Weeds in Cotton: Their Biology, Ecology, and Control

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Abstract

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This publication brings together over 25 years of accumulated knowledge about the biology and ecology of weeds in cotton that growers can put to practical use in weed management. The weeds studied include three perennials (bermudagrass, johnsongrass, and yellow nutsedge) and four annuals (ivyleaf morningglory, barnyardgrass, black nightshade, and Palmer amaranth). Although applicable to some extent to all cotton-growing states, this knowledge was developed under the irrigated growing conditions of the West (California, Arizona, and New Mexico) and may be most useful in weed management there.

The publication addresses four major areas of weed biology and control: (1) plant characteristics that contribute to weed success, (2) weed reproduction, (3) the influence of weed-competition and weed-free periods on yields of cotton and on weed reproduction, and (4) the use of herbicides. The authors present information emphasizing how extensively weeds can damage cotton and suggesting how much weed control cotton can provide for itself.

Keywords: barnyardgrass, bermudagrass, cotton, farm management, herbicides, johnsongrass, lint, morningglory, nightshade, nutsedge, Palmer amaranth, weed competition, weed control, weed reproduction, weeds.

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Introduction

Studies have been conducted over the last 25 years at the U.S. Department of Agriculture Cotton Research Station, Shafter, CA, to develop biological and ecological knowledge about some important weeds in cotton. The goal in writing this bulletin is to compile the findings of those studies so they may be put to practical use in managing weeds in cotton. Although applicable to some extent to all cotton-growing States, this knowledge was developed under irrigated growing conditions of the West and may be most useful there.

The seven weeds chosen for study are bermudagrass [*Cynodon dactylon* (L.) Pers.]; johnsongrass [*Sorghum halepense* (L.) Pers.]; nutsedge (*Cyperus esculentus* L.); barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]; Palmer amaranth, also called pigweed (*Amaranthus palmeri* S. Wats.); nightshade (*Solanum nigrum* L.); and morningglory [*Ipomoea hederacea* (L.) Jacq.]. These weeds are among the 10 most troublesome in California alone and the three Western cotton-growing States comprising California, Arizona, and New Mexico (table 1). Johnsongrass, yellow nutsedge, and bermudagrass (the perennials in the study) ranked as the top three most troublesome weeds in 1975 and among the top 10 in 1989, when averaged over all 15 cotton-producing States. In terms of acres infested or cotton losses or both, barnyardgrass, pigweed, nightshade, and annual morningglory (the four annual weeds studied) also ranked within the top 10 when averaged over all 15 cotton-producing States. Weeds other than those mentioned in table 1 are troublesome in one or more cotton-producing States, and they are reported in the 1989 survey by Patterson (32).

Changes in ranking from 1975 to 1989 may reflect the more recent successes of control practices. For example, in cotton yield losses, johnsongrass and bermudagrass appeared to be less troublesome in 1989 than in 1975, perhaps reflecting the recent successes of selective grass herbicides. On the other hand, where control practices worked poorly, the ranking has remained the same, as for nutsedge, or increased considerably, as for nightshades and annual morningglories.

This bulletin addresses three major areas of weed biology: (1) plant characteristics that contribute to weed success, (2) reproduction of weeds, and (3) the influence of weed-competition and weed-free periods on cotton yields and weed reproduction. A fourth section discusses the general use of herbicides to control weeds in cotton.

Plant Characteristics Contributing To Weed Success

Researchers have attempted for some time to identify characteristics that best describe the competitive success of plants (5–7, 25, 30, 33–35). Some characteristics helpful in successful competition include germination at cool temperatures, high relative growth rates, and tall stature. Charted in tables 2 and 4 and figures 1–5, these three important characteristics contributed to the competitive success of the weeds in our studies.

Weed Emergence

When planted at monthly intervals from March 1 to October 1, all seven of the weeds were found to be capable of emerging from early to mid-March (table 2). Average monthly air and soil temperatures recorded for those months are shown in table 3. Discussion here focuses on soil temperatures, since they probably influenced seed germination more than air temperatures. In these studies many weeds were capable of emerging when soil temperatures reached 16 °C, or 60 °F, meaning that weeds can emerge with the earliest planted cotton. Of course, the earlier that weeds emerge the earlier they compete for resources, such as light, water, and nutrients.

The soil temperatures required in the field for weed germination are similar to lower thresholds observed in growth chamber studies. Generally, with the exception of morningglory, at least 15 percent of seeds in the growth chamber produced seedlings at 16/10 °C (60/50 °F) day/ night temperatures (13, 15, 18, 21, 22, 36). This compared to 1 percent or less for annual morningglory (36). The poor germination of morningglory from a March planting in the field indicates this weed may be the least cold tolerant of those studied. Kempen (25) also found that morningglory emerges later than the other weeds in his studies. Although he suggested that morningglory begins emerging in early May, we have observed relatively good emergence in early April in two separate studies (see table 2) (17, 36).

Relative Growth Rates of Weeds and Cotton

Although not grown under strictly comparable environmental conditions (the relative growth rates [RGR's] of weeds and cotton were determined in different years), the growth rates of weeds and cotton shown in figures 1–5 offer strong evidence that weeds grow faster than cotton during the first 9 weeks (see figs. 1 and 2 in particular). When growth

rates were determined for 9- to 12-week-old plants, weeds appeared to lose this growth advantage (fig. 3).

The relative growth rate of yellow nutsedge was determined for only a 12-week growing period (fig. 5), and cotton appeared to exceed this. However, in a recent study, Holt and Orcutt (7) reported higher RGR's for both yellow nutsedge and johnsongrass than for cotton. The weeds maintained this growth advantage for 5 to 7 weeks, after which the RGR for cotton increased to equal that of johnsongrass and surpassed that of yellow nutsedge. The RGR of yellow nutsedge may also have been greater than that of cotton the first few weeks in our study, but the relatively long 12-week growing period masked any early advantage.

Others have reported the RGR of plants (5), but only Patterson et al. (30) and Potter and Jones (33) compared the RGR of weeds to that of cotton. Patterson et al. found that three weeds—pigweed, sesbania, and velvetleaf—had higher RGR's than cotton at most growth irradiance levels. Potter and Jones (33) reported that johnsongrass and pigweed had higher RGR's than cotton in three temperature regimes. In a study of the competitive relationships among four annual weeds, Roush and Radosevich (35) reported that RGR's did not vary among the four. In fact, RGR was found to be poorly correlated with the aggressiveness of the four species.

Although RGR might not always be helpful in predicting the competitive success of plants, the high RGR's of the weeds in our study, as compared to that of cotton, appear to explain why these weeds gain a competitive advantage. The differences in RGR's between weeds and cotton become less apparent after 9 weeks (see figs. 3–5), but by that time weeds may have already gained an advantage.

Relative Heights of Weeds and Cotton

As indicated by Radosevich and Holt (34), growth advantages, once established, appear to have serious consequences for season-long competition. One obvious growth advantage is height, shown in table 4. It is known that aboveground competition is primarily a function of canopy development (34). In our studies, ivyleaf morningglory, barnyardgrass, johnsongrass, and Palmer amaranth grew taller than cotton within 3 to 6 weeks and maintained this height advantage for the season. As we will discuss later, these weeds, when present in large numbers, were extremely injurious to cotton.

Another weed, black nightshade, was intermediate in height (table 4), being shorter than the four tallest weeds, but taller than the two shortest weeds of the study—bermudagrass and yellow nutsedge. Nightshade did not reach the height of cotton until about 9 weeks after planting, but then was as tall or taller for the remainder of the season. Like the tallest weeds, nightshade was extremely injurious to cotton.

Although relatively short weeds such as bermudagrass and yellow nutsedge reduce yields of cotton, they are less competitive for aboveground resources than nightshade and the tall weeds. If losses from short weeds can be avoided during periods of high weed pressure soon after crop establishment, then cotton canopies will soon provide sufficient shade to minimize crop losses. If short weeds are present at the time of or soon after crop establishment, their populations need to be reduced to a minimum to prevent the crop seedlings from becoming moisture stressed.

Relative Numbers of Weeds and Cotton

When present in small numbers, even aggressive weeds will do little damage to crops (40). However, when the number of weeds greatly exceeds the number of crop plants, the weeds may soon gain an advantage by depleting essential resources such as light, nutrients, or water.

In our studies at Shafter, the density of cotton plants was commonly 7–10 plants/m of row. The density of barnyardgrass, bermudagrass, nightshade, johnsongrass, and yellow nutsedge was sometimes several fold greater than that of cotton (refer to table 9 on page 18). Since our studies were conducted in weed nurseries (areas planted to obtain uniform weed populations), populations of weeds probably exceeded those normally found in grower fields. Nevertheless, weeds can reach such high populations when neglected, and if they do, can severely reduce yields of cotton.

Reproduction of Weeds

Time Required To Reproduce

Since the number of weeds may determine the degree of damage to crops (40), weed populations should be maintained at low numbers. This is accomplished by preventing weeds from reproducing. Knowing when reproduction begins after emergence can help improve the timing of weed control measures. As shown in figures 6–11, the earliest plantings of weeds (on March 1) began flowering after 9–15

weeks and producing seed after 12–15 weeks. This compared with 9–12 weeks for April plantings. Except for bermudagrass, most weeds planted May 1 produced seed within 9 weeks. The weeks required for seed production continued to decrease for some weeds, reaching as few as 6 weeks for August and September plantings of Palmer amaranth and ivyleaf morningglory and July and August plantings of barnyardgrass.

In general, weeds tended to flower and produce seed quicker when days began to shorten in July and August. However, barnyardgrass and johnsongrass required 12 weeks to produce seed in September after producing seed in 6–9 weeks in July and August. Although not proven, the longer time September plantings needed to produce seed probably reflected the slower plant growth in that month, compared to July and August. In other words, plants probably had to reach a certain size, before flowering began, regardless of the length of days. This also seemed to be the case with early spring plantings, since April plantings produced seed in fewer weeks than March plantings, and May plantings in fewer weeks than April plantings. March plantings of yellow nutsedge did not begin tuber production until 12 weeks, whereas April–July and September plantings produced tubers within 8 weeks (fig. 12). August plantings produced some tubers as early as 4 weeks. Daylength and plant size seemed to determine when yellow nutsedge began vegetative reproduction.

Whereas March–May plantings of bermudagrass produced rhizomes in 8–12 weeks and seed in 12–15 weeks, June–September plantings produced both rhizomes and seed within 8 weeks. All johnsongrass plantings produced rhizomes in fewer weeks (6–9) than they produced seed (9–15).

As shown in figures 6–12, the time required for weeds to reproduce depends somewhat on when they emerge. In general, the weeds that emerge in early March and April will all begin producing seed within the same timeframe. For example, barnyardgrass, morningglory, and nightshade planted in early March and April produced seed in 12 and 9 weeks, respectively; seed from these plantings could be expected from May 24 to June 3. Amaranth, bermudagrass, and johnsongrass planted in March produced seed within 15 weeks, as compared to 12 weeks for April plantings; seed from these plantings could be expected from June 14 to June 24. To prevent seed production in all of these weeds, it is essential to remove by early June weeds that commonly emerge with cotton.

Another time that weeds commonly emerge is late May to early June, or 1 to 2 weeks after the first postemergence irrigation of cotton in mid- to late May. In our studies all of the weeds planted on June 1 but nutsedge produced seed within 8 to 9 weeks (figs. 6–11), meaning that seed could be produced from July 27 through August 3. Therefore, to prevent seed production of weeds emerging in early June, control practices should begin no later than late July.

All seven of the weeds planted in September in the absence of crops were capable of reproducing by seed, rhizomes, tubers, or a combination before killing frosts occurred in late November. However, in the presence of crops, competition normally prevents or reduces reproduction of late emerging weeds; this will be discussed later in more detail.

As mentioned previously, rhizome production of some plantings of bermudagrass and johnsongrass may occur 3–4 weeks before seed production. Accordingly, control practices to prevent rhizomes should begin 3–4 weeks earlier than those needed to prevent seed production. In general, control practices to prevent tuber production of yellow nutsedge that emerges from April 1 to September 1 should begin within 8 weeks. In the case of August 1 plantings of nutsedge, which produced some tubers within 4 weeks, control should begin by early September.

Accumulative Degree Days Required To Reproduce

Knowledge about the accumulative degree days (ADD's) has been helpful in producing some crops and managing certain pests in crops (1, 2, 4, 26–28, 39). For example, using a lower threshold of 50 °F and an upper threshold of 86 °F, the number of heat units required for corn to silk remained relatively constant for different planting dates (4). This was in contrast to the required number of calendar days, which varied widely for planting dates. Knowing the number of accumulative heat units (degree days) has also been helpful in managing cotton (26, 27, 39).

Zalom et al. (39) reported that the amount of heat required to complete any given organism's development does not vary. They explained that the combination of temperature above the lower threshold and of time is always the same, regardless of constant or fluctuating temperatures. As one example, they cited the development of laboratory-reared cotton bollworms from newly hatched larvae to newly emerged adults. As temperature increased, the time taken to

develop decreased, but the heat accumulation required to complete development remained approximately the same.

Our main objective in calculating ADD was to determine if the number of heat units required for reproduction would remain constant for weeds emerging at monthly intervals from March to September (figs. 6–12, tables 5 and 6). If the number of heat units remained constant, then ADD should be a good predictor of reproduction in weeds emerging through-out the growing season. Using a lower threshold of 60 °F and no upper threshold, we compared the number of heat units needed for reproduction over all the different planting dates and found the number of units probably varied as much as time did in predicting reproduction. In addition, while earlier plantings (March and April) required more time to reproduce than later ones, the converse was generally true for heat units. In fact, the general equation explaining the type of curve was polynomial rather than the equation of a straight line (table 6, figs. 13–15). As shown in figures 6–12, the curves are somewhat bell shaped, with May–July or August plantings generally requiring more heat units to reproduce than earlier or later plantings.

Kerby and Goodell (26) plotted the distribution of heat units over a 30-year period in the San Joaquin Valley of California and found a bell-shaped curve for monthly distribution from April through October. Whereas only 40 percent of the heat units accumulated during the 4 months of April, May, September, and October, 60 percent accumulated in the 3 months from June through August. The similarity of Kerby and Goodell's curve plotting the distribution of heat units and our curves representing the heat units required for weed reproduction may indicate the need for some upper threshold in calculating heat units. In fact, others found that using upper thresholds of 80–86 °F were helpful in improving the accuracy of degree days in predicting plant development (2, 4, 28). We found, however, that varying lower and upper thresholds did not reduce the variability in the number of heat units required for the different plantings (figs. 13–15).

As shown in table 5, the range in the number of heat units needed for flowering, seed, rhizome, or tuber production was rather great for all seven weeds. This being the case, one might conclude, then, that average degree days would be the better predictor of weed reproduction. An average value, however, would overestimate the number of heat units needed in early plantings and underestimate them in some later plantings. Consider, for example, that the average degree days required for seed production ranged from a low of 713 in barnyardgrass to a high of 871 in bermudagrass; compare

these to the 509 and 707 needed for rhizome production in johnsongrass and bermudagrass, respectively.

Since the number of heat units needed for weed reproduc-tion is either unknown or seldom reported, there is little opportunity to compare the ADD we calculated with those of others. Orwick et al. (29) determined that anthesis of foxtail begins at approximately 800 ADD, which is similar to the 700 to 800 heat units we found for seed production (table 5). Holt and Orcutt (8) reported that the ADD required for reproduction of johnsongrass, purple nutsedge, and yellow nutsedge varied with years; initial development of belowground propagules occurred between 564 and 936 degree days in 1984 and 507 and 611 degree days in 1985. Here again, our findings of 500 to 700 ADD for propagule production in johnsongrass and yellow nutsedge compared favorably. What appears most obvious at the present time is the need for additional studies to explore the usefulness of heat units in predicting the maturation of weeds. Until such studies are conducted, the data presented in figures 6–12 and tables 5 and 6 offer a beginning to our understanding of this matter.

We did vary the lower and upper thresholds in calculating the number of heat units required for reproduction of johnsongrass (table 6). Since there were considerable data for all weeds, johnsongrass was selected to represent the other six. Based on the emergence of weeds (table 2) and research by Wiese and Binning (38), 55 °F may be more appropriate than 60 °F as the lower threshold at which some weed species begin germinating. Wiese and Binning reported that four weeds, including barnyardgrass and redroot pigweed, began germinating at 54 °F or below. Orwick et al. (29) used a lower threshold of only 50 °F in calculating heat units for foxtail.

Using a lower threshold of 55 °F, instead of 60 °F, did increase the number of heat units required for reproduction for all planting dates (table 6). This lower threshold of 55 °F added proportionally more heat units to the early and late plantings than to the intermediate plantings, regardless of whether an upper threshold of 80 or 85 °F was used. Nevertheless, as shown in table 6 and figures 13–15, decreasing the lower and upper thresholds did not lessen variability in the number of heat units required for the different planting dates. Figures 13–15 indicate that the general equation explaining the type of curve was polyno-mial (bell shaped) rather than the equation of a straight line. This variability persisted when the lower threshold remained at 60 °F and an upper threshold of 80 or 90 °F was used.

The number of heat units changed little when an upper threshold of 90 °F was used.

Number of Seeds, Rhizomes, or Tubers Produced

Weeds produce numerous seeds, rhizomes, tubers, or combinations of these (table 7). Although the numbers of seeds per plant may not seem to be extremely high, populations of amaranth seed can easily reach 500 million/ha with a population of only 1 weed/m of row, and the number could be much greater if the plant was permitted to grow for longer than 12 weeks. Based on estimates of only 1 weed/m of row, barnyardgrass, bermudagrass, johnsongrass, morningglory, and nightshade could easily produce from 50 to 300 million seeds/ha yearly. We believe the numbers of seeds estimated in table 7 are very conservative in that black nightshade seeds have reached 770 million/ha in studies conducted at Shafter, CA (19). In that study, amaranth seeds averaged 380 million/ha. In addition to seeds, bermudagrass, johnsongrass, and yellow nutsedge produced numerous rhizomes or tubers or both within 12–30 weeks (table 7). Even though these numbers are few compared to the numbers of seeds, permitting weeds to become established as perennials is highly objectionable.

Another reason to prevent weeds from reproducing is that once they do several years of control are required to rid the field of seed (19), since only a small percentage of seeds produce seedlings in any 1 year. In a nightshade study at Shafter, CA, (19) about 5 percent of the seed in irrigated plots produced seedlings in a single year, compared to only 1 percent for nonirrigated plots. Even after 5 years of control, 20 to 40 percent of starting numbers of black nightshade seed were still present in the soil.

In the same study, however, only about 3 to 5 percent of the starting populations of Palmer amaranth were present after 5 years, making it clear that the depletion of seed in soil is more difficult with some weed species than others. Although the longevity of weed seed in soil is not fully understood, sufficient knowledge exists to indicate that it is not wise to permit weeds to produce seeds. It stands to reason that less intense management practices (those not usually successful under heavy weed pressures) could successfully control weeds if the number of weed seeds were reduced in the soil.

Weed-free and Weed-competition Periods

Effects on Yields of Cotton

Although weeds are objectionable for many reasons, the threat of their damaging crops is of greatest concern. Not only can weeds reduce the yields of cotton, but grasses can also reduce the grades of cotton by contaminating the lint with leaf residues (20, 23, 24).

Measured cotton losses resulting from weed competition are shown in table 8. Losses resulting from competition or weed-free periods are presented to provide guidelines for improving our ability to protect yields of cotton. The populations of weeds shown in table 9 are probably greater than those commonly found in cotton fields, because, as mentioned, the studies were conducted in weed nurseries where populations were unusually abundant and uniform. Although extremely heavy populations of weeds would normally lead to overestimation of cotton losses, the use of moderate and high populations in competition studies probably yields results useful in predicting the amount of weed control needed to protect cotton yields. These results do not address losses from harvest inefficiency and reductions in lint quality because of weed trash.

As previously mentioned, the tallest weeds of the study—barnyardgrass, ivyleaf morningglory, and johnsongrass—did the greatest damage (table 8). When these weeds competed for 25 weeks (all season), cotton yield reductions ranged from 90 to 100 percent. Although insufficient Palmer amaranth was present to measure its role in cotton-yield reductions, observations of this tall and aggressive plant (18) indicate that it could be as injurious to cotton as the other three weeds. Black nightshade, which was usually shorter than the four tallest weeds but taller than bermudagrass and yellow nutsedge, reduced yields of cotton by an average of 65 percent. The shortest weeds, bermudagrass and yellow nutsedge, when permitted to compete all season, reduced yields 26 and 34 percent, respectively. Although these reductions in yield would be highly objectionable, these shortest weeds, even when present in large numbers (table 9), appear to be less damaging to cotton than the tallest weeds. One point of particular interest is the highly aggressive nature of ivyleaf morningglory. When permitted to compete all season, only 1 plant/m of row was able to reduce cotton yields by 100 percent. The twining nature of this weed enables it to move

from cotton plant to cotton plant as it seeks light until it has entwined a large crop area (17). In addition, the morningglory foliage may become so heavy that it lodges the cotton.

Although we used only four weeds to observe the influence of relatively short periods of competition (0–12 weeks), we saw that as little as 3 or 4 weeks usually had a noticeable influence on yields, and 8 weeks reduced yields 10–24 percent (table 8). These results indicate that early removal of weeds, before 6–8 weeks, is necessary to protect cotton yields.

It seems logical that we will achieve the most economical control of weeds in cotton when we supply only that control which cotton cannot supply by itself. So, while studies of competition periods promote understanding of how much weeds cost to control and studies of weed-free periods of how much weed control is needed to protect cotton, perhaps such studies can answer the most important question: How much weed control can cotton provide for itself? As shown in table 8, a weed-free period of only 3–4 weeks resulted in relatively large cotton losses (5–100 percent). But doubling that time to 6–8 weeks greatly reduced losses. In the case of barnyardgrass and johnsongrass, a weed-free period of 9 weeks was required to protect cotton yields, compared with only 6 weeks for black nightshade.

The response of Palmer amaranth was very similar to that of black nightshade. Any amaranth plants that emerged following a hoeing 3 weeks after planting were covered with soil and aggressively cultivated until layby of cotton, that is, the discontinuation of cultivation. Late-emerging weeds did not exceed 25 cm in height and provided little competition (table 8). Morningglory required 12 weeks of control to prevent yield losses; bermudagrass, only 8 weeks; and yellow nutsedge, 4 weeks.

It seems apparent that the length of the required weed-free period depends on the density of the weeds as well as on the species. For example, high weed density could require a longer weed-free period than low density. If that is the case, then the heavy weed infestations used in most of our studies would require longer periods of weed control than would light to moderate infestations. However, we reported conservative estimates of control, meaning that the predicted periods of control should be sufficiently long to manage even the most aggressive weeds. Weed-free periods of about 9 weeks should be sufficient to protect cotton yields from the most aggressive weeds, such as

morningglory, and 6 weeks should be sufficient, when accompanied by cultivation, for the less aggressive bermudagrass, nightshade, and yellow nutsedge.

Effects on Reproduction of Weeds

As discussed, all the weeds studied are capable of producing seed or underground propagules in the absence of crops when planted as late as September 1. These same weeds, however, produce very few seeds or propagules when they emerge in cotton after July 1 (table 10). The success of these short weed-free periods in preventing or suppressing weed reproduction is largely due to the ability of cotton to shade small emerging weeds (17, 19, 20). For example, cotton planted in early April had by May 22 intercepted 85 percent of the photosynthetically active radiation (PAR) in the drill row (table 11). This increased to 94 percent on June 5. At that time, cotton canopies were intercepting an average of 54 percent of PAR on the shoulder of planting beds, and by June 19, the interception of PAR increased to 94 percent. Interception of PAR in furrows on July 3 and 17 was 58 and 98 percent, respectively.

Although the interception of light by cotton can vary, depending on the planting date or rapidity of growth, the data presented in table 11 are probably typical for cotton grown in 40-inch spaced rows. Since the layby of cotton commonly occurs from late June to early July, it is important that canopies intercept most PAR, even in furrows, soon after that. In the absence of shading or other limiting resources, such as skimpy stands of cotton, weed-free periods would be needed which exceed those presented in table 10.

Of the weeds studied, morningglory required the longest weed-free period to prevent seed production. Some of these plants emerged as late as early July and produced seed by cotton harvest in October (17). The weed-free requirements for the other weeds did not usually exceed 8–9 weeks, including those which produced underground propagules (table 10). To prevent production of johnsongrass rhizomes, the weed-free period may slightly exceed 9 weeks.

It is also important to determine how long weeds can compete with cotton without producing seed or underground propagules. Barnyardgrass and johnsongrass, when permitted to compete for 3, 6, 9, and 12 weeks, produced seed or rhizomes or both within 9 weeks. To prevent reproduction, then, these weeds cannot be allowed to compete longer than 6 weeks (table 10). Although they

were not included in these studies, morningglory and black nightshade, when planted at monthly intervals in the absence of crops, produced seed within 9 weeks (15, 36). They should be controlled within 6 weeks. Palmer amaranth was not included in these studies either, but April and May plantings produced seed within 9 to 12 weeks (18). Control within 6 weeks should prevent seed production. When permitted to compete with cotton for 4, 6, 8, and 12 weeks, yellow nutsedge produced tubers within 6 weeks (10), compared with bermudagrass, which produced seed and rhizomes in 12 weeks (23). The maximum competition period recommended is 4 weeks for nutsedge and 8 for bermudagrass. Although these periods may be shorter than needed, adhering to the times suggested in table 10 should prevent production of either seed or underground propagules.

The high losses in yield resulting from season-long competition emphasize that cotton is a poor competitor with weeds that emerge with the crop. Cotton did, however, become a successful competitor within 6 to 9 weeks after planting (tables 8 and 10). Success from relatively short weed-free periods is due to increases in interception of light by cotton canopies.

Although our knowledge concerning the sensitivity of weeds to shading is incomplete, many studies indicate that shading by crop canopies is an important aspect of weed management (31). Of particular interest has been successful crop competition in reducing tubers of yellow nutsedge over time (12, 14). Handweeding of yellow nutsedge in cotton for only 6 weeks reduced tuber populations 92 percent after 2 years (14). Also applications of the herbicide MSMA 3 and 6 weeks after cotton planting have reduced tuber populations of yellow nutsedge by 91 percent in 3 years (12). In both cases, the relatively short weed-free period of 6 weeks, when combined with shading by the cotton plant, have been successful in reducing tuber populations. Also successful in reducing these tuber populations is rotating the cotton with competitive crops that grow quickly (11). Examples include alfalfa, barley, corn, potatoes, soybeans, and milo.

Herbicide Use in Cotton

Results of a recent survey of herbicides used in cotton are presented in table 12. This information is intended to inform the reader which herbicides are most commonly used and when treatments are commonly applied. Herbicides are most frequently applied as preplant soil-incorporated treatments, preemergence treatments, and postemergence treatments. They are also applied, but less frequently, as preplant foliar, spot, and layby treatments.

Preemergence treatments are seldom used in the arid Western region comprising Arizona, California, and New Mexico, because of insufficient rain to incorporate the herbicides into the soil. In addition, a larger percentage of acreage is treated with postemergence herbicides in the East than the West. Although there are some regional differences in the use of herbicides, approximately the same number of acres receive preplant foliar, preplant soil-incorporated, spot, and layby treatments.

The greater use of herbicides in the East is due to its greater rainfall, which increases weed problems. When rain occurs during cotton planting in California, black nightshade populations increase greatly, and early preplant treatments of appropriate herbicides are extremely helpful in controlling weeds in the drill row that escape cultivation (19). Since rainfall and irrigation have such a profound influence on weed problems, farmers in the West should take advantage of arid conditions to aid weed management.

Whenever used, herbicides supplement mechanical cultivation in controlling weeds in cotton. It is generally believed that few, if any, herbicides can by themselves control weeds all season. Nevertheless, many herbicides do provide adequate control until the cotton is well established and able to shade late-emerging weeds. Since herbicides and shade in combination provide season-long weed control, good stands and crop vigor both become essential to overall management.

Because there are several times that several herbicides can be applied over a season, farmers should consult a good source of information about the most appropriate treatment for a particular weed problem.

If weed control is started in time and maintained as suggested, then weeds should not become a threat to cotton yields or have the opportunity to produce seed or propagules or both. With continued control for several years, populations of weeds will diminish.

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Table 1. Most troublesome weeds in cotton, ranked according to 1975 and 1989 surveys

	California ranking (1975)	California ranking (1989)		Western States* ranking (1989)		All cotton States† ranking (1989)	
		Acres infested	Cotton losses	Acres infested	Cotton losses	Acres infested	Cotton losses
Johnsongrass	1	7	6	8	5	2	5
Yellow or purple nutsedge	2	2	2	2	3	10	3
Bermudagrass	3	6	7	5	8	17	9
Barnyardgrass	4	5	5	6	6	8	15
Pigweeds	5	3	3	3	4	1	4
Nightshades	6	1	1	1	2	3	6
Field bindweed	7	8	8	9	12	29	22
Lambsquarter	8	9	9	11	13	26	22
Annual morningglory	9	4	4	4	1	4	1
Cocklebur	10	10	10	12	11	6	2
Groundcherries	—	11	11	7	7	16	16

Note: The survey results were previously reported (9,32).

*Western States include Arizona, California, and New Mexico.

†All cotton States include, in addition to the three Western States, Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas.

Table 2. Influence of planting date on the emergence of weeds

Planting date of weeds	Percentage of seeds producing seedlings 2 to 3 weeks after planting						
	Annual morning-glory	Barnyard-grass	Bermuda-grass*	Black nightshade	Johnson-grass	Palmer amaranth	Yellow nutsedge*
March 1	<1	85	—	17	24	14	—
April 1	40	89	—	17	25	31	—
May 1	81	93	—	16	40	56	—
June 1	73	93	—	20	73	52	—
July 1	83	91	—	17	67	67	—
August 1	90	87	—	5	91	58	—
September 1	85	88	—	22	79	54	—
October 1	68	88	—	12	60	48	—

NOTE: Tabular data for each weed are from the following sources: morningglory (36), barnyardgrass (22), bermudagrass (21), nightshade (15), johnsongrass (13), Palmer amaranth (18), and yellow nutsedge (37).

*Information is not available on emergence of bermudagrass and yellow nutsedge from seed. Culms from bermudagrass plugs were observed 2 weeks after all plantings from March 1 to September 1, and 14 percent of seeds germinated at an average air temperature of 12.5 °C in a growth chamber. About 10 percent of yellow nutsedge tubers planted March 1 produced shoots within 4 weeks. Sprouting increased with later plantings. The authors have consistently observed emerged yellow nutsedge shoots in late February and early March in Shafter, CA.

Table 3. Average monthly air and soil temperatures recorded at Shafter, CA

Month	1976–77	1979–80	1983–84	1986–87	1990
Air temperatures (°C)					
March	10.8 °C	12.7 °C	12.8 °C	13.6 °C	14.0 °C
April	15.8	16.0	13.8	17.1	18.1
May	19.0	20.1	20.8	20.8	18.9
June	24.2	23.1	23.6	24.4	22.6
July	26.1	26.0	26.1	24.0	26.2
August	24.4	24.2	25.8	25.5	24.6
September	22.6	22.8	24.1	21.0	22.2
October	18.4	18.8	16.5	17.7	18.4
Soil temperatures (°C at 5 cm deep)*					
March	15.5	16.8	18.2	17.1	—
April	20.2	19.9	19.6	20.9	—
May	25.0	25.6	25.9	26.2	—
June	31.2	29.8	30.0	29.9	—
July	36.5	32.9	31.5	32.7	—
August	35.2	32.4	31.9	32.8	—
September	30.6	29.6	28.1	28.3	—
October	22.8	21.5	23.6	22.6	—

NOTE: Air and soil temperatures were previously reported (13, 15, 18, 21).

*Soil temperatures were not recorded in 1990.

Table 4. Heights of cotton and weeds at 3-week intervals after planting

Plant	Height (in cm)				
	3 wks	6 wks	9 wks	12 wks	15 wks
Cotton	7	21	49	82	114
Annual morningglory	9	63	174	220	—
Barnyardgrass	16	52	115	138	187
Bermudagrass	7	10	28	47	75
Black nightshade	2	11	45	75	127
Johnsongrass	20	49	130	170	248
Palmer amaranth	—	27	82	133	185
Yellow nutsedge	18	25	33	44	—

NOTE: Heights of cotton were determined from four plantings in 1990 (March 22, April 5, April 17, and May 10). Heights of weeds were previously reported (10, 15, 17, 18, 20, 23, 24).

Table 5. Accumulative degree days required for reproduction of weeds

Weed and type of reproduction	Range of degree days	Average degree days
Barnyardgrass		
Flowering	481–849	663
Seed	481–996	713
Black nightshade		
Flowering	170–1085	655
Seed	370–1116	774
Berries	370–1116	774
Bermudagrass		
Flowering	514–942	760
Seed	584–1165	871
Rhizomes	472–942	707
Ivyleaf morningglory		
Flowering	233–843	539
Seed capsules	370–1116	723
Seed	370–1116	723
Johnsongrass		
Flowering	466–1117	807
Seed	608–1132	847
Rhizomes	215–780	509
Palmer amaranth		
Flowering	285–671	448
Seed	588–1190	819
Yellow nutsedge		
Tubers	299–956	592

Note: This table summarizes accumulative degree day information presented in figs. 6–12.

Table 6. Accumulative degree days required for reproduction of johnsongrass (using lower/upper threshold temperatures)

Type of reproduction and planting date	Accumulative degree days				
	60 °F	60/80 °F	60/90 °F	55/80 °F	55/85 °F
Flowering					
March 1	608	562	610	873	922
April 1	466	409	437	632	646
May 1	770	652	749	922	983
June 1	1117	888	1070	1195	1305
July 1	793	638	780	853	934
August 1	701	583	698	792	876
September 1	642	578	635	844	881
Average	807	616	711	873	935
Seed					
March 1	608	562	610	873	922
April 1	761	668	744	981	1056
May 1	770	652	749	922	983
June 1	1117	888	1070	1195	1305
July 1	1132	919	1098	1237	1350
August 1	897	772	882	1075	1148
September 1	642	613	645	915	954
Average	847	725	827	1028	1102
Rhizomes					
March 1	215	209	214	354	359
April 1	242	227	250	359	384
May 1	390	353	396	520	543
June 1	697	564	682	766	855
July 1	793	638	780	853	934
August 1	701	583	698	792	876
September 1	528	486	538	674	729
Average	509	437	508	617	668

Table 7. Production of seeds or vegetative propagules by weeds in studies at Shafter, CA

Type of seed or propagule	Maximum seeds or propagules/plant*		Estimated number/ha[†] x 10⁶
	12 wks	12–30 wks	(population=1 plant/m)
Barnyardgrass seed	25,200	—	248
Bermudagrass seed	10,700	73,420	105–722
Bermudagrass rhizome nodes	129	916	1–9
Johnsongrass seed	28,900	—	205
Johnsongrass rhizome nodes	156	—	2
Morningglory seed	5,400	—	53
Nightshade seed	30,800	—	303
Palmer amaranth seed	51,072	613,074	502–6033
Yellow nutsedge tubers	—	2,100	20

*Information is from previous studies (13, 15, 18, 21, 22, 36, 37).

[†]Estimated numbers were calculated using row width spacing of 100 cm and row length of 9,841 m = 1 ha.

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Table 8. Influence of weed-free and weed-competition periods on cotton yields

Weed	Percentage reduction in cotton yields				
	3–4 wks	6–8 wks	9 wks	12 wks	25 wks
Weed-free periods					
Barnyardgrass	89	15	0	0	0
Bermudagrass	9	0	—	0	0
Black nightshade	5	0	0	0	0
Ivyleaf morningglory	100	10	—	0	0
Johnsongrass	29	11	3	0	0
Palmer amaranth*	—	—	—	—	—
Yellow nutsedge	1	2	—	0	0
Weed-competition periods					
Barnyardgrass	3	24	69	92	98
Bermudagrass	7	10	—	16	26
Black nightshade	—	—	—	—	65
Ivyleaf morningglory	—	—	—	—	100
Johnsongrass	0	20	60	80	90
Palmer amaranth*	—	—	—	—	—
Yellow nutsedge	8	12	—	20	34

SOURCE: Information is drawn from previous studies (10, 16, 17, 19, 20, 23, 24).

NOTE: Weed populations are reported in table 9. Dashes indicate data were not taken.

*Information on Palmer amaranth was collected from plants that escaped preplant applications of the herbicide trifluralin in the black nightshade competition study (19). Only five or fewer plants/plot (48 m of row) reached sufficient height of 150 cm to compete with cotton in unhoed plots where weeds competed for 25 weeks. The 10–20 plants/plot that emerged after hoeing ceased did not exceed 25 cm in height and competed little with cotton.

Table 9. Weed populations at cotton harvest for weed-free periods and at the end of weed-competition periods

Weed	Number of culms or shoots of weeds/m of row				
	3–4 wks	6–8 wks	9 wks	12 wks	25 wks
Weed-free periods					
Barnyardgrass	195	90	1	0	0
Bermudagrass	172	62	—	32	0
Black nightshade	23	24	12	8	0
Ivyleaf morningglory	1	1	—	1	0
Johnsongrass	10	3	2	1	0
Palmer amaranth*	1	1	1	1	0
Yellow nutsedge	20	15	—	8	0
Weed-competition periods					
Barnyardgrass	42	152	180	172	180
Bermudagrass	104	184	—	196	240
Black nightshade	—	—	—	—	37
Ivyleaf morningglory	—	—	—	—	1
Johnsongrass	9	30	45	55	55
Palmer amaranth*	—	—	—	—	<1
Yellow nutsedge	79	100	—	100	100

SOURCE: Information is drawn from previous studies (10, 16, 17, 19, 20, 23, 24).

NOTE: Dashes indicate data were not taken. Weeds were counted in a 15-cm band (band left after cultivation).

*Information on Palmer amaranth was collected from plants that escaped preplant applications of the herbicide trifluralin in the black nightshade competition study (19). Only five or fewer plants/plots (48 m of row) reached sufficient height of 150 cm to compete with cotton in unhoed plots where weeds competed for 25 weeks. The 10–20 plants/plot that emerged after hoeing ceased did not exceed 25 cm in height and competed little with cotton.

Table 10. Approximate weed-free periods required to prevent reproduction and maximum periods weeds can compete without reproduction

Type of seed or propagule	Weed-free period required* (wks)	Maximum period weeds can compete (wks)
Barnyardgrass seed	9	6
Bermudagrass seed or rhizomes	8	8
Black nightshade seed	9	—*
Ivyleaf morningglory seed	12	—*
Johnsongrass seed or rhizomes	9	6
Palmer amaranth seed	9	—†
Yellow nutsedge tubers	6	4

Source: Information is based on reproduction studies of weeds reported previously (10, 16, 17, 19, 20, 23, 24).

Note: The times are approximate. They are most applicable under conditions of good, vigorous cotton stands of normal height (150 cm) and canopies that intercept the majority of light, even in furrows, by layby in early July. When grown in the absence of crops, essentially all seven weeds can reproduce before killing frosts—even when planted as late as September 1. Therefore, weed-free periods of considerable length are needed where cotton stands are poor or where the cotton grows and intercepts light slowly.

*Morningglory and nightshade were not included in the competition studies, but when planted in the absence of crops at monthly intervals from April 1 to September 1, they produced seed within 9 weeks (15, 36).

†Palmer amaranth was not part of the competition studies, but when planted in April and May, it produced seed within 9–12 weeks (18).

Table 11. Relationship of cotton height and canopy width to the ability of cotton to intercept light

Date	Cotton		Percentage of light intercepted*		
	Height (in cm)	Canopy (in cm)	Drill row	Shoulder	Furrow
April 24	5	4	0	0	0
May 8	15	10	0	0	0
May 22	26	19	85	0	0
June 5	42	35	94	54	0
June 19	61	54	96	94	0
July 3	100	89	98	98	58
July 17	127	115	99	99	98

Note: Data are averages of numbers presented in three previous studies (17, 19, 20).

*Readings were taken at noon P.s.t. at the soil surface.

Table 12. Estimated herbicide use in cotton in 1988

Type of treatment and herbicides used	Percentage of acres treated		
	California	Western region*	All cotton States[†]
Preplant foliar			
MSMA	0	0	1
Paraquat	2	1	1
Glyphosate	5	2	2
Other	7[‡,§]	2[‡,§]	<1[‡,§]
Preplant soil-incorporated			
Trifluralin	35	36	49
Pendimethalin	55	30	34
Prometryn	0	9	2
Trifluralin + prometryn	2	8	2
Pendimethalin + prometryn	2	6	1
Norflurazon	0	0	10
Preemergence			
Cyanazine	0	0	2
Fluometuron	0	0	48
Diuron	0	0	3
Norflurazon	0	0	19
Other	0	3[‖]	10[‖,¶,**]
Postemergence			
MSMA/DSMA	3	5	40
Cyanazine ± MSMA	1	4	23
Fluometuron ± MSMA	2	1	31
Prometryn ± MSMA	2	9	10
Diuron ± MSMA	0	3	5
Methazole ± MSMA	0	0	3
Sethoxydim/Fluazifop-P-Butyl	2	3	12
Oxyfluorfen	2	2	3
Spot treatment			
Dalapon	0	0	<1
Glyphosate	1	9	7
MSMA	0	2	3
Sethoxydim/Fluazifop-P-Butyl	1	6	15
Layby			
Diuron	0	4	4
Linuron	0	0	4
Cyanazine	25	18	15
Prometryn	5	32	6

Source: Adapted from M. Patterson (32).

*Western region comprises Arizona, California, and New Mexico.

[†]All cotton States include, in addition to the three Western States, Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas.
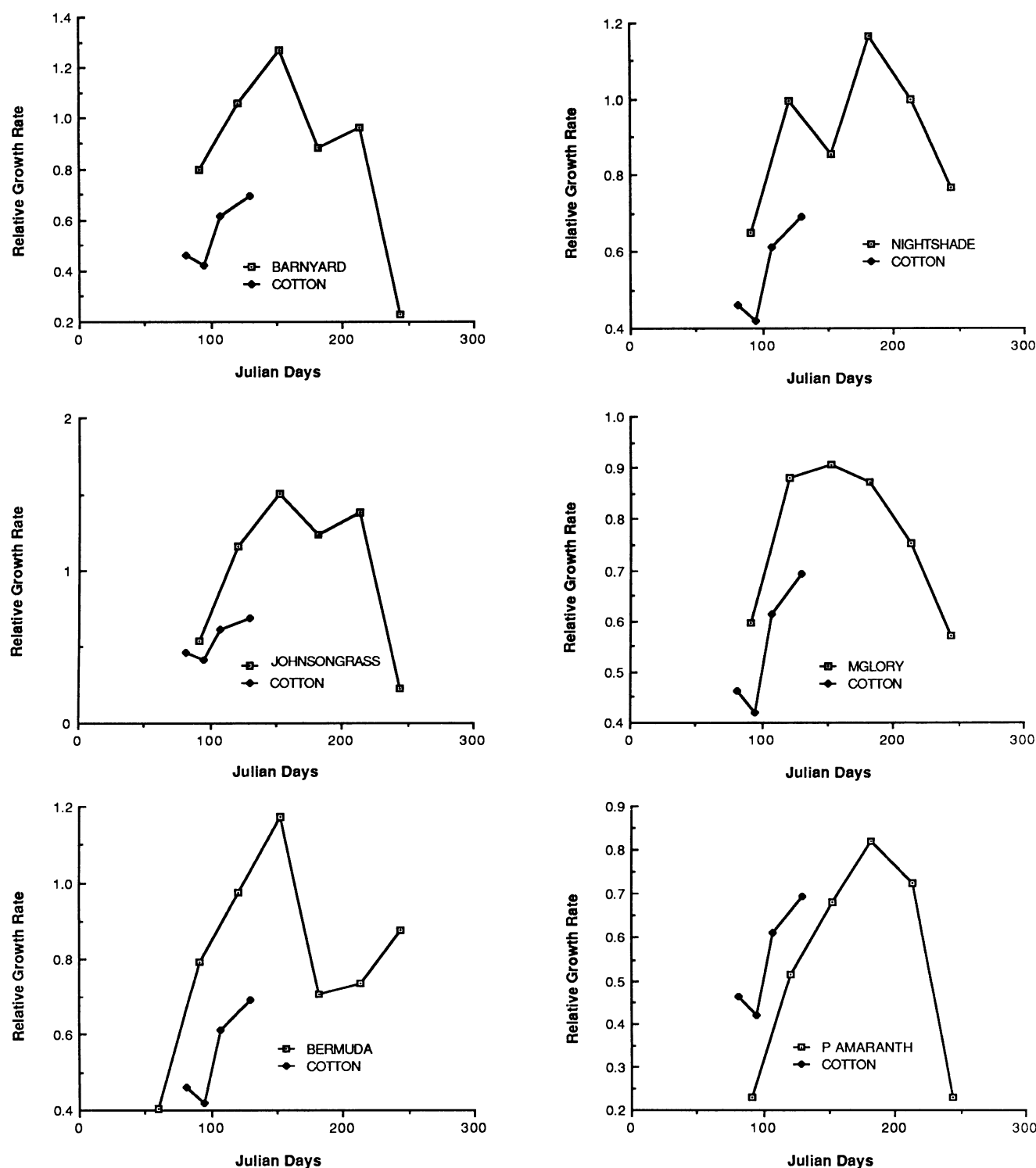
[‡]Dalapon.

[§]Oryzalin.

[‖]Metolachlor.

[¶]Prometryn.

[**]Pendimethalin.

Figure 1. Mean relative growth rates 3-6 weeks after planting cotton and weeds
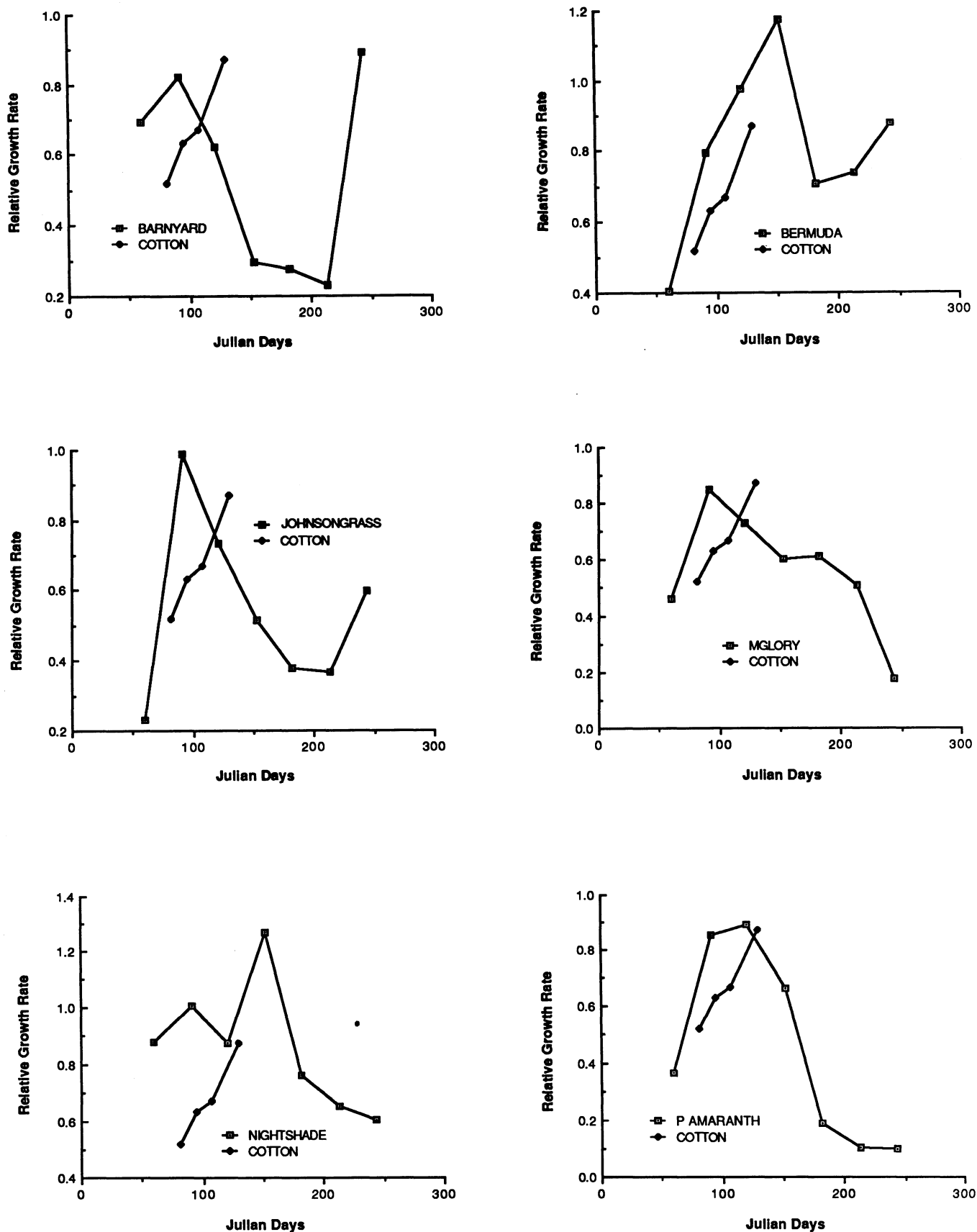

NOTE: The mean relative growth rate (R=g/g x week) was calculated according to Evans (3) using the following equation: $R = \log_e W_2 - \log_e W_1/t_2 - t_1$. R values were derived from plant weight determinations over successive harvests. R represents a mean value for the time interval $t_2 - t_1$. W_2 and W_1 are the total shoot weights at the beginning (W_1) and end (W_2) of the harvest interval.

For cotton, R values were calculated for plantings March 22, April 5, April 17, and May 10, 1990. These dates correspond to Julian days 81, 95, 107, and 130, respectively.

For weeds, R values were calculated from weights reported previously (13, 15, 18, 21, 22, 36, 37). Weeds were planted at monthly intervals from March 1 to September 1 in the following years: johnsongrass, 1976 and 1977; morningglory and nightshade, 1979 and 1980; nutsedge, 1982 and 1983; Palmer amaranth, 1983 and 1984; and barnyardgrass and bermudagrass, 1986 and 1987. All weeds were grown in the absence of crops. The seven monthly planting dates beginning March 1 to September 1 correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively.

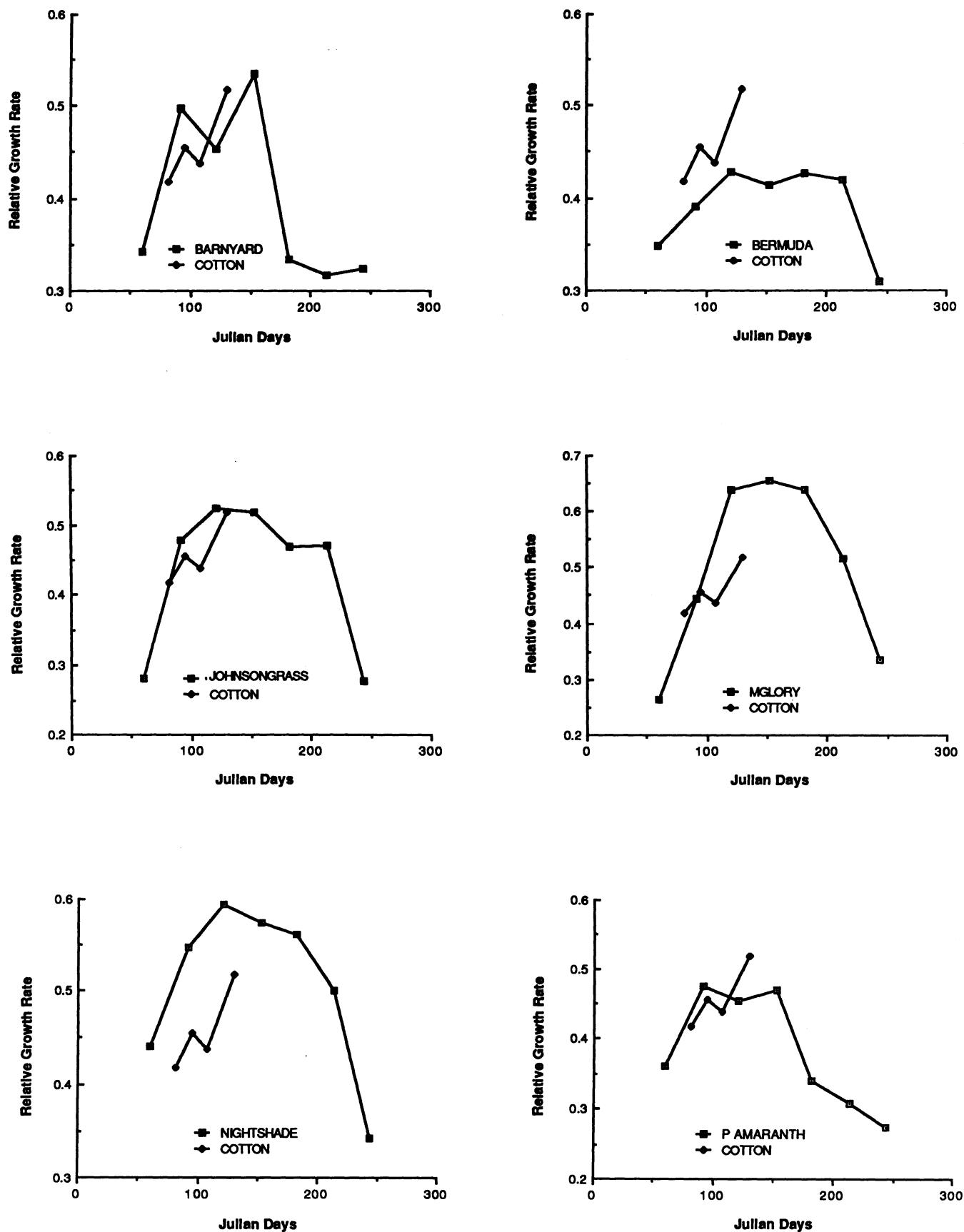Figure 2. Mean relative growth rates (R=g/g x week) 6–9 weeks after planting cotton and weeds

NOTE: See fig. 1 for calculation of R values and planting dates of cotton and weeds.

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Figure 3. Mean relative growth rates (R=g/g x week) 9–12 weeks after planting cotton and weeds

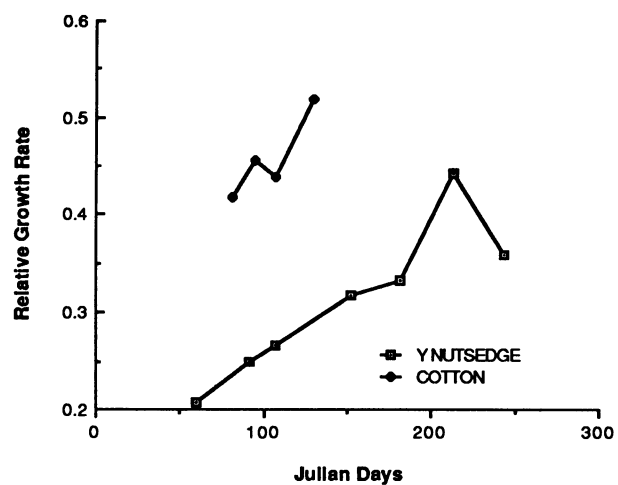
NOTE: See fig. 1 for calculation of R values and planting dates of cotton and weeds.

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Figure 4. Mean relative growth rates (R=g/g x week) 0-12 weeks after planting cotton and weeds
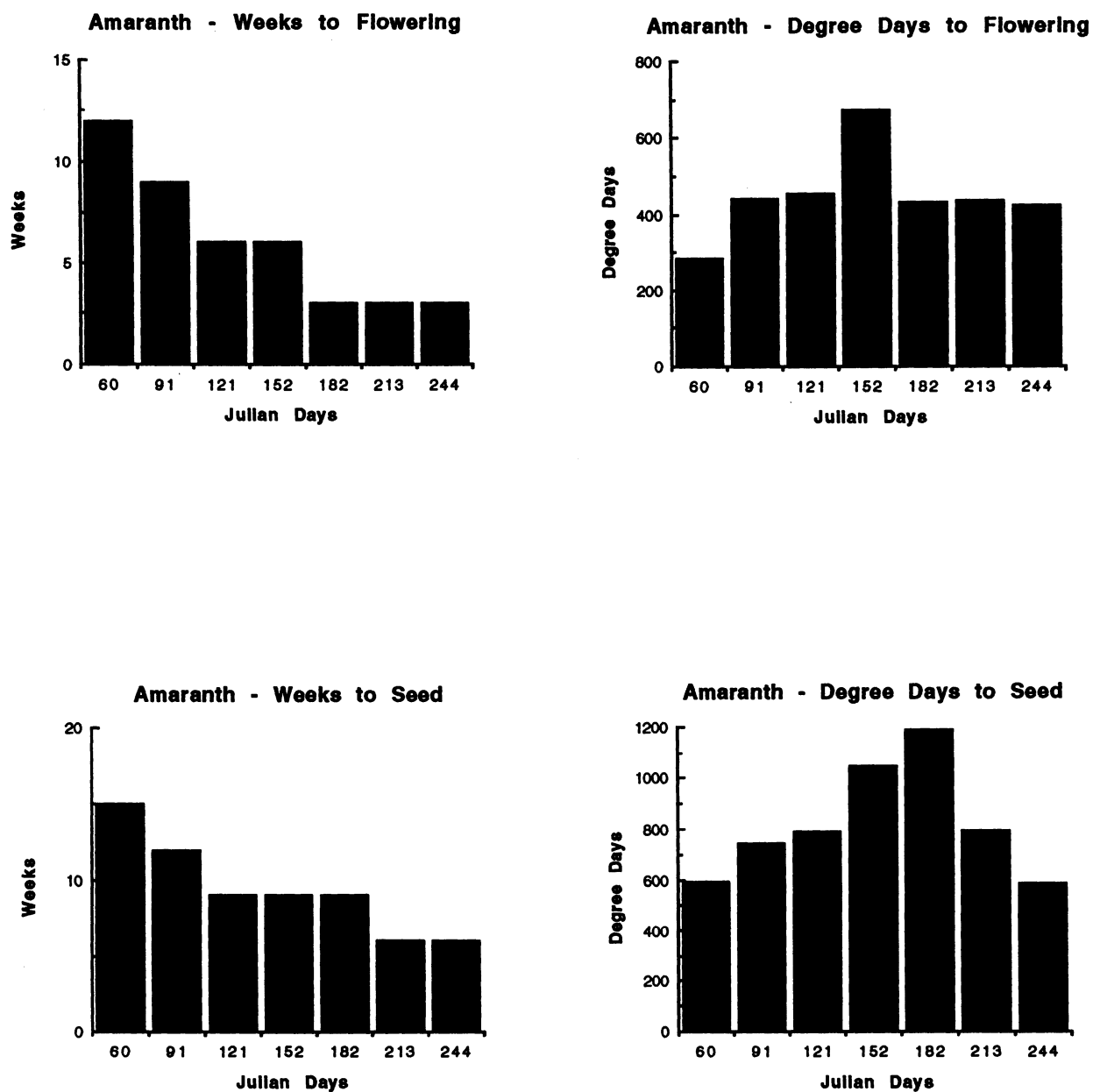

NOTE: See fig. 1 for calculation of R values and planting dates of cotton and weeds.

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Figure 5. Mean relative growth rates (R=g/g × week) 0–12 weeks after planting cotton and yellow nutsedge
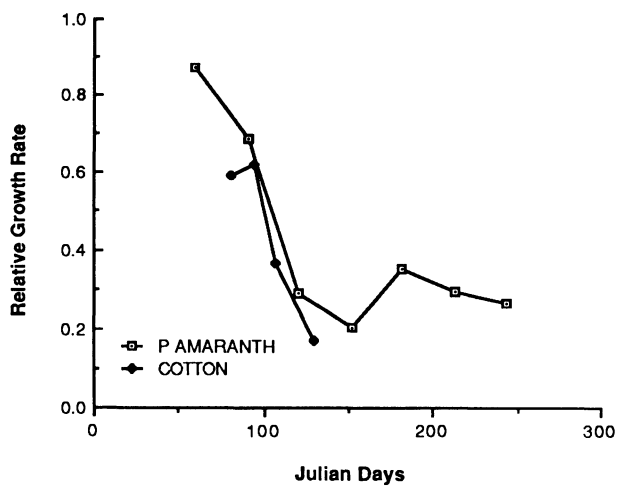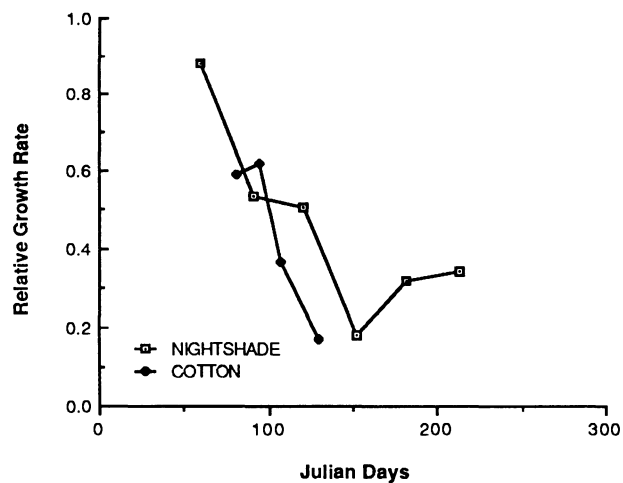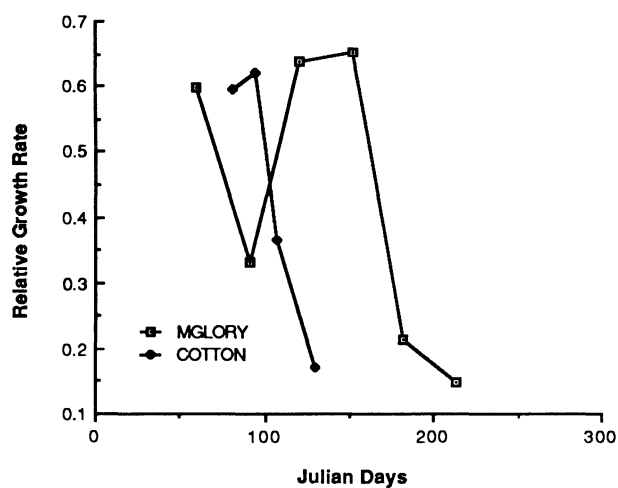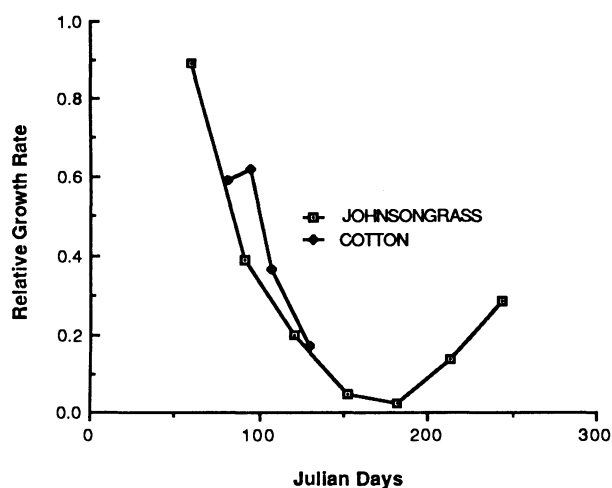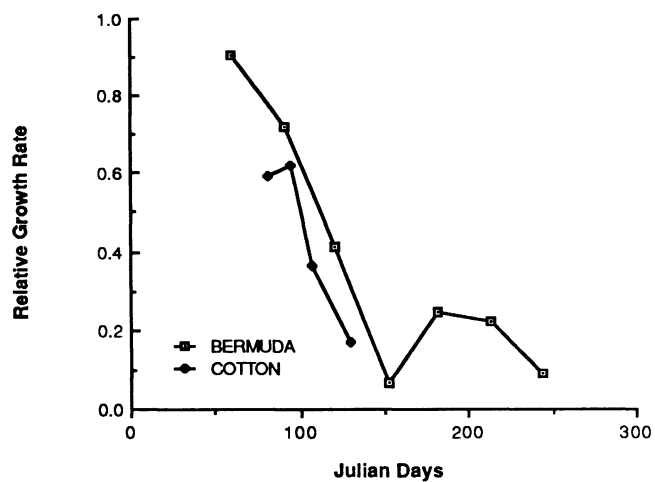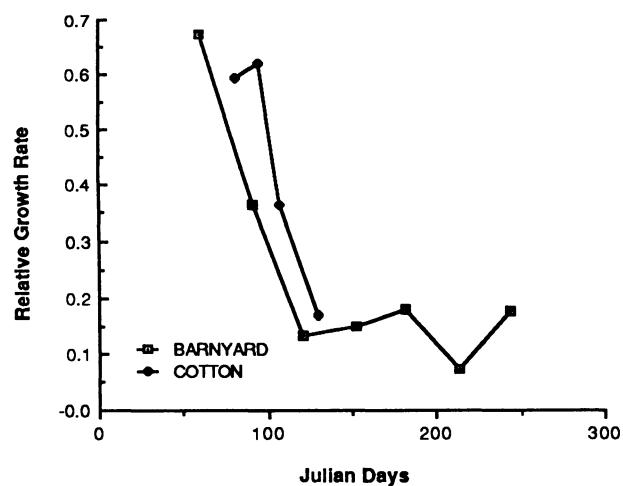

NOTE: See fig. 1 for calculation of R values and planting dates of cotton and weeds.

Figure 6. Palmer amaranth: Weeks and accumulative degree days (ADD) to produce flowers and seed

Amaranth - Weeks to Flowering

(bar chart: y-axis "Weeks" 0 to 15; x-axis "Julian Days" 60, 91, 121, 152, 182, 213, 244)

Amaranth - Degree Days to Flowering

(bar chart: y-axis "Degree Days" 0 to 800; x-axis "Julian Days" 60, 91, 121, 152, 182, 213, 244)

Amaranth - Weeks to Seed

(bar chart: y-axis "Weeks" 0 to 20; x-axis "Julian Days" 60, 91, 121, 152, 182, 213, 244)

Amaranth - Degree Days to Seed

(bar chart: y-axis "Degree Days" 0 to 1200; x-axis "Julian Days" 60, 91, 121, 152, 182, 213, 244)

NOTE: Reproduction was previously reported (18). The averaging method reported by Zalom et al. (39) was used to calculate ADD. ADD were derived from weather data collected at the U.S. Department of Agriculture Cotton Research Station, Shafter, CA, using a lower threshold temperature of 60 °F (15.6 °C). Planting dates at seven monthly intervals from March 1 to September 1, in 1983 and 1984, correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively.

Figure 7. Barnyardgrass: Weeks and accumulative degree days (ADD) to produce flowers and seed

Barnyardgrass - Weeks to Flowering

Barnyardgrass - Degree Days to Flowering

Barnyardgrass - Weeks to Seed

Barnyardgrass - Degree Days to Seed
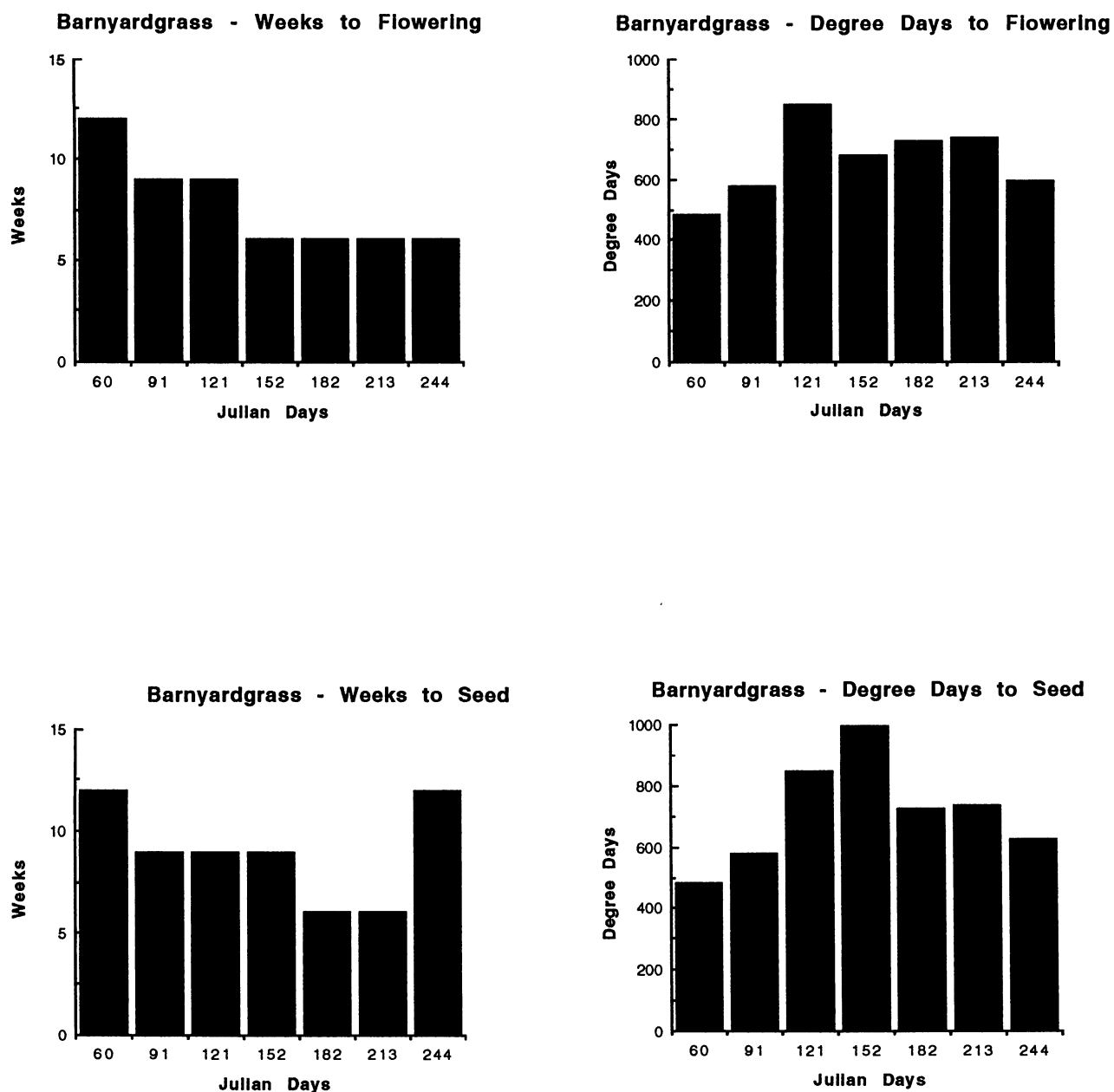
NOTE: See fig. 6 for calculation of ADD. Reproduction was previously reported (22). Planting dates at seven monthly intervals from March 1 to September 1, in 1986 and 1987, correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively.

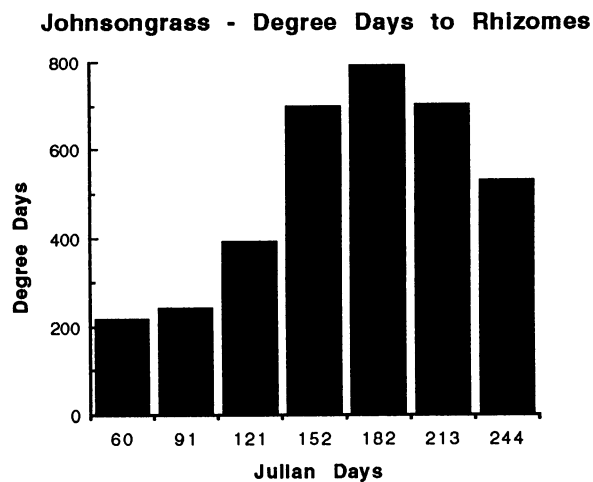Figure 8. Bermudagrass: Weeks and accumulative degree days (ADD) to produce flowers, seed, and rhizomes
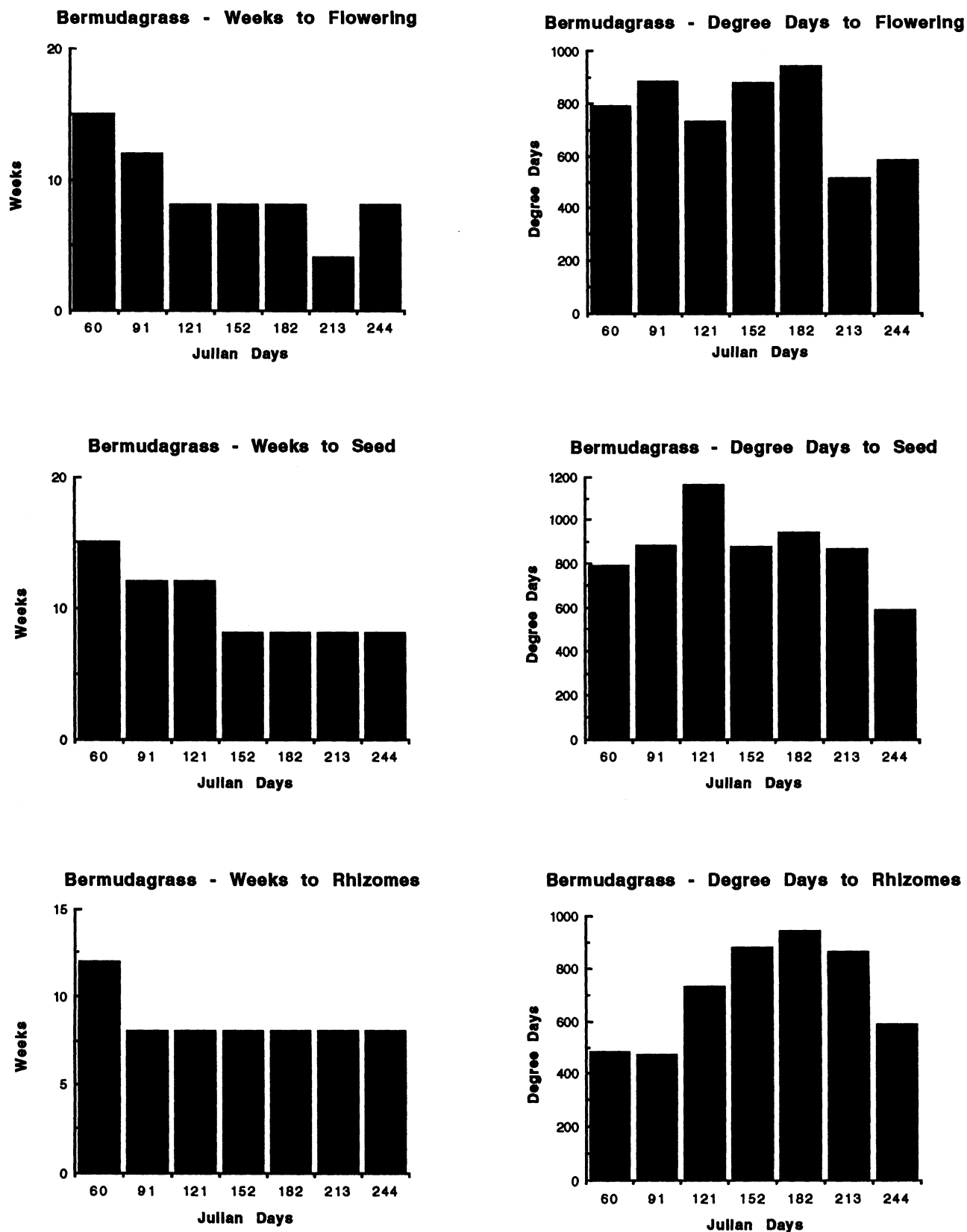
NOTE: See fig. 6 for calculation of ADD. Reproduction was previously reported (21). Planting dates at seven monthly intervals from March 1 to September 1, in 1986 and 1987, correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively.

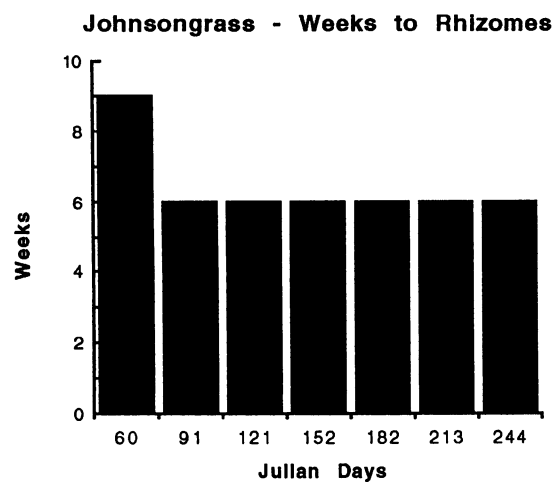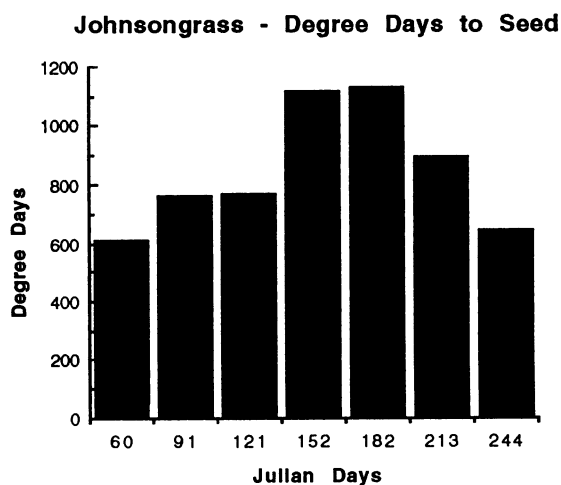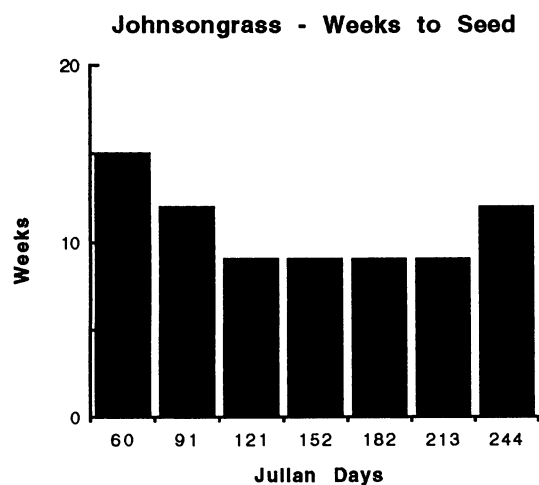Figure 9. Johnsongrass: Weeks and accumulative degree days (ADD) to produce flowers, seed, and rhizomes

See fig. 6 for calculation of ADD. Reproduction was previously reported (13). Planting dates at seven monthly intervals from March 1 to September 1, in 1976 and 1977, correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively.

Figure 10. Ivyleaf morningglory: Weeks and accumulative degree days (ADD) to produce flowers and seed

Morningglory - Weeks to Flowering

Morningglory - Degree Days to Flowering

Morningglory - Weeks to Seed
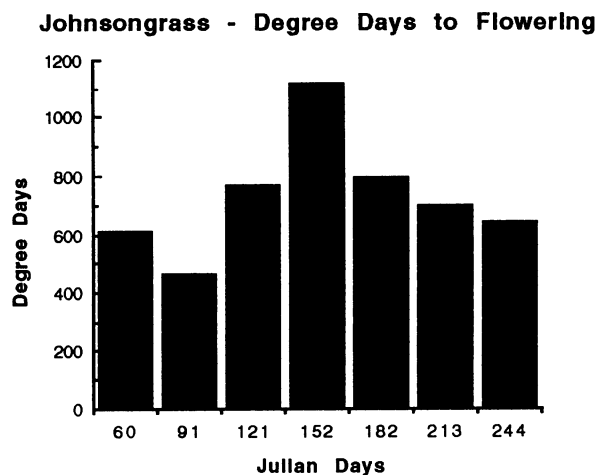
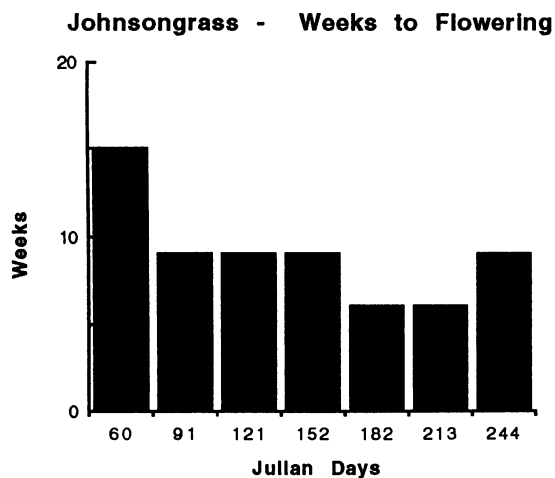**Morningglory - Degree Days to Seed**

NOTE: See fig. 6 for calculation of ADD. Reproduction was previously reported (36). Planting dates at seven monthly intervals from March 1 to September 1, in 1979 and 1980, correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively.

Figure 11. Black nightshade: Weeks and accumulative degree days (ADD) to produce flowers and seed

Nightshade - Weeks to Flowering

Nightshade - Degree Days to Flowering

Nightshade - Weeks to Seed
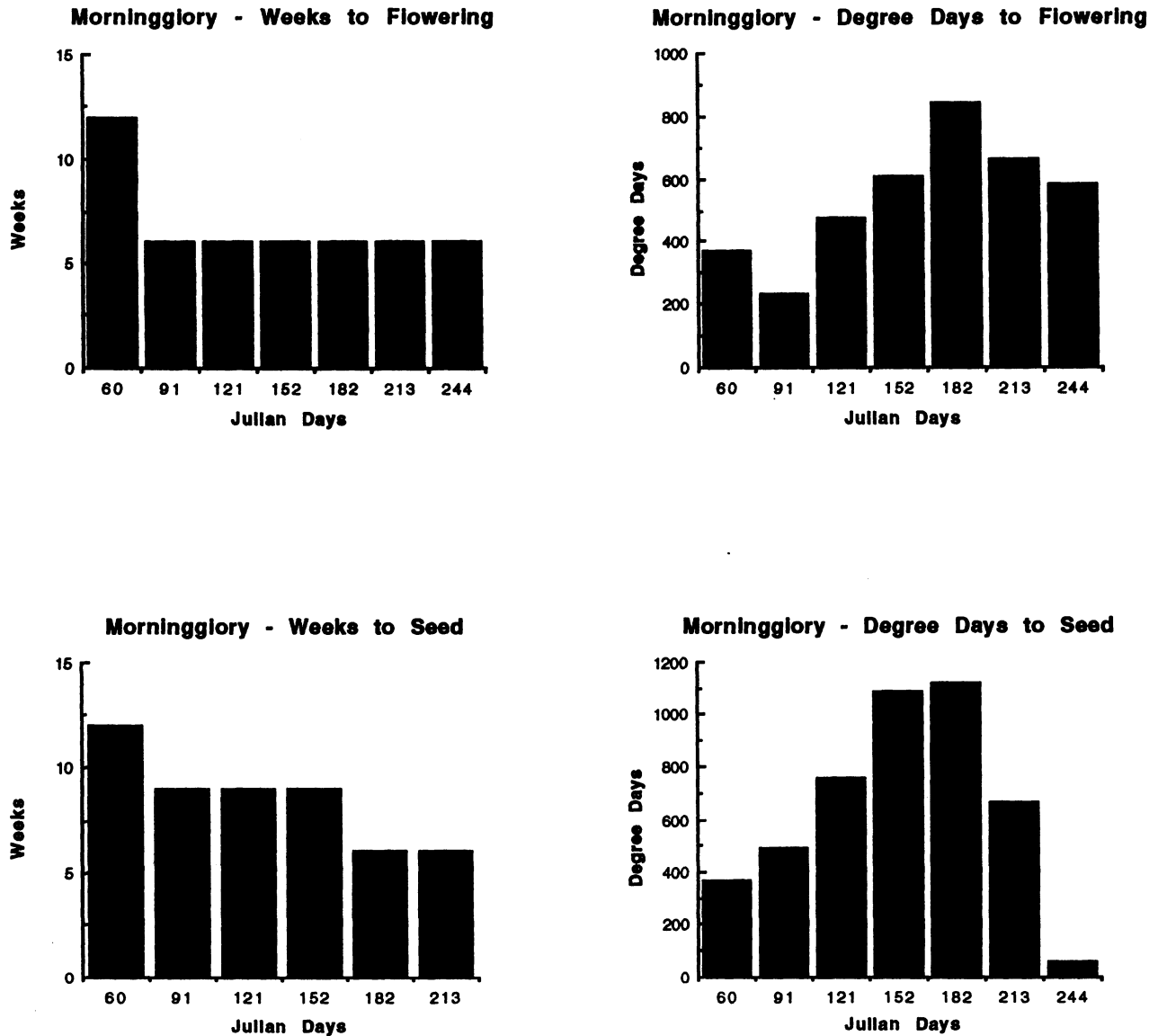
Nightshade - Degree Days to Seed

NOTE: See fig. 6 for calculation of ADD. Reproduction was previously reported (15). Planting dates at seven monthly intervals from March 1 to September 1, in 1979 and 1980, correspond to Julian days 60, 91, 121, 152, 213, and 244, respectively.

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Figure 12. Yellow nutsedge: Weeks and accumulative degree days (ADD) to produce tubers

Yellow Nutsedge - Weeks to Tubers

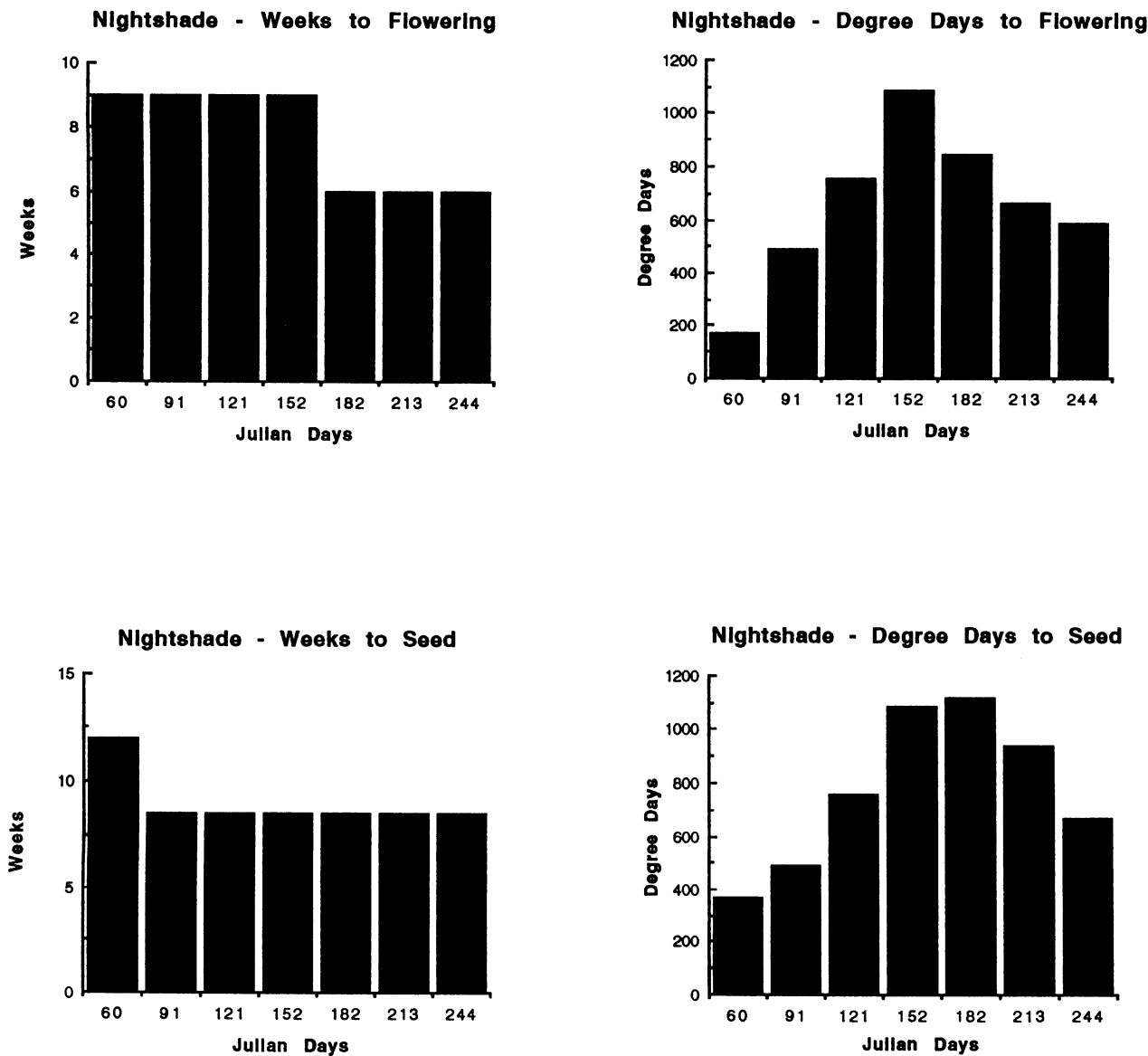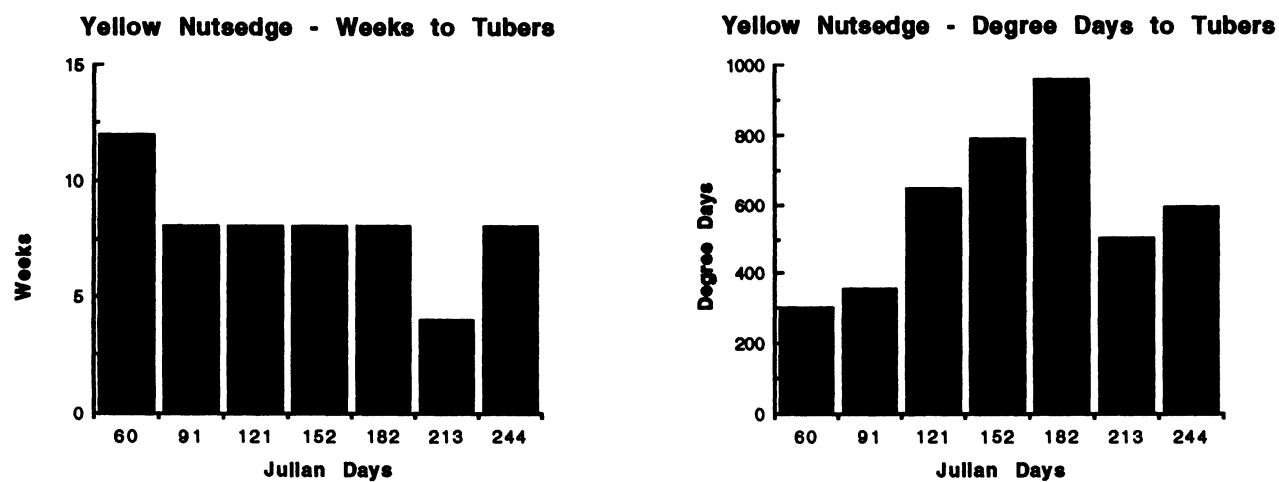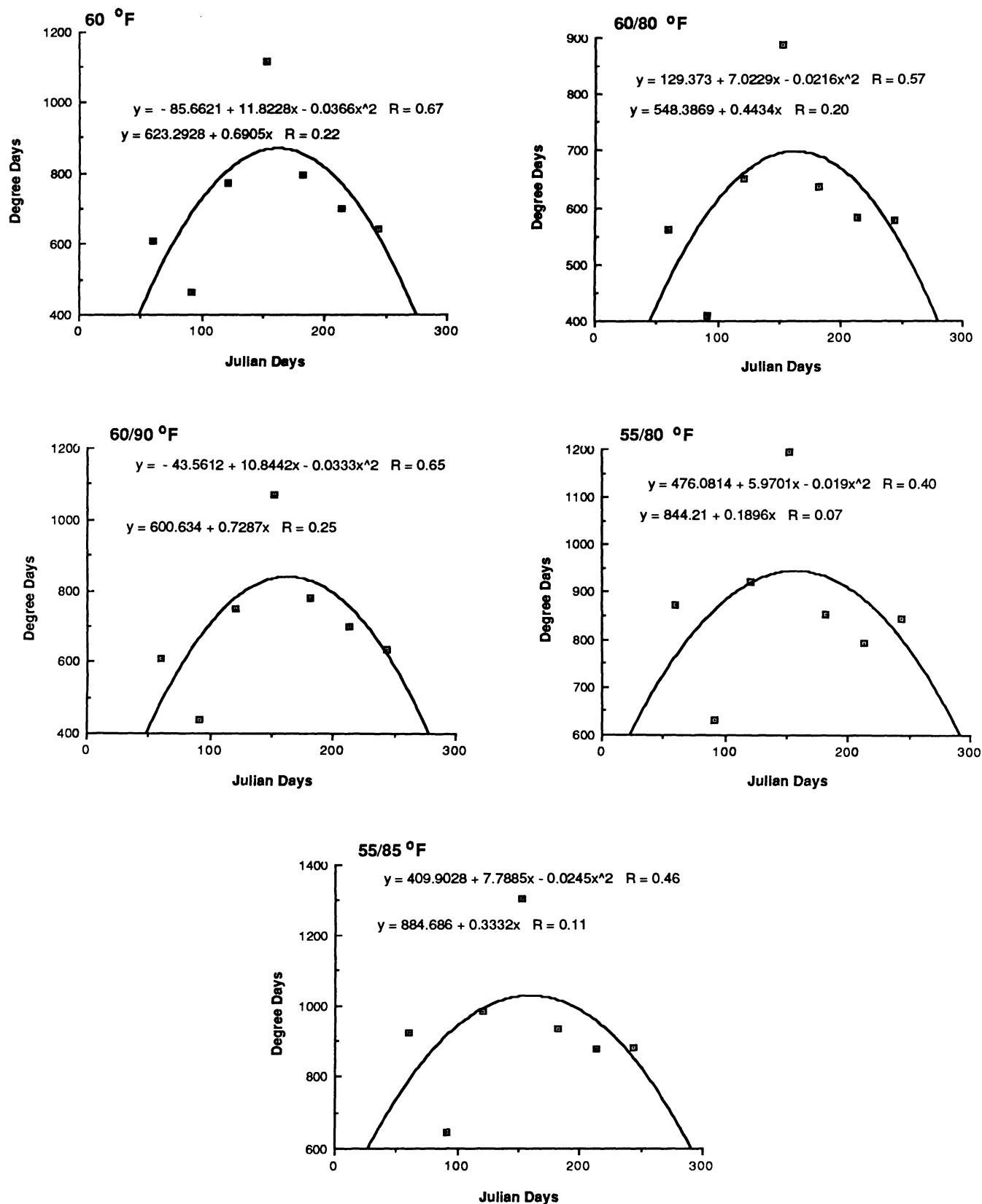**Yellow Nutsedge - Degree Days to Tubers**

NOTE: See fig. 6 for calculation of ADD. Tuber production was previously reported (37). Planting dates at seven monthly intervals from March 1 to September 1, in 1982 and 1983, correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively.

Figure 13. Accumulative degree days required for johnsongrass to flower

60 °F

y = - 85.6621 + 11.8228x - 0.0366x^2   R = 0.67
y = 623.2928 + 0.6905x   R = 0.22

60/80 °F

y = 129.373 + 7.0229x - 0.0216x^2   R = 0.57
y = 548.3869 + 0.4434x   R = 0.20

60/90 °F

y = - 43.5612 + 10.8442x - 0.0333x^2   R = 0.65

y = 600.634 + 0.7287x   R = 0.25

55/80 °F

y = 476.0814 + 5.9701x - 0.019x^2   R = 0.40

y = 844.21 + 0.1896x   R = 0.07

55/85 °F

y = 409.9028 + 7.7885x - 0.0245x^2   R = 0.46

y = 884.686 + 0.3332x   R = 0.11

NOTE: Planting dates at seven monthly intervals from March 1 to September 1 correspond to Julian days 60, 91, 121, 152, 182, 213, and 244, respectively. R values at the top of the graphs show the fit of the data to a second-degree or quadratic equation or a parabola curve. The R values beneath show the fit of the data to the equation of a straight line.

Figure 14. Accumulative degree days required for johnsongrass to produce seed

60 °F

$y = -246.2584 + 15.9822x - 0.0498x^2 \quad R = 0.87$

$y = 717.2624 + 0.8525x \quad R = 0.27$

Degree Days / Julian Days

60/80 °F

$y = 26.7869 + 9.9523x - 0.0303x^2 \quad R = 0.85$
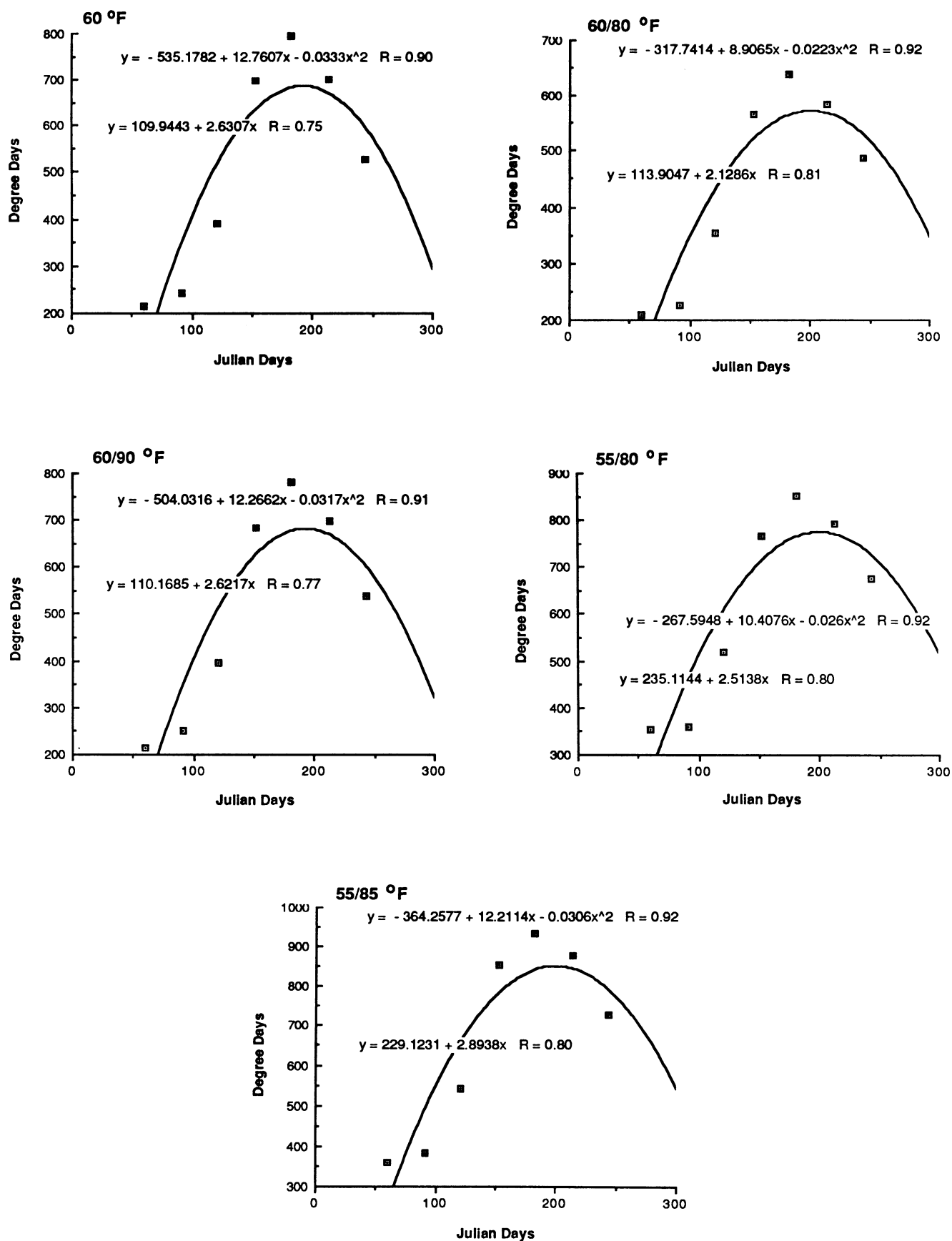
$y = 614.1732 + 0.7289x \quad R = 0.35$

Degree Days / Julian Days

60/90 °F

$y = -171.0795 + 14.5215x - 0.045x^2 \quad R = 0.86$

$y = 699.8378 + 0.8458x \quad R = 0.29$

Degree days / Julian Days

55/80 °F

$y = 347.4453 + 9.6799x - 0.0294x^2 \quad R = 0.80$

$y = 917.3967 + 0.7302x \quad R = 0.34$

Degree Days / Julian Days

55/85 °F

$y = -364.2577 + 12.2114x - 0.0306x^2 \quad R = 0.92$

$y = 229.1231 + 2.8938x \quad R = 0.80$

Degree Days / Julian Days

NOTE: See fig. 13 for significance of R values and planting dates.

Figure 15. Accumulative degree days required for johnsongrass to produce rhizomes

60 °F

$y = -535.1782 + 12.7607x - 0.0333x^2 \quad R = 0.90$

$y = 109.9443 + 2.6307x \quad R = 0.75$

60/80 °F

$y = -317.7414 + 8.9065x - 0.0223x^2 \quad R = 0.92$

$y = 113.9047 + 2.1286x \quad R = 0.81$

60/90 °F

$y = -504.0316 + 12.2662x - 0.0317x^2 \quad R = 0.91$

$y = 110.1685 + 2.6217x \quad R = 0.77$

55/80 °F

$y = -267.5948 + 10.4076x - 0.026x^2 \quad R = 0.92$

$y = 235.1144 + 2.5138x \quad R = 0.80$

55/85 °F

$y = -364.2577 + 12.2114x - 0.0306x^2 \quad R = 0.92$

$y = 229.1231 + 2.8938x \quad R = 0.80$

NOTE: See fig. 13 for significance of R values and planting dates.