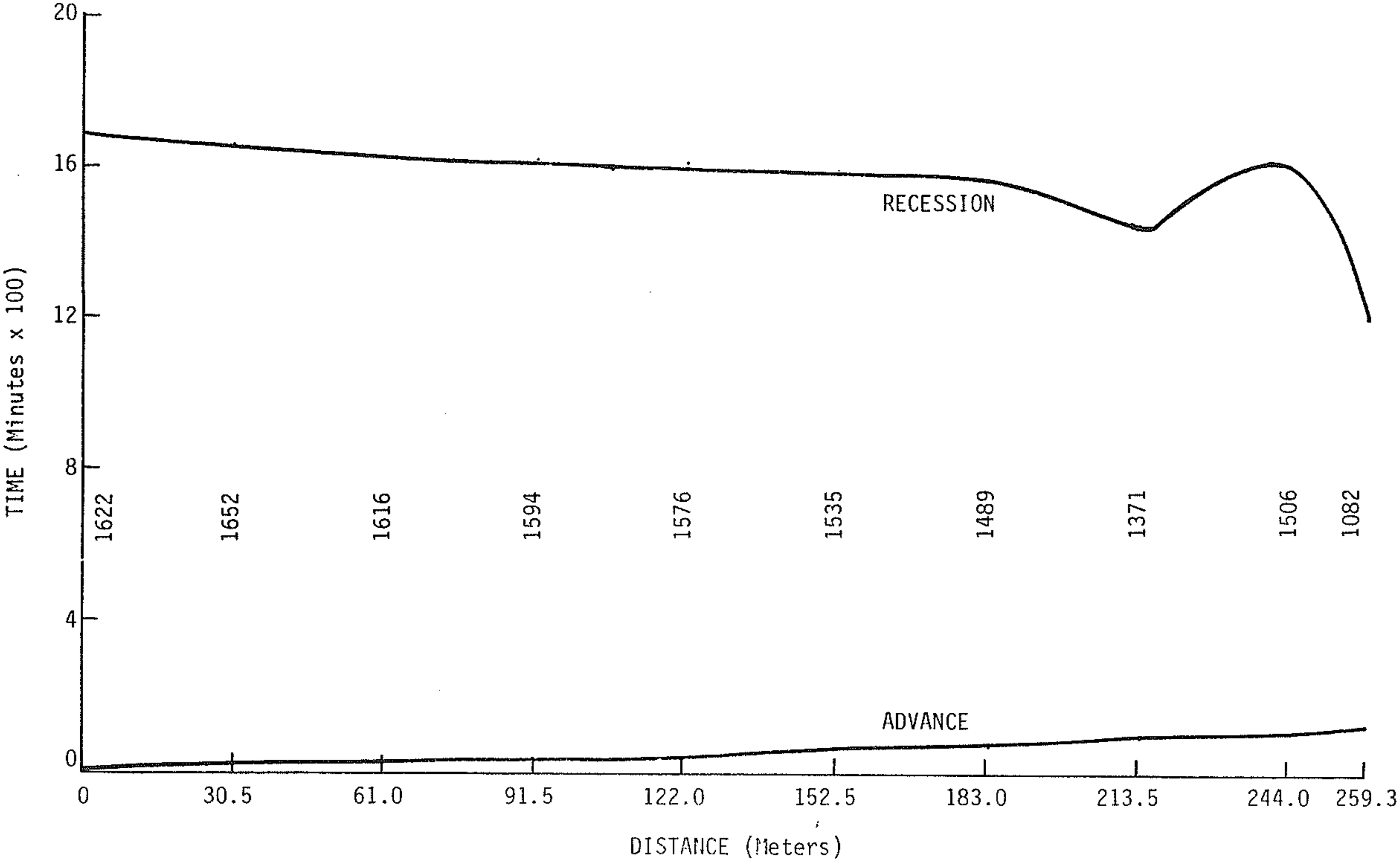

Figure 29. Advance/recession curves for CHILE81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

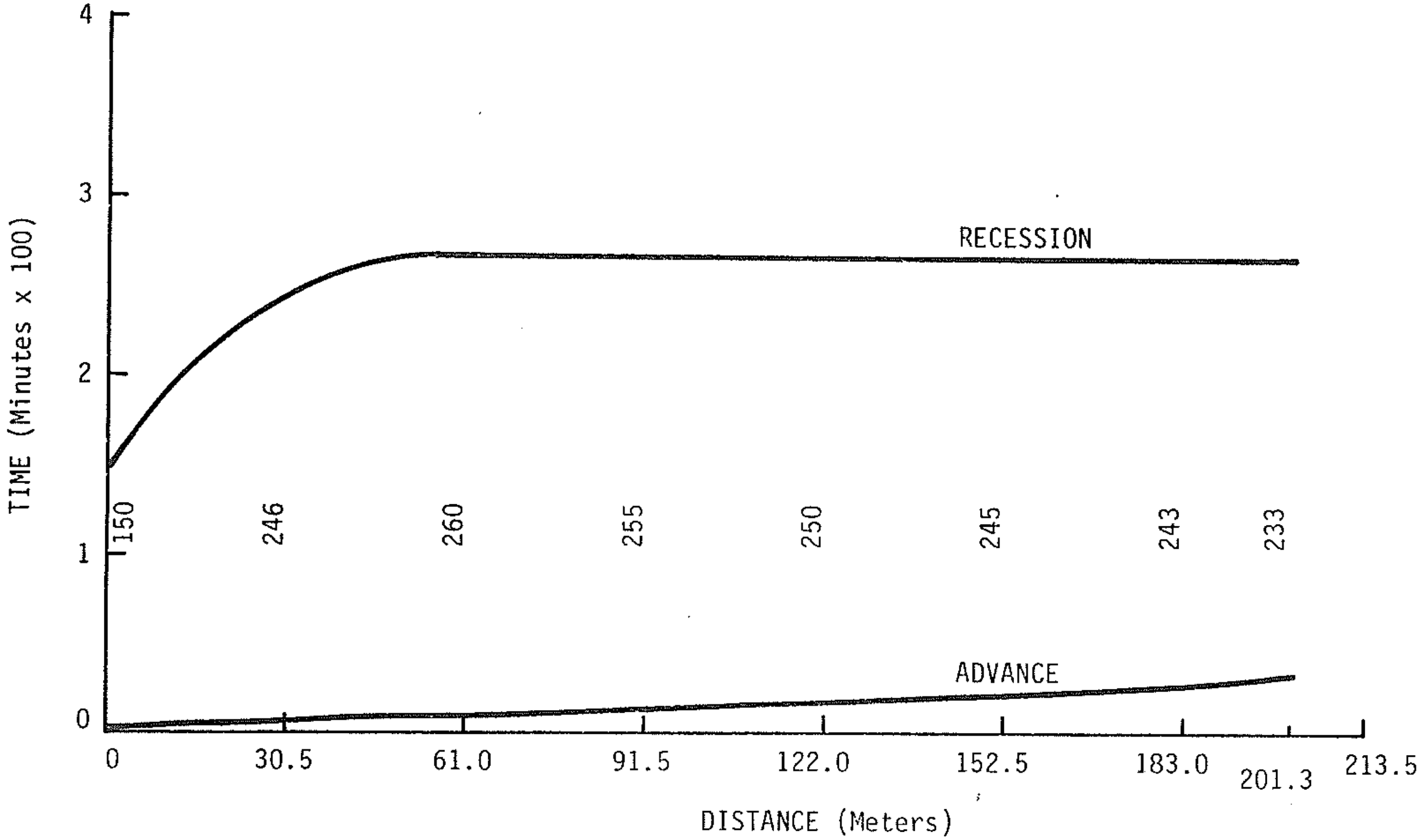

Figure 30. Advance/recession curves for CHILE82. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

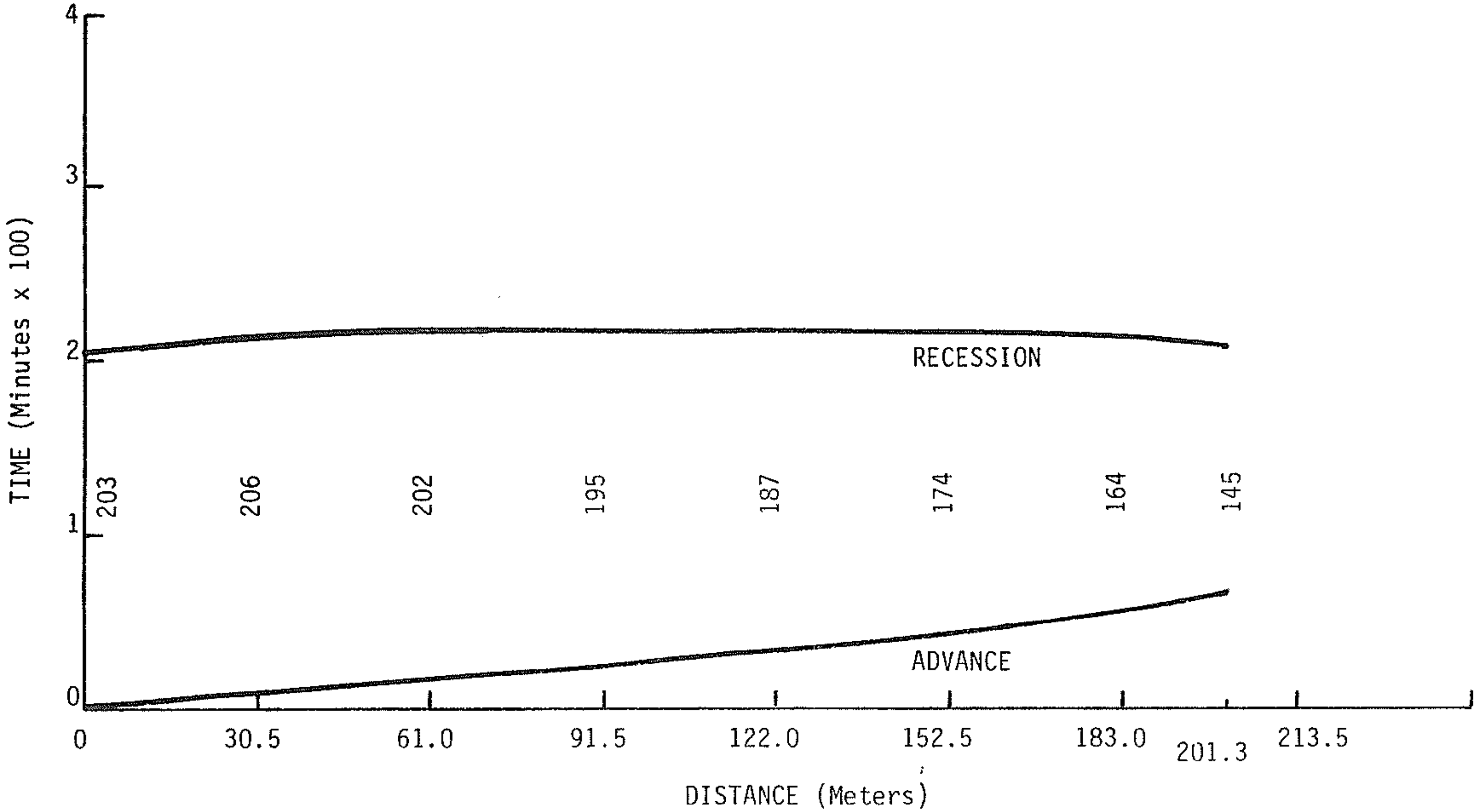

Figure 31. Advance/recession curves for CHILE82. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

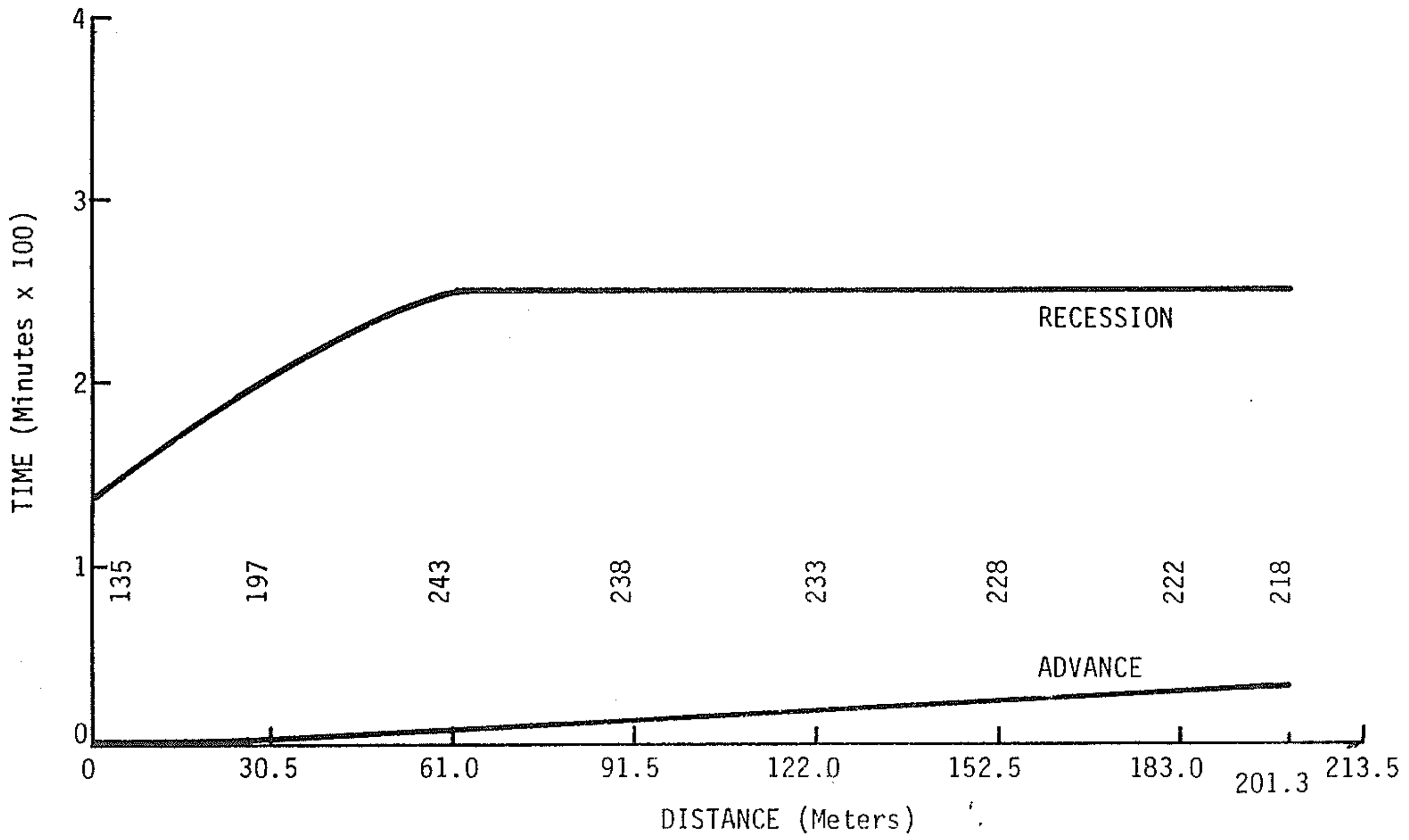

Figure 32. Advance/recession curves for CHILE82. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

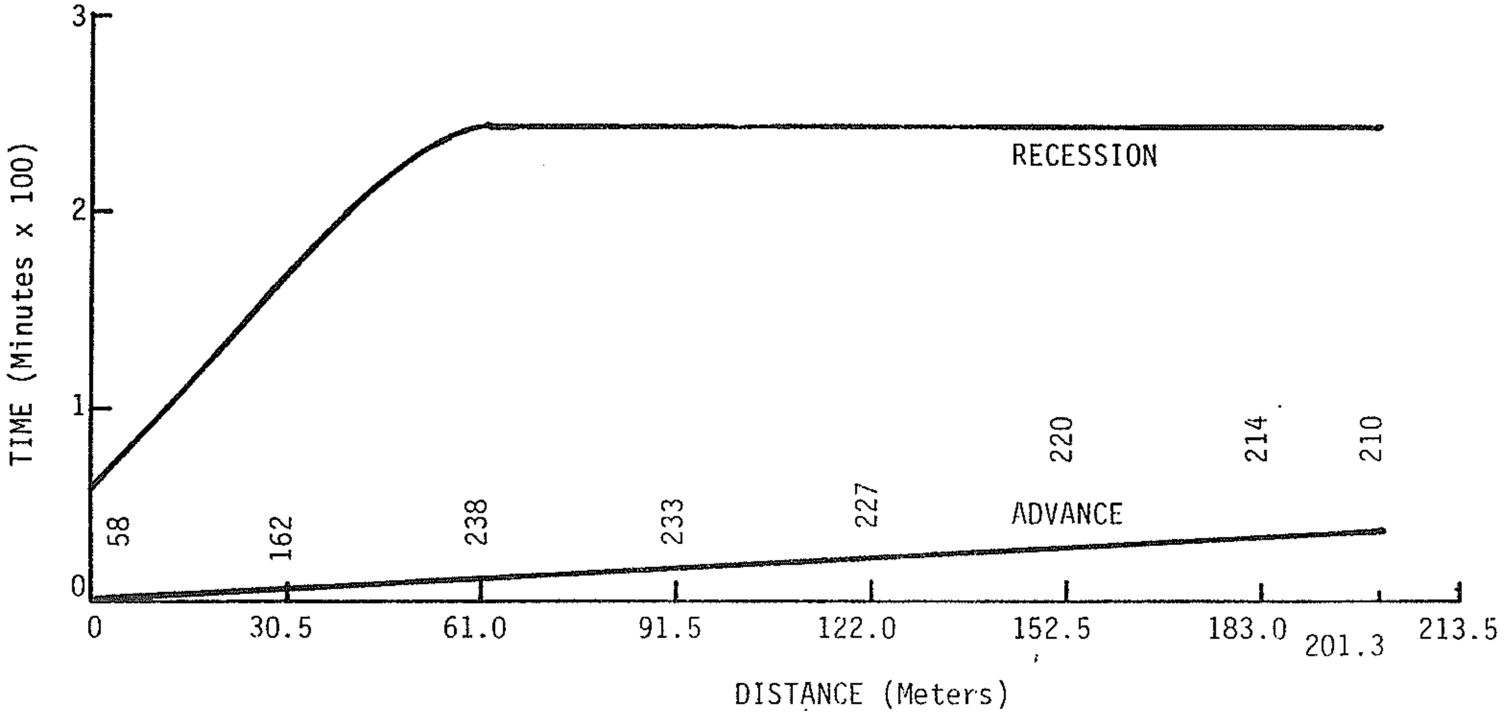

Figure 33. Advance/recession curves for CHILE82. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

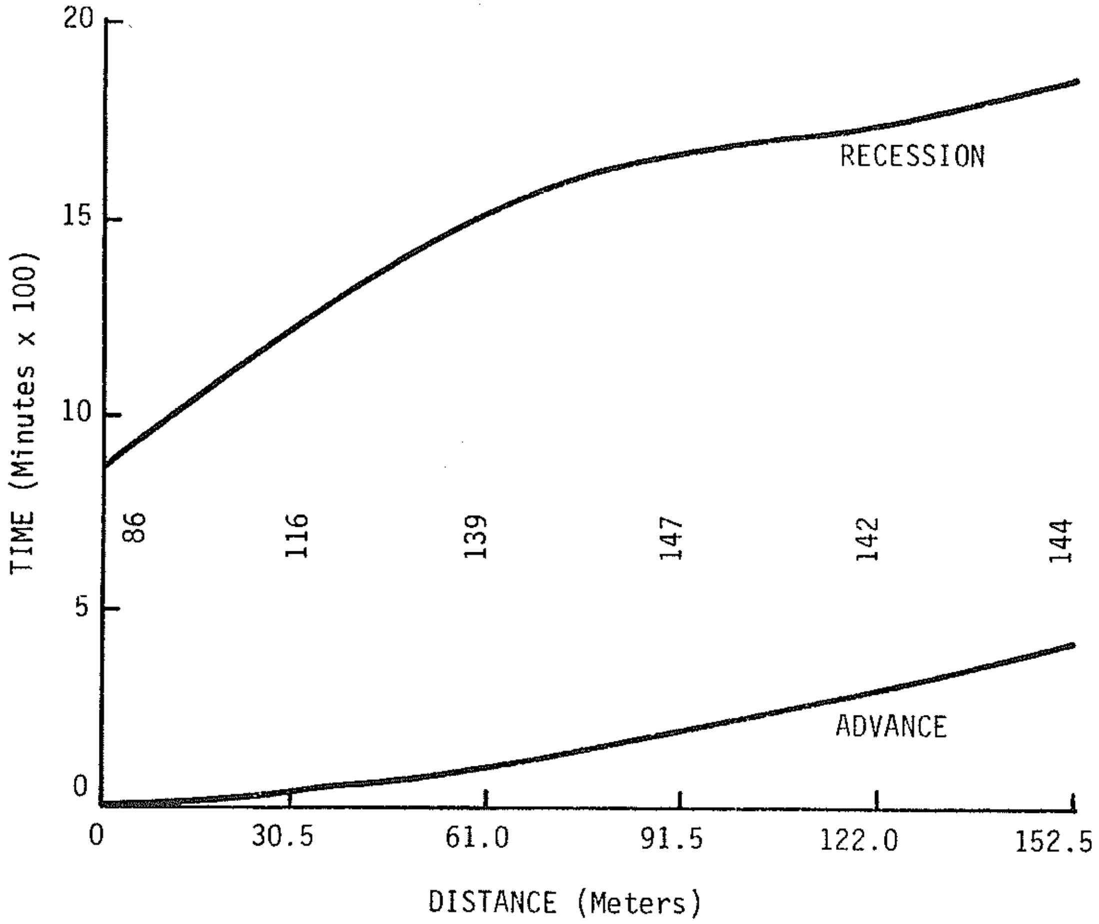

Figure 34. Advance/recession curves for COTTON80. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

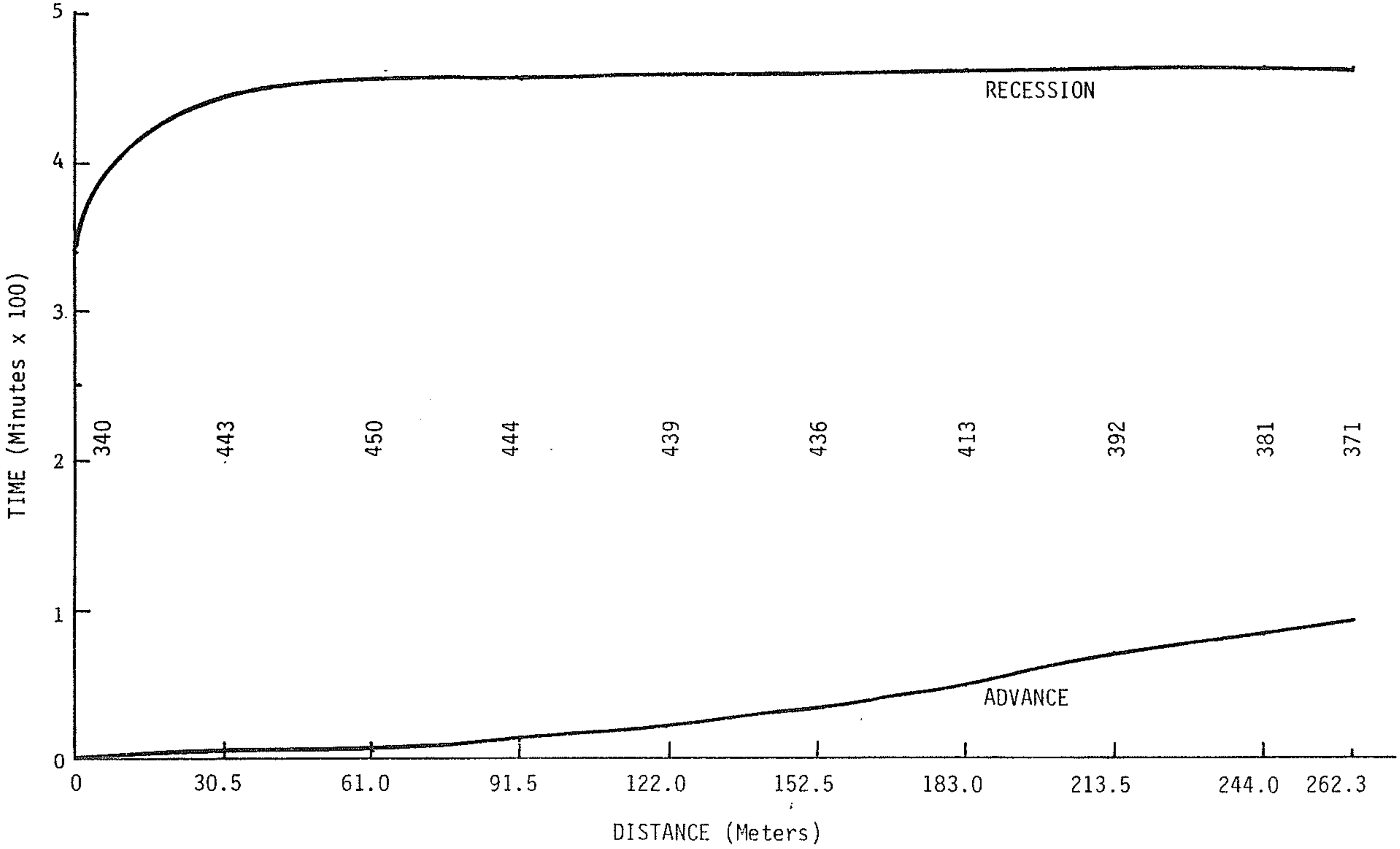

Figure 35. Advance/recession curves for CUCUMBERS82. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

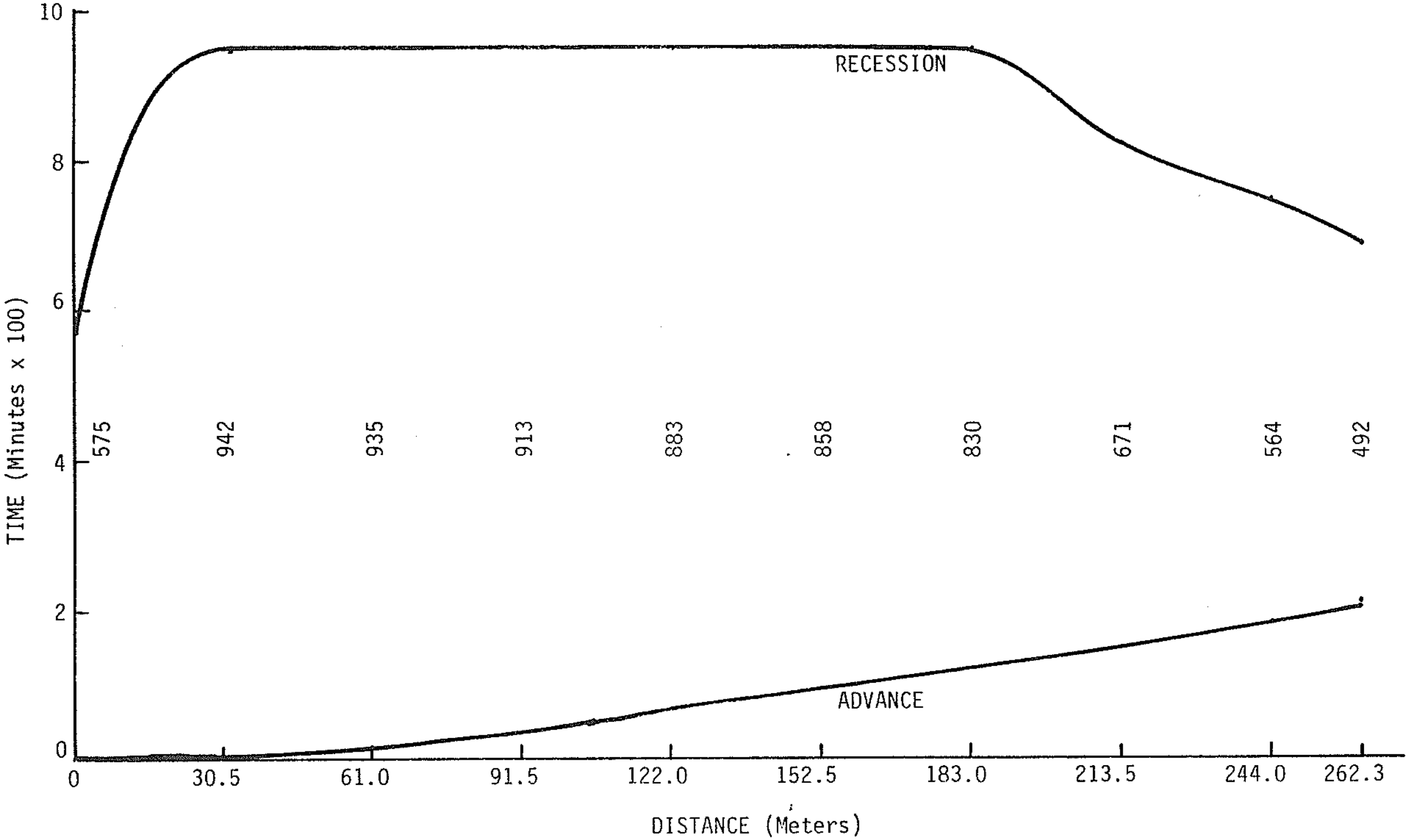

Figure 36. Advance/recession curves for CUCUMBERS82. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

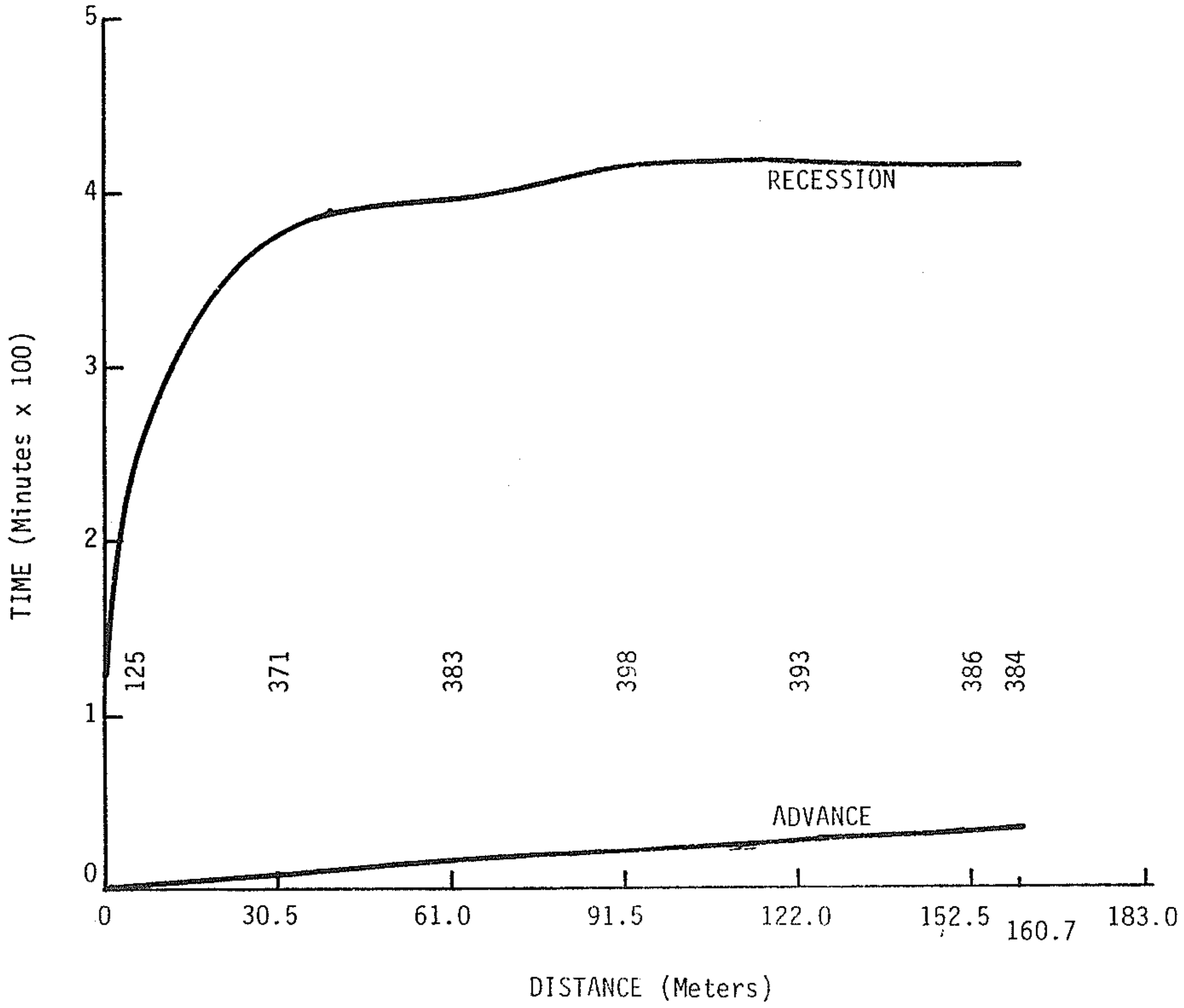

Figure 37. Advance/recession curves for LETTUCE821. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

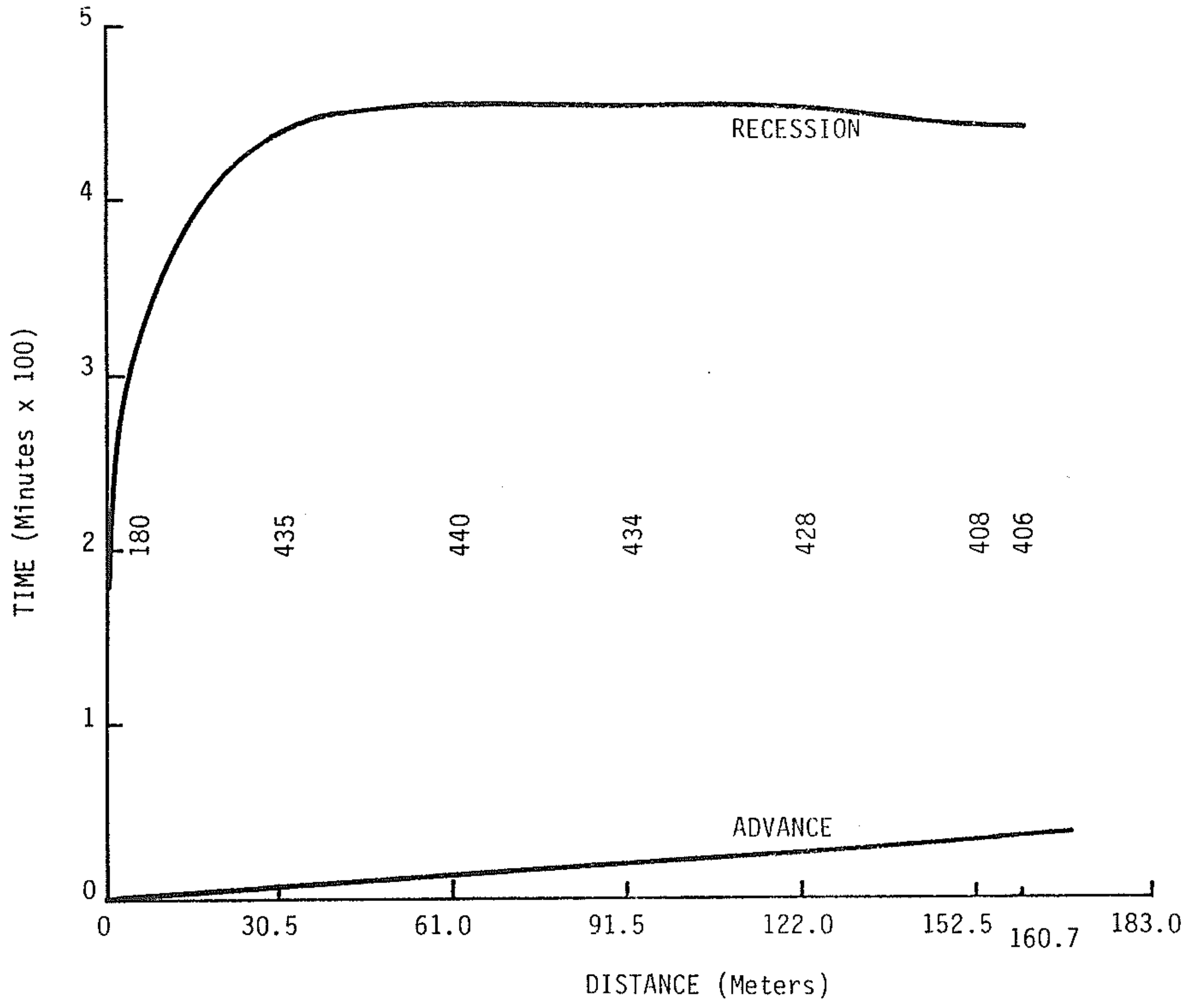

Figure 38. Advance/recession curves for LETTUCE821. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

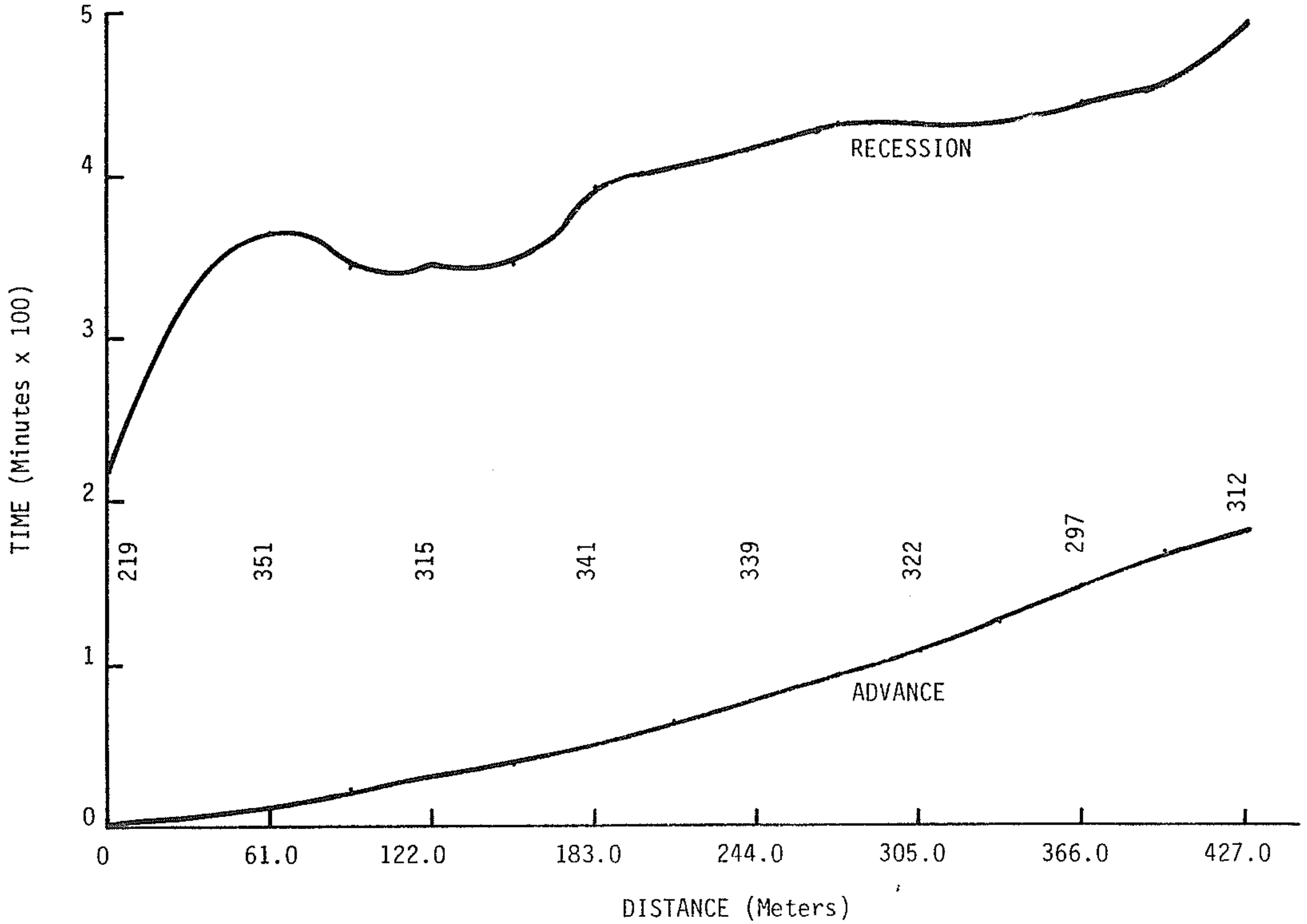

Figure 39. Advance/recession curves for LETTUCE822. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

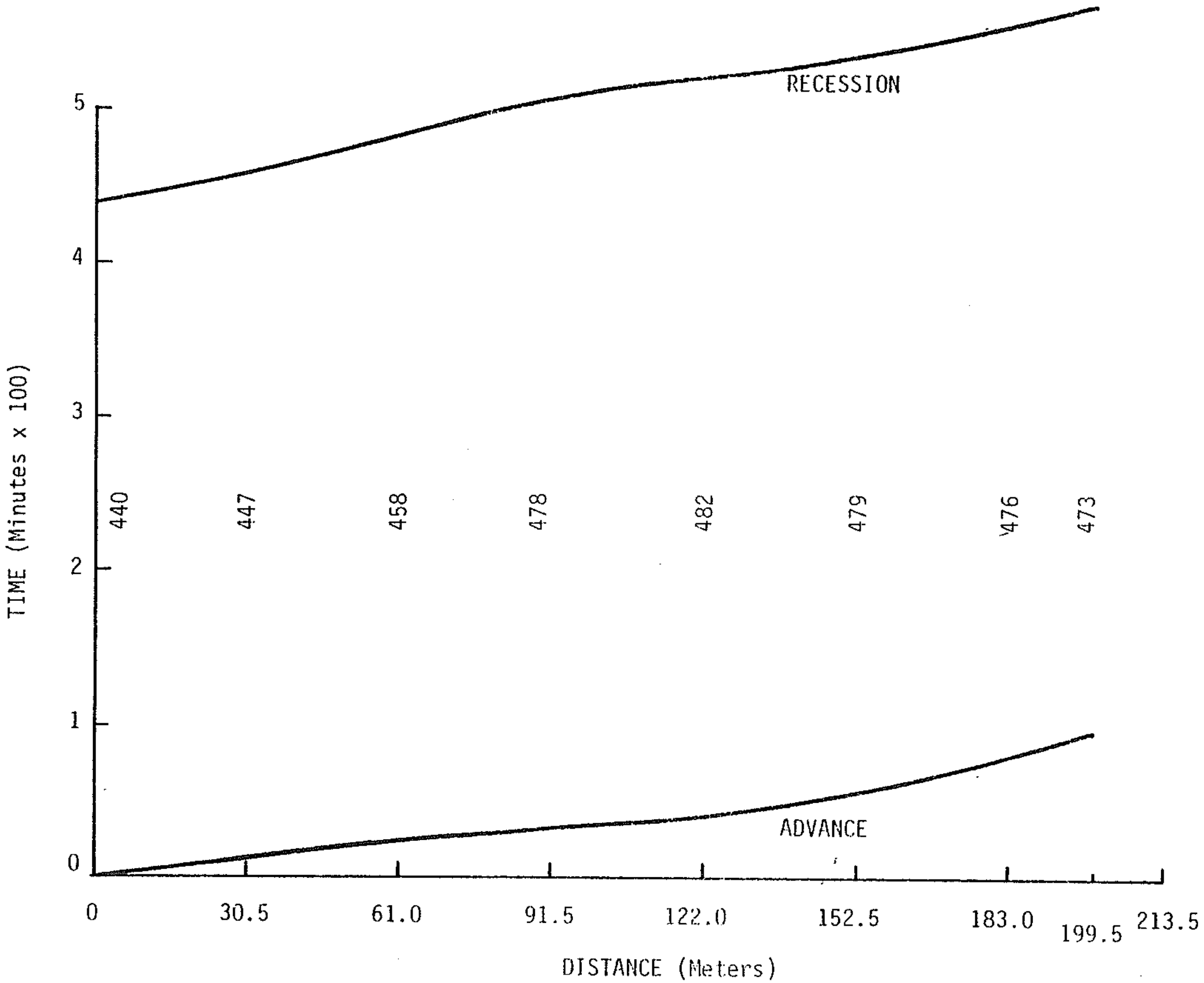

Figure 40. Advance/recession curves for ONIONS80. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

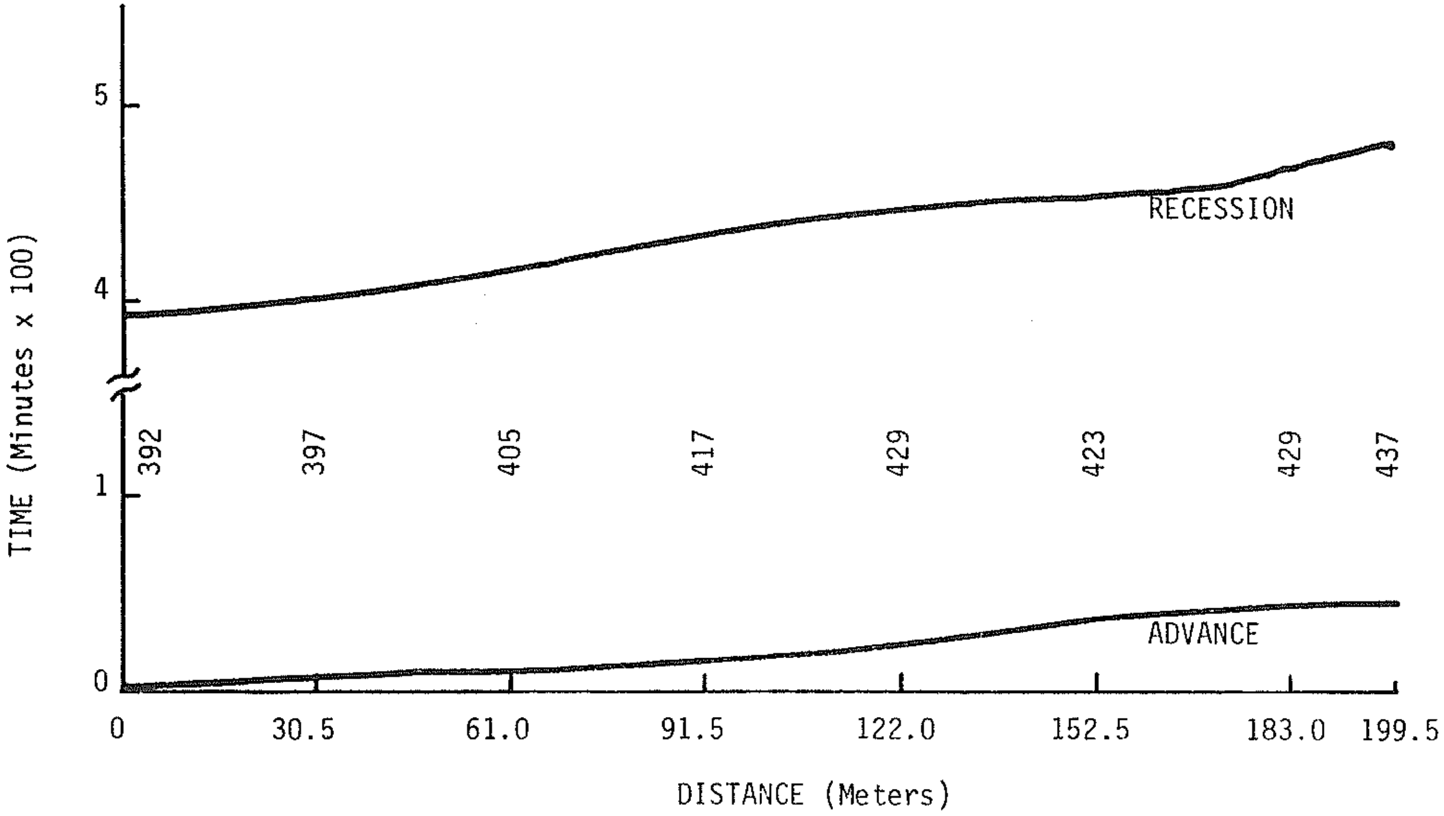

Figure 41. Advance/recession curves for ONIONS80. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

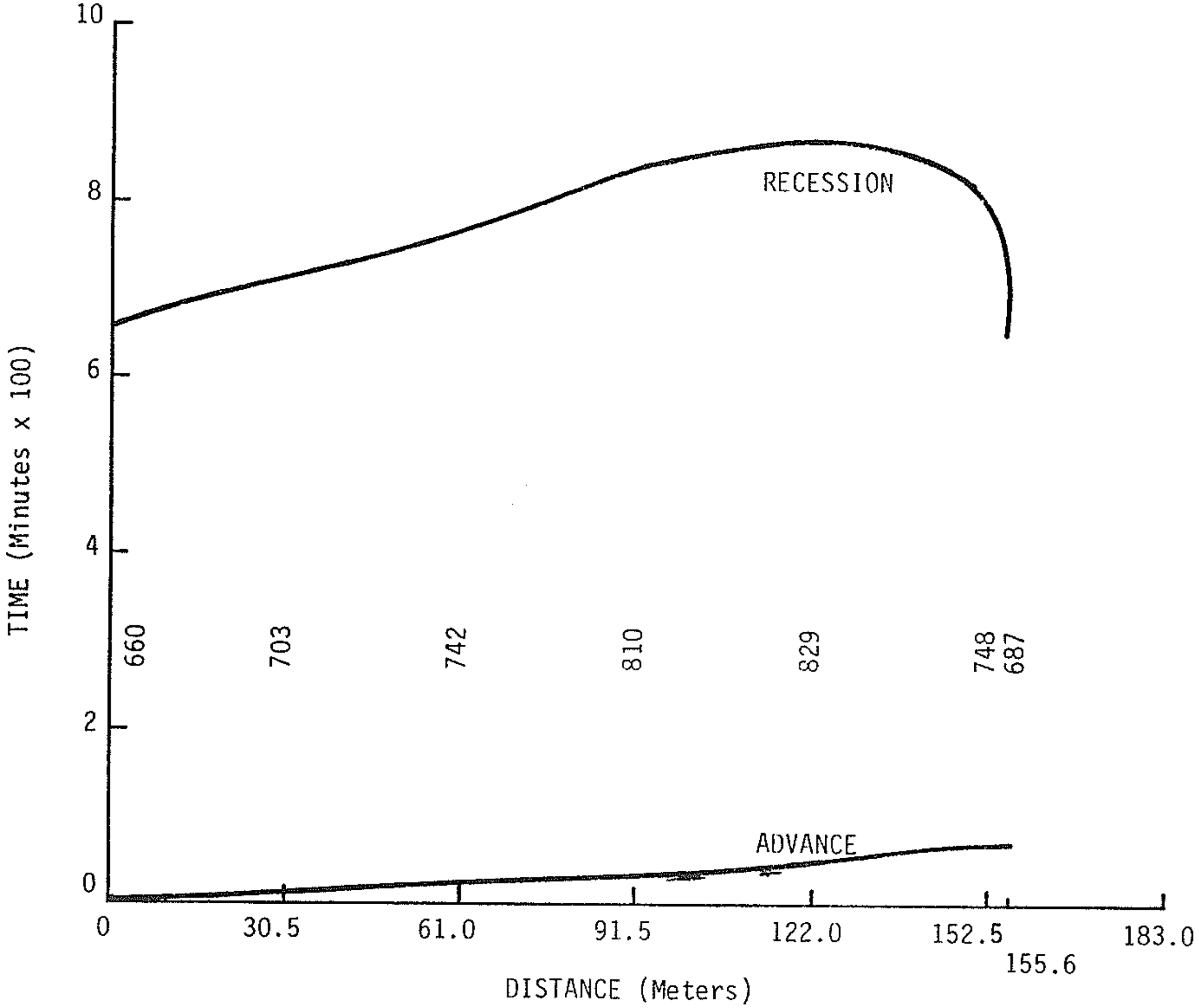

Figure 42. Advance/recession curves for ONIONS81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

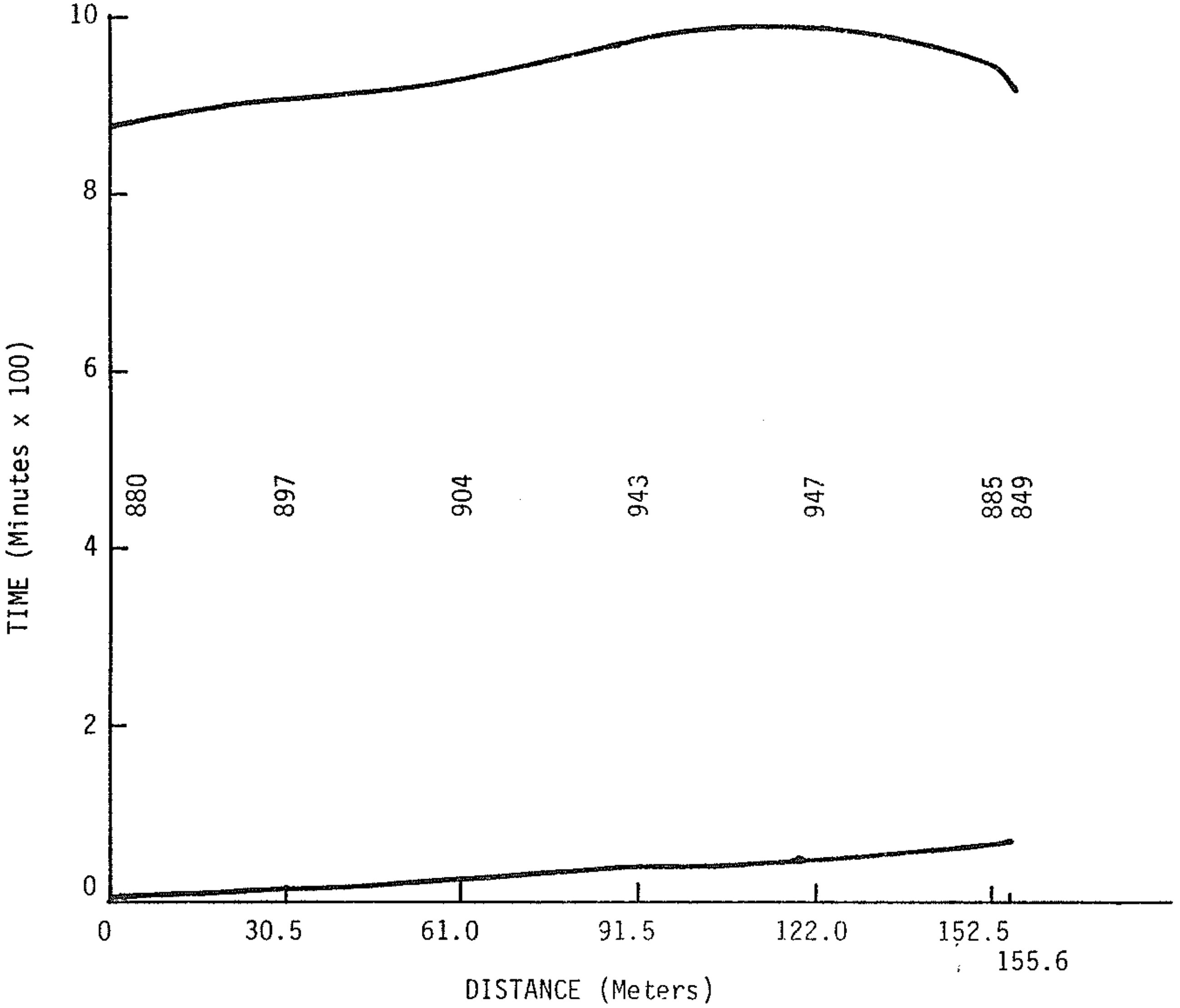

Figure 43. Advance/recession curves for ONIONS81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

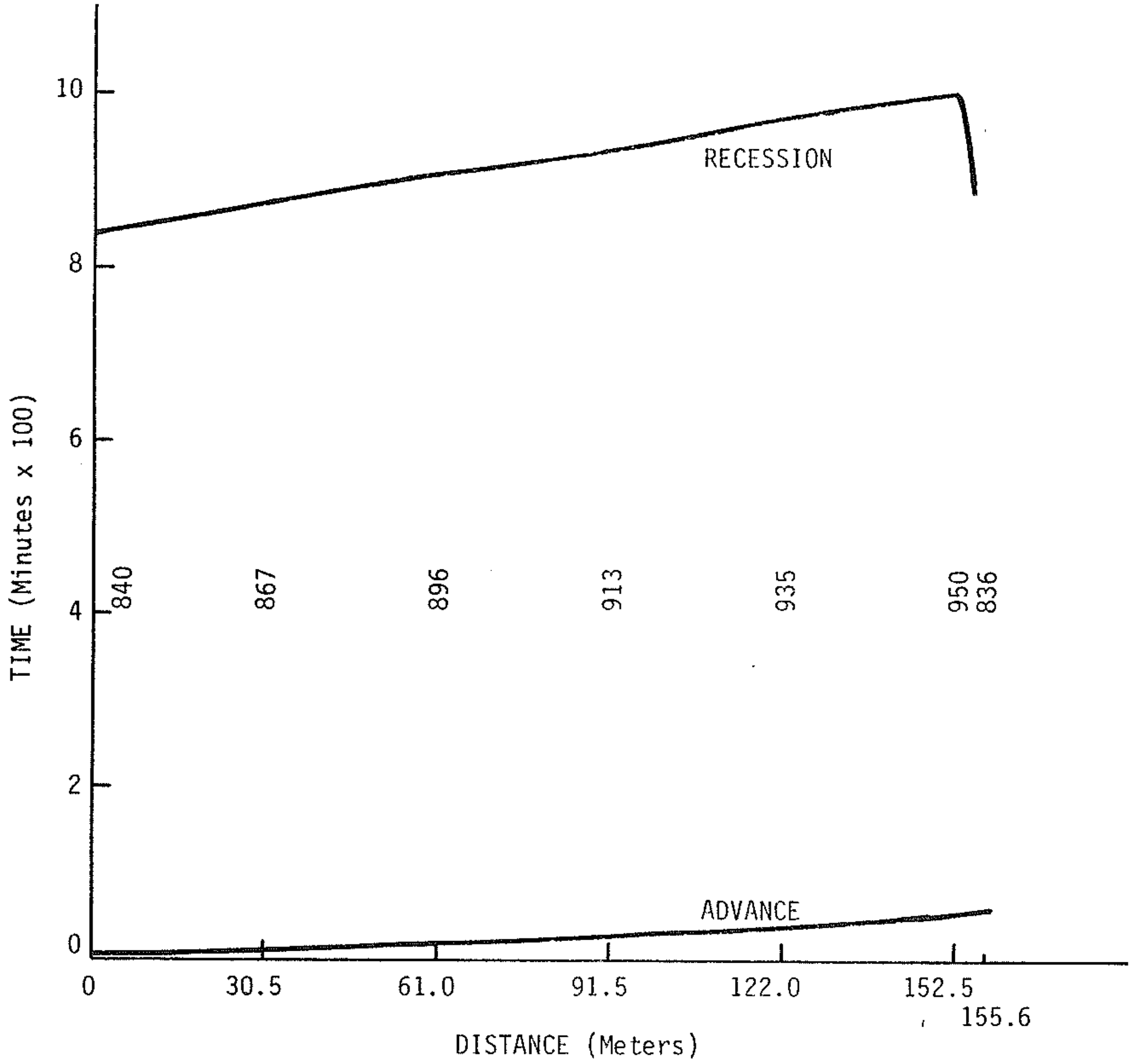

Figure 44. Advance/recession curves for ONIONS81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

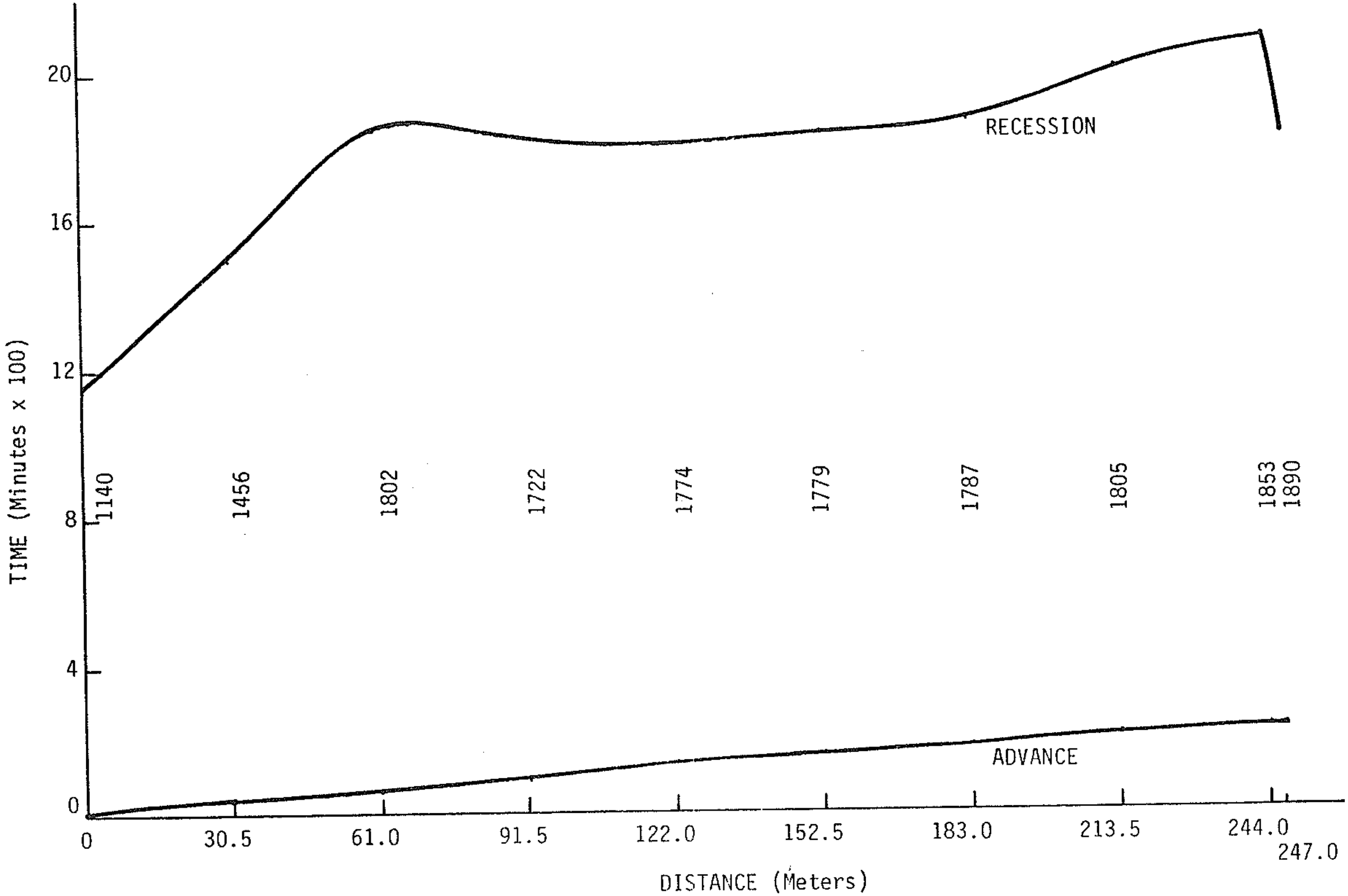

Figure 45. Advance/recession curves for PECANS81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.

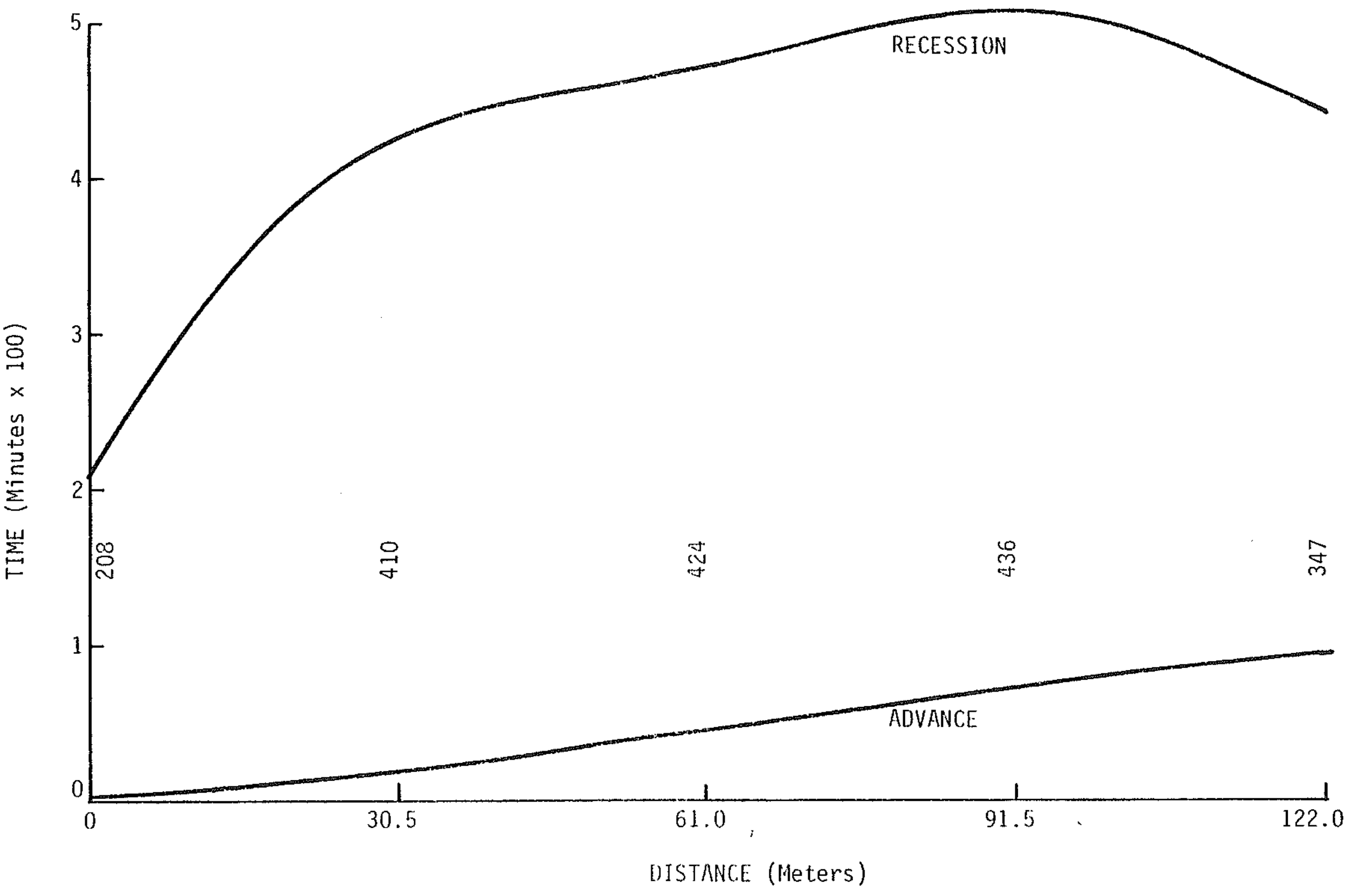

Figure 46. Advance/recession curves for WHEAT81. Numeric values between the two curves indicate opportunity times (in minutes) at that station.