9-1-1989

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ABSTRACT

Irrigated soybean production in Nebraska spans a region with diverse soils and climates. Irrigators can easily adopt irrigation scheduling using a stage of growth for timing applications. However, simplifying assumptions, including soil water holding capacity, rainfall, stored soil water, and adequate irrigation system capacity, are implicit in the development of stage of growth irrigation scheduling recommendations. Reliance on these can lead to misapplication of irrigation water.

This project tested irrigation scheduling techniques for indeterminate soybean production in Nebraska, with stage of growth indicating the initiation of irrigation. The range of soils and climate in the study area gave a range of irrigation scheduling recommendations. In the semi-arid, west-central Nebraska, full-season irrigation to meet evapotranspiration demand has been recommended. In sub-humid, south-central and eastern Nebraska, irrigation can be delayed until flowering on deep medium to fine textured soils if the potential root zone is filled at planting time.

INTRODUCTION

In recent years irrigated soybean production has spread from the sub-humid climate of eastern Nebraska to the semi-arid climate of west-central Nebraska. Average annual precipitation ranges from 700 mm (27.5 in.) in the east to 460 mm (18 in.) in west-central Nebraska. The available soil water capacities are from 80 mm/m to 210 mm/m (1.0 in./ft to 2.5 in./ft) on a volumetric basis. The variability in climate, precipitation and soil textures require different irrigation management procedures.

Researchers in eastern and south-central Nebraska demonstrated that soybean irrigation can be delayed until after flowering, especially in the case of indeterminate cultivars. They also showed positive yield responses when soybeans are irrigated only during pod elongation and/or bean enlargement. (Elmore et al., 1988; Kadhem et al., 1985; Korte et al., 1983). However, Elmore et al. (1988) found that restricting irrigation applications to represent maximum amounts possible from typical center-pivot systems reduced yields in soybeans receiving delayed irrigations in low-rainfall years. Ritter and Scarborough (1988) found that full season irrigation of soybeans did not increase yields significantly over irrigating soybeans from flowering to maturity.

Producers can schedule the amount and timing of irrigation according to the stage of crop growth. However, this article will illustrate that recommendations for stage of growth irrigation scheduling must be carefully presented to irrigators. The irrigation system capacity should be included in recommendations for scheduling irrigation by growth stages. The irrigator needs to understand the irrigation system capacity, climate, precipitation, and soil water holding capacity in order to irrigate by stage of growth. Soybean irrigation research that has been conducted in eastern, south-central and west-central Nebraska will illustrate soybean irrigation response in diverse climates. The research tested irrigation management strategies for soybean production, especially irrigation scheduling by stage of growth. Irrigation management guidelines were developed as a result of this research.

PROCEDURES

The field researcher was conducted in four Nebraska locations: Mead, eastern; Clay Center, south-central (Elmore et al., 1988); North Platte, west-central; and Tryon, west-central. The studies investigated delaying soybeans irrigation until reproductive and/or grain filling growth stages. The site characteristics are listed in Table 1.

The soybean varieties were indetermine and were representative of adapted varieties for the specific area. The soybeans were planted in 76 cm (30 in.) rows. The irrigation treatments in the experiments at Clay Center, North Platte and Tryon were:

1. **Full-Season (Full).** Irrigation began prior to flowering if necessary to supply water according to the evapotranspiration of the crop. Available soil moisture was maintained above 50% in the active root zone.

TABLE 1. Research site characteristics

	Average precipitation*				Soils	Available water capacity	
	Annual		Growing season				
	mm	(in.)	mm	(in.)		mm/m	(in./ft)
Mead	700	(28)	270	(11)	Silty clay loam	170	(2.0)
Clay Center	660	(26)	220	(9)	Silt load	180	(2.2)
North Platte	480	(19)	180	(7)	Silt loam	180	(2.2)
Tryon	460	(18)	170	(7)	Fine sand	80	(1.0)

*From National Oceanic and Atmospheric Administration, Climatological Data.

Article was submitted for publication in June 1988; reviewed and approved for publication by the Soil and Water Div. of ASAE in October 1988. Presented as ASAE Paper No. MCR 87-105.

This manuscript has been assigned Journal Series No. 8659, Agricultural Research Division, University of Nebraska.

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2. **Flower.** Irrigation began when a flower opened at a node immediately below the uppermost node on the main stem with a completely unrolled leaf. During both flowering and pod elongation a maximum of 76 mm (3 in.) of water was applied in two weeks. During bean enlargement, a maximum of 114 mm (4.5 in.) of water was applied in three weeks. Irrigation amounts were adjusted each week for rainfall.

3. **Pod Elongation (Pod).** Irrigation began when a pod at one of the four uppermost nodes on the main stem with a fully developed leaf was 19 mm (0.75 in.) long. During pod elongation, a maximum of 76 mm (3 in.) of water was applied in two weeks. During bean enlargement, a maximum of 114 mm (4.5 in.) of water was applied in three weeks. Irrigation amounts were adjusted each week for rainfall. At the North Platte site, a total of 152 mm (6 in.) of irrigation was applied in three irrigations after commencement of pod elongation.

4. **Dryland.** Water was applied only if needed for stand establishment.

Water applications from center pivot irrigation systems range from 19 (0.75 in.) to 38 mm (1.5 in.) per irrigation event. System capacity usually limits applications to 38 (1.5 in.) to 51 mm (2 in.) per week. Therefore, individual irrigation applications in this experiment were limited to total 38 mm (1.5 in.) to 51 mm (2 in.) per week. Additional water was applied in subsequent weeks to satisfy the protocol of the irrigation treatment.

The irrigation treatments at Mead commenced during the same stage of growth as the Clay Center, North Platte, and Tryon studies. However, at Mead all of the irrigation treatments received nearly the same total application. The irrigation treatments that were initiated later received additional water to eliminate the variable of water amounts applied. The objective of the Mead experiment was to find best timing for irrigation initiation. At all other locations, this objective was combined with system capacity limitations to supply water. Therefore, extra water was not applied to later starting irrigation treatments.

Crop water use or evapotranspiration (ET) was estimated from mid-June to mid-September using a water balance of rainfall, irrigation, and change in soil water content. Drainage was assumed to be negligible. Soil moisture was measured weekly with neutron attenuation methods at Clay Center, North Platte, and Tryon. Soil moisture was measured at 30 cm (12 in.) intervals to a depth of 150 cm (60 in.). At the Mead site, soil moisture was measured weekly at 30 cm (12 in.) intervals to a depth of 120 cm (48 in.) with gypsum electrical resistance blocks.

The experimental design was a randomized complete block with four replications. The plots were irrigated with solid set sprinkler systems. The protocol for the North Platte experiment called for the water treatments to follow the same water treatments of the year before. For example, dryland plots followed dryland corn from the year before and fully irrigated plots followed fully irrigated corn from the year before. Plots in other locations were randomized without regard to previous water treatments.

RESULTS

The growing season (June 1-September 15) rainfall, growing degree days, and potential evapotranspiration for the field sites during each year of the study are in Table 2. The North Platte site received somewhat below normal precipitation during the three growing seasons with the driest year in 1986. The Tryon site received near normal rainfall during the 1985 growing season and less than normal rainfall in 1984. The Tryon site is at the highest elevation and has the most exposure to advective evaporation of all the field sites. Therefore, the growing degree days were the lowest and the potential evapotranspiration was the highest at Tryon. The growing season rainfall at Clay Center was near normal, below normal, and above normal for 1984, 1983, and 1982, respectively. The growing season rainfall at Mead was below normal both years. The sub-humid climate and lower elevation at the Mead site caused more growing degree days and less potential evapotranspiration.

The results from all locations established a pattern of yield response to initiation of irrigation. Table 3 summarizes the results by location and year. Rainfall during the growing season, the change in soil water storage during the growing season (soil water used) and irrigation were the three components that contributed to evapotranspiration. Relative yields were based on the yield from the full irrigation treatment at each location for that year.

Soybean yields at Mead were not reduced when irrigation was delayed until flower or pod elongation. However, soybeans at Mead did not lack for water after irrigation commenced since supplemental water was added so that total irrigation was nearly the same for all treatments. The Mead location received approximately two-thirds of normal precipitation during the 1983 growing season. The 1983 dryland soybeans yielded less than those in irrigated treatments. Yields were reduced at Mead in 1984 due to an early frost.

Irrigation applications were limited to 38 mm (1.5 in.) per week after commencement of irrigation at Clay

TABLE 2. Summary of growing season (June 1 - September 15) weather characteristics for experimental field sites‡

Year	Site	Rainfall, mm	(in.)	Growing degree days* °C	(°F)	Potential ET,† mm	(in.)
1987	North Platte	160	6.3	1148	2066	747	29.4
1986	North Platte	137	5.4	1128	2030	734	28.9
1985	North Platte	155	6.1	1019	1834	752	29.6
1985	Tryon	168	6.6	833	1499	774	30.5
1984	Tryon	140	5.5	1131	2035	767	30.2
1984	Clay Center	204	8.0	1270	2286	688	27.1
1983	Clay Center	165	6.5	1308	2354	–	–
1982	Clay Center	281	11.1	–	–	–	–
1982	Mead	182	7.2	1339	2410	716	28.3
1983	Mead	208	8.2	1397	2515	630	24.8

*Calculated using 10° C (50° F) base and 30° C (86° F) maximum temperature for accumulation.
†Calculated from air temperature, solar radiation, wind run, and relative humidity measurements at field sites using Penman combination equation (Kincaid and Heermann, 1984).
‡Data from the Automated Weather Data Network (AWDN) operated by the High Plains Climate Center (HPRCC), University of Nebraska, Lincoln.

TABLE 3. Results from irrigating soybeans by growth stages in Nebraska (English units)

Year	Site	Irrigation treatment	Irrigation amount, in.	Growing season rainfall, in.	Soil water used, in.	Total water use, in.	Grain yield, lb/ac	Relative yield, %
1987	North Platte	Full	12.4	6.3	1.4	20.1	3600a*	100
		Pod	6.0	6.3	7.0	19.3	3120a	87
		Dryland	0	6.3	4.7	11.0	1080b	30
1986	North Platte	Full	13.0	5.4	2.1	20.5	3910a*	100
		Pod	6.1	5.4	4.9	16.4	3600a	92
		Dryland	0	5.4	5.9	11.3	2770b	71
1985	North Platte	Full	11.9	6.1	1.7	19.7	3680a*	100
		Pod	6.0	6.1	1.4	13.5	2640a	72
		Dryland	0	6.1	0.8	6.9	1160b	31
1985	Tryon	Full	10.5	6.6	3.1	20.2	2110a†	100
		Flower	6.0	6.6	3.0	15.6	1860b	88
		Pod	3.7	6.6	2.7	13.0	1570b	74
		Dryland	0	6.6	5.4	12.0	1450c	68
1984	Tryon	Full	11.6	5.5	2.4	19.5	3310a‡	100
		Flower	9.3	5.5	3.0	17.8	3010ab	91
		Pod	5.8	5.5	3.0	14.3	2770b	84
		Dryland	0.3	5.5	5.4	11.2	1510c	45
1984	Clay Center	Full	10.5	8.0	3.8	22.3	1510a†	100
		Flower	9.2	8.0	3.2	20.4	2930a	110
		Pod	6.2	8.0	3.9	18.1	2630b	99
		Dryland	0	8.0	7.8	15.8	1960c	74
1983	Clay Center	Full	13.7	6.5	1.3	21.5	2830a†	100
		Flower	9.2	6.5	4.5	20.2	2650a	94
		Pod	6.2	6.5	4.6	17.3	2440b	79
		Dryland	0	6.5	6.5	13.0	1720c	61
1982	Clay Center	Full	6.0	11.1	0.6	17.7	2570a†	100
		Flower	5.5	11.1	0.2	16.8	2650a	103
		Pod	4.5	11.1	1.7	17.3	2811a	109
		Dryland	0	11.1	3.7	14.8	2350c	91
1984	Mead	Full	9.0	7.2	5.5	21.7	1800a†	100
		Flower	10.1	7.2	5.9	23.2	1840a	102
		Pod	9.9	7.2	0.9	18.0	1990a	110
		Dryland	0	7.2	7.1	14.3	1700a	94
1983	Mead	Full	9.4	8.2	3.6	21.2	3640a†	100
		Flower	9.3	8.2	3.8	21.3	3650a	100
		Pod	9.7	8.2	3.1	21.0	3610a	99
		Dryland	0	8.2	7.0	15.2	2040b	56

*Means within location followed by the same letter are not significantly different (= 0.05).
†Means within location and year followed by the same letter are not significantly different (= 0.05).
‡Means within location and year followed by the same letter are not significantly different (= 0.10).

Center. Yields from the full-season and flower treatments were the same each year. Soybeans in the pod-elongation treatment also yielded the same as soybeans with full-season irrigation during 1982. Growing-season rainfall was above normal that year. During the other two years with below normal growing-season rainfall, pod-elongation treatment yields were significantly lower than yields from the flower and full-season irrigation treatments.

The Tryon site, on a sandy soil, produced the most grain yields from full-season irrigation. Soybeans in the flower treatment yielded the same as the full-season treatment in 1984 with near-normal growing season precipitation. Soybean yields from the pod treatment increased with respect to the dryland treatment, but they were less than those from full-season irrigation. The results from North Platte showed trends similar to Tryon. However, the yield potential at North Platte was higher for all treatments due to inherently better soil fertility.

The average relative yields by location and water treatment are in Fig. 1. The dryland relative yields were greater at Mead and Clay Center than at Tryon or North Platte. More precipitation before and during the growing season at the eastern locations may have increased dryland relative yields. Relative yields from the pod treatments decreased from the eastern to west-central locations. Soil water storage and rainfall were not enough to produce maximum yields from the pod-elongation treatment in the west-central locations; although, the pod-elongation treatment showed a positive yield response due to late season water application in all locations.

Water use and its components, averaged over years for each treatment and locations, are represented in Fig. 2. The trends in water use follow those for relative yield in Fig. 1. Relative yields for the flower and pod treatments at Clay Center showed that soybeans used water more efficiently when irrigation was delayed. However, the timing of rainfall in relation to irrigation caused season to season variation. Total soil water from the surface to a depth of 165 cm (66 in.) for the 1984 season at Tryon is shown in Fig. 3. Roots extracted water to 150 cm (60 in.) in the dryland plots, but water was extracted only to 120 cm (48 in.) in the three irrigated treatments.

The relationship between relative yield and water use (evapotranspiration) is represented in Fig. 4. A regression of relative yield as a function (quadratic) of growing season water use was calculated using data from

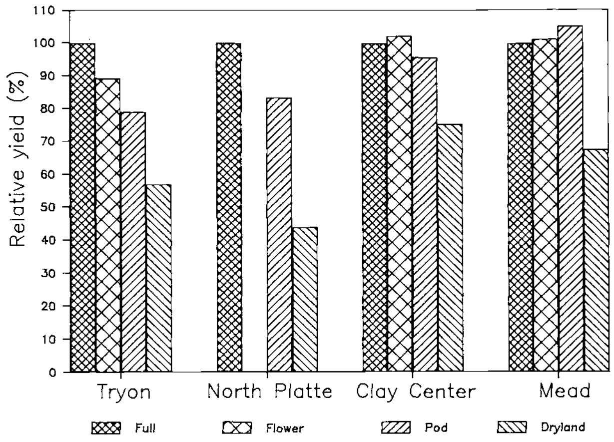

Fig. 1—Relative yields for soybeans with respect to full season irrigation.

TABLE 3. Results from irrigating soybeans by growth stages in Nebraska (SI units)

Year	Site	Irrigation treatment	Irrigation amount, mm	Growing season rainfall, mm	Soil water used, mm	Total water use, mm	Grain yield, kg/ha	Relative yield, %
1987	North Platte	Full	315	160	36	511	4040a*	100
		Pod	152	160	178	490	3500a	87
		Dryland	0	160	119	279	1210b	30
1986	North Platte	Full	330	137	53	520	4380a*	100
		Pod	155	137	124	416	4040a	92
		Dryland	0	137	150	287	3100b	71
1985	North Platte	Full	302	155	43	500	4130a*	100
		Pod	152	155	36	343	2960a	72
		Dryland	0	155	20	175	1300b	31
1985	Tryon	Full	267	168	79	513	2370a†	100
		Flower	152	168	76	396	2080b	88
		Pod	94	168	69	330	1760b	74
		Dryland	0	168	137	305	1620c	68
1984	Tryon	Full	295	140	61	496	3710a‡	100
		Flower	236	140	76	452	3370ab	91
		Pod	147	140	76	363	3100b	84
		Dryland	8	140	137	285	1690c	45
1984	Clay Center	Full	267	204	97	568	2990a†	100
		Flower	234	204	81	519	3280a	110
		Pod	157	204	99	460	2950b	99
		Dryland	0	204	198	402	2200c	74
1983	Clay Center	Full	348	165	33	546	3170a†	100
		Flower	234	165	114	513	2970a	94
		Pod	157	165	117	439	2510b	79
		Dryland	0	165	165	330	1930c	61
1982	Clay Center	Full	152	281	15	448	2880a†	100
		Flower	140	281	5	426	2970a	103
		Pod	114	281	43	438	3150a	109
		Dryland	0	281	94	375	2630c	91
1984	Mead	Full	229	182	140	551	2020a†	100
		Flower	257	182	150	589	2050a	102
		Pod	251	182	23	456	2230a	110
		Dryland	0	182	180	362	1900a	94
1983	Mead	Full	239	208	91	538	4080a†	100
		Flower	236	208	97	541	4090a	100
		Pod	246	208	79	533	4050a	99
		Dryland	0	208	178	386	2290b	56

*Means within location followed by the same letter are not significantly different (= 0.05).
†Means within location and year followed by the same letter are not significantly different (= 0.05).
‡Means within location and year followed by the same letter are not significantly different (= 0.10).

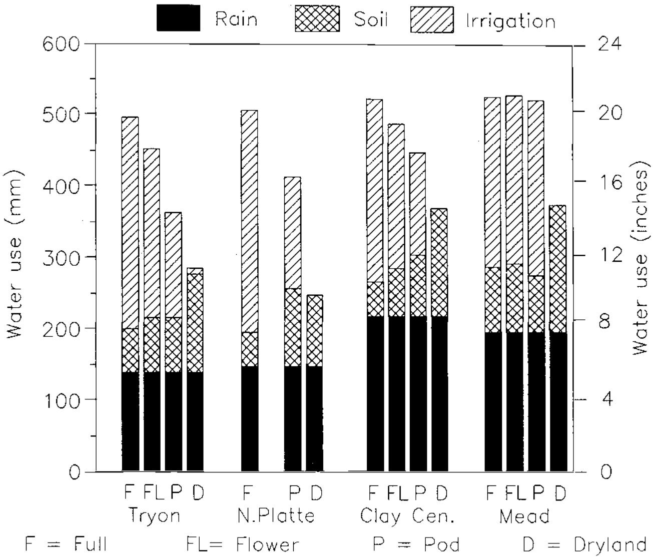

Fig. 2—Sources of water use (evapotranspiration) for soybeans during the growing season.

all locations and all years. The overall regression and regressions by locations were:

Overall	$Y = -66.0 + 0.58\,X - 0.00050\,X^2$	$R^2 = 0.75$
Mead	$Y = -119.3 + 0.81\,X - 0.00074\,X^2$	$R^2 = 0.35$
Clay Center	$Y = -205.1 + 1.20\,X - 0.00120\,X^2$	$R^2 = 0.58$
Tryon	$Y = -162.6 + 1.07\,X - 0.0011\,X^2$	$R^2 = 0.93$
North Platte	$Y = -27.9 + 0.35\,X - 0.0002\,X^2$	$R^2 = 0.84$

where

Y = Relative yield, %

X = Water use, mm

R^2 = Coefficient of determination.

The data from Mead and Clay Center did not fit a quadratic function as well as the data from Tryon and North Platte. The variation from the two eastern locations may indicate the interaction of yield with the timing of rainfall and irrigation. Rainfall patterns in the east may have influenced yields more positively some years than others, especially in the dryland and pod treatments.

SUMMARY, CONCLUSIONS AND RECOMMENDATION

It is convenient to base irrigation timing decisions on the crop's stage of growth. Stage of growth irrigation may work for a crop like indeterminate soybeans that seems to respond well to water during later growth stages, including pod formation and pod development. However, the results from this study underscore that stage of growth irrigation scheduling is also dependent on the capability of the irrigation system to supply sufficient water a crop. Precipitation during the growing season, stored soil moisture prior to the growing season, and irrigation system capacity combine to furnish water to the crop. As demonstrated in this study from eastern to west-central Nebraska, indeterminate soybeans responded to delayed watering at all locations. However, as rainfall and stored soil moisture decreased from east to west, the delayed irrigation caused yield compared with full-season irrigation.

Since soybeans responded well to irrigation at particular growth stages, irrigators could focus their management on those stages. However, the recommended management strategies must consider the total capacity to deliver water to the crop, which includes irrigation system capacity, soil water holding capacity and rainfall.

Based on this study we have made the following recommendations to Nebraska irrigators:

1. Growth stage irrigation scheduling for soybeans should be limited to deep, medium to fine textured soils in central and eastern Nebraska. If the soil moisture is at field capacity at planting, irrigation can be delayed until flowering.
2. If one or more of the following exists, irrigation should be scheduled according to soil moisture depletion and depletions should not exceed 50%:
   (a) soil texture is sandy loam or coarser
   (b) the root zone depth is impeded (shallow)
   (c) irrigation system capacity is 38 mm (1.5 in.) per week or less
   (d) west-central Nebraska location.

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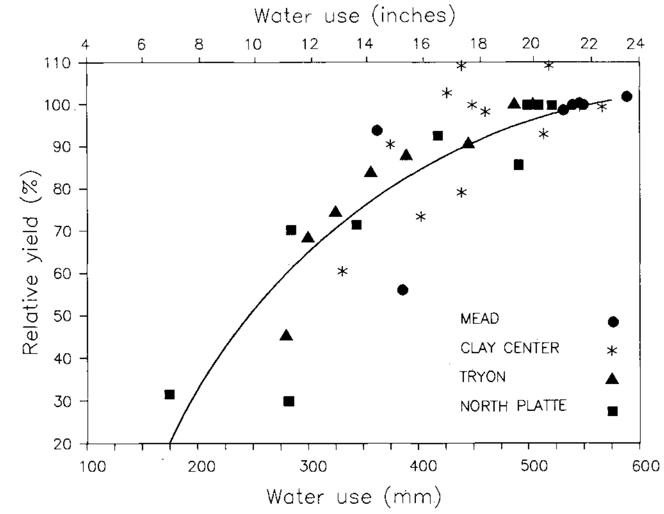

Fig. 4—Relative yield for soybeans with respect to full season irrigation as a function of water use.

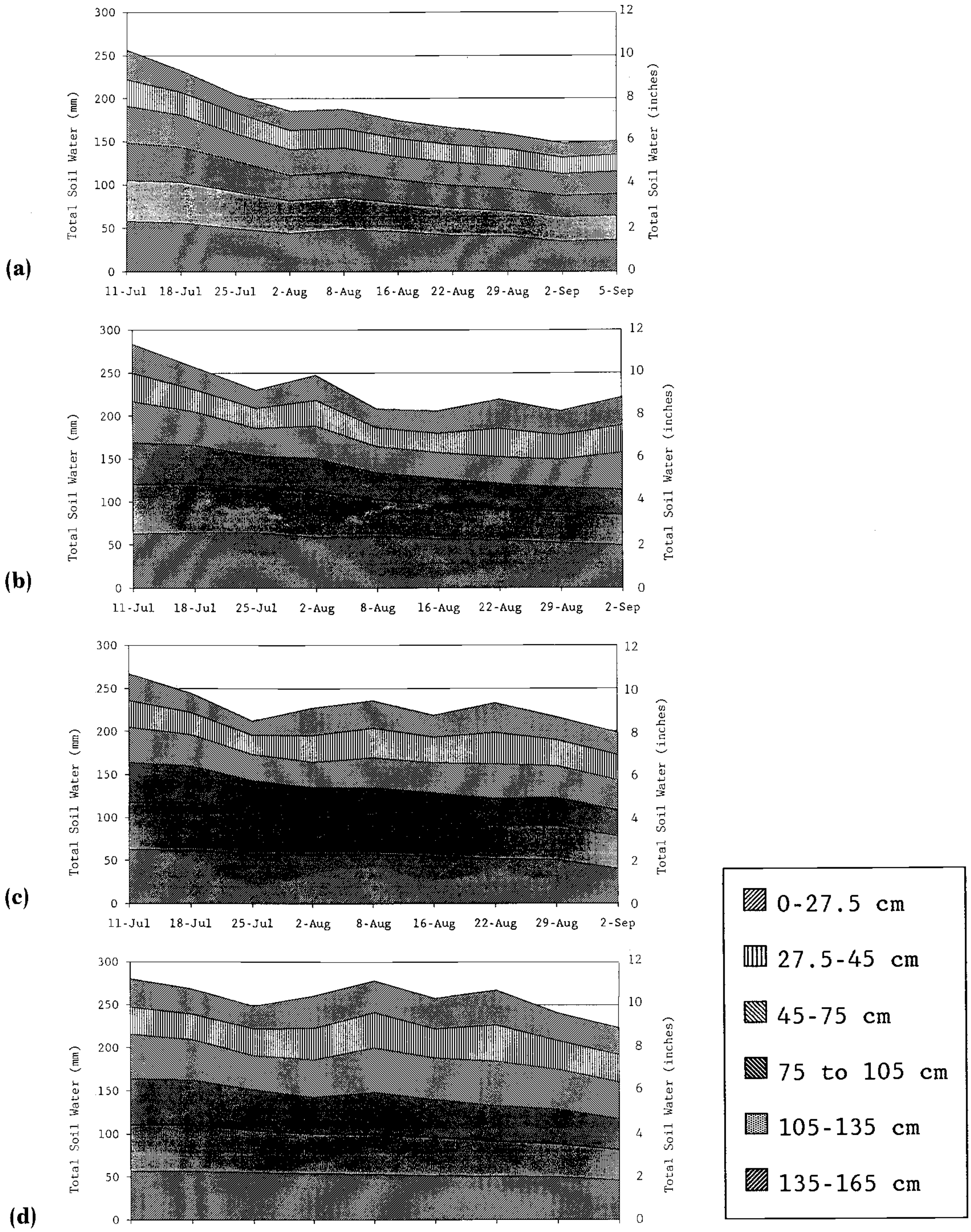

Fig. 3—Total soil water by depth for soybeans at Tryon site. (a) Dryland Treatment (b) Pod Elongation Treatment (c) Flower Treatment (d) Full Season Treatment.