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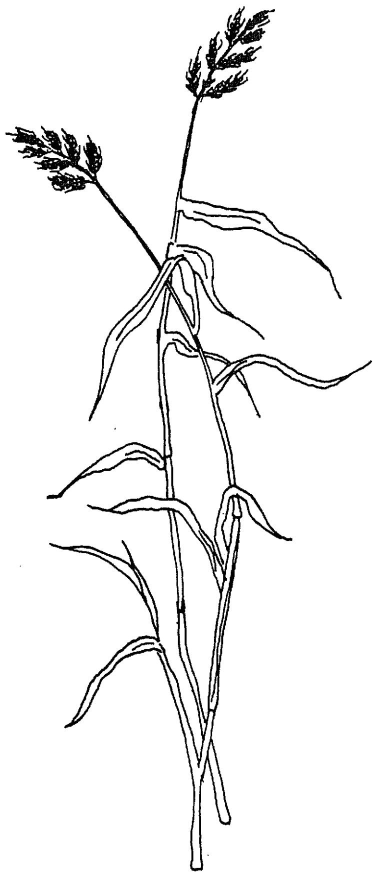
LIFE HISTORY STUDIES AS RELATED TO WEED CONTROL IN THE NORTHEAST



5 -- Barnyardgrass

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This bulletin is one of a series that pertains to life history studies of weeds that are important in the Northeastern states.

This series of bulletins is being published by the Northeast Regional Weed Control Technical Committee (NE-42).

Bulletins previously published pertain to the following weeds: nutgrass (Rhode Island Agr. Expt. Sta. Bul. 364. 1962), quackgrass (Rhode Island Agr. Expt. Sta. Bul. 365. 1962), horse nettle (Rhode Island Agr. Expt. Sta. Bul. 368. 1962), yellow foxtail and giant foxtail (Rhode Island Agr. Expt. Sta. Bul. 369. 1963).

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INTRODUCTION

Barnyardgrass, *Echinochloa crusgualli* (L.) Beauv, also commonly known as watergrass, is a serious weed in many agricultural areas of the 12 northeastern states. This weed is spreading rapidly to uninfested fields, and fields where it is already present are becoming much more heavily infested with seed.

In 1950 and 1951, a survey was made by Vengris (39) of weed population in fields of tobacco, corn, potatoes, and onions growing in the Connecticut River valley in Massachusetts. Barnyardgrass was found in 97.8 percent of the fields of potatoes, in more fields than any other weed. This weed was second to large crabgrass, *Digitaria sanguinalis,* in tobacco fields and third in onion fields, exceeded only by large crabgrass and common purslane, *Portulaca oleracea.* It was eighth in corn fields, with large crabgrass; common lambs quarters, *Chenopodium album;* redroot pigweed, *Amaranthus retroflexus;* Pennsylvania smartweed, *Polygonum pensylvanicum;* common ragweed, *Ambrosia artemisiifolia;* witchgrass, *Panicum capillare;* and carpetweed, *Mollugo verticillata,* present in more fields.

Growers consider barnyardgrass a severe competitor with row crops in the warmer areas. It usually emerges before or with the crop, and during the first several weeks usually rapidly out-grows crop plants. This makes control in crop rows practically impossible without hand-hoeing.

Heavy infestations of barnyardgrass not only reduce crop yields; they also make mechanical harvesting much more difficult. This is particularly true with potatoes, lima beans, and snap beans. When digging potatoes in a heavily infested field, it is difficult to separate potatoes from clumps of barnyardgrass. When clumps of barnyardgrass with considerable soil attached go into lima bean viners along with lima bean plants, beaters and canvases are frequently broken. With snap beans, the tops of barnyardgrass, particularly the panicles, become wrapped around the reels of mechanical snap bean pickers causing breakage.

Increasing losses caused by this pest in the Northeast, and insufficient knowledge of the growth and development of barnyardgrass as affected by environmental factors, as well as herbicides, resulted in a regional study beginning in July 1962 by the Northeast Regional Weed Control Technical Committee (NE-42). The state experiment stations of Delaware, Massachusetts, New York, and New Hampshire cooperated in this study.

CHARACTERISTICS OF BARNYARDGRASS PLANTS

Morphology

The plant is grass-like in nature, with the sessile leaf blades attached to a smooth sheath which encircles the stem in the absence of a ligule (Figures 1, 2, 3 and 4). Leaves are rolled in a flattened bud-shoot. The sheath is flattened, keeled, split with hyaline margins and pale green. The collar is broad and glabrous with auricles absent. The blade itself is narrowly strap-shaped and entire, with numerous parallel veins. The dimension of the blade varies from 10 to 30 cm long and 5 to 20 mm wide. The mid-rib may be very prominent (16).

Figure 1. Barnyardgrass plant. (from R. J. Lambert in Bazer (4)).

Figure 2. Barnyardgrass. A, panicle; B, raceme; C, closeup of raceme; D, spikelet; E, seed. (from R. J. Lambert in Bazer (4)).

B

A

Figure 3. Barnyardgrass. A, branching tiller; B, collar. (from R. J. Lambert in Bazer (4)).

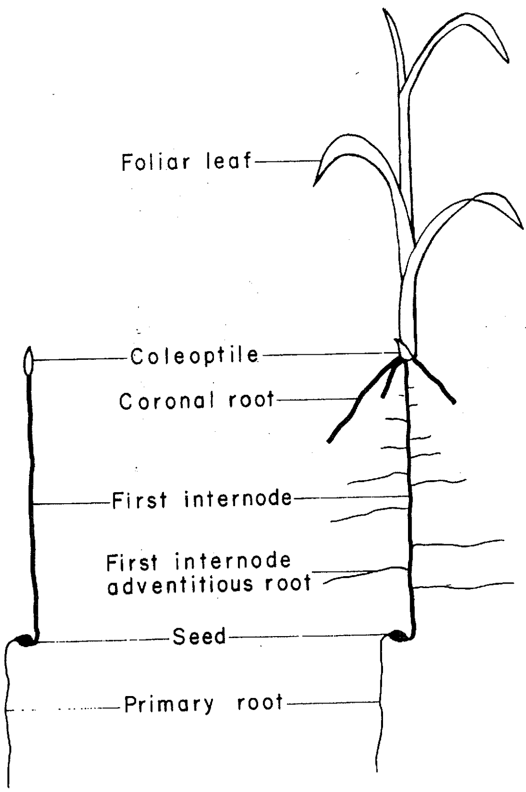

Figure 4. Barnyardgrass seeding with parts labeled (after Dawson (10)).

The stems are stout, prostrate to ascending, and glabrous, reaching a diameter of 6 mm. The 60 to 150 cm culm often branches at the base to produce tillers. The stem is terminated by the 10 to 20 cm-long inflorescence, which is a slender and almost spike-like panicle with the branches ascending and pressed together, green or purplish in color. The lower branches of the panicle are often remote from each other, whereas the upper ones are more or less aggregated into a terminal clump. Panicles may also be borne in the leaf axils along the stem.

The spikelets are densely crowded in 2 to 4 rows on each side of the stem. Each of the green or purple spikelets is about 6 mm long. The spikelets are oval in shape with unequal glumes that are pointed and bristly on the back. A spikelet is composed of one perfect floret and one sterile floret (34). The lemma of the fertile floret is smooth, shining, and hard with the margins unrolled below, partly enclosing the palea which in turn surrounds the ovary. The sterile floret is represented by the lemma only, which is pointed and sometimes long-awned, and enclosing a membranous palea and stamens. The awns are variable, mostly 5 to 10 mm long, but sometimes they may reach as much as 3 cm in length.

The seeds are strongly convex on one side and flat on the other, being broad below and narrow toward their apex. They are a light orange-yellow to buckhorn brown in color and 2.5 to 3.5 mm long. Seed coats are obscurely three-veined (19).

Anatomy

Recent work by Kacperska-Palacz, et al. (26), has revealed the developmental anatomy of the barnyardgrass plant from germination to maturity. The developmental steps, calendarized in relation to the age of the plant, are shown in Table 1. The developmental morphology can be described as follows: (a) the embryonic phase consisting of the primary root ensheathed by the coleorhiza and root cap and a short axis bearing the plumule enclosed within the coleoptile; (b) the ensuing vegetative phase, which initiates and matures the photosynthetic leaves, axillary shoots (tillers) and permanent root system, but with no internodal elongation of the stem organ; and (c) the reproductive phase which is signalled by internodal elongation and the transformation of the growing point into an inflorescence primordium.

Tiller primordia form only during the vegetative phase of development. The first tiller primordium arises in the axil of the first or second leaf at the moment of seedling emergence from the soil. The first tillers are observable in the field ten days after emergence. They are initiated by periclinal divisions in the third layer of cells of the embryonic internode in a position just above a leaf primordium. As the primordium further enlarges, the apex turns upward between the inner surface of the leaf sheath. The stem forms an intra-vaginal shoot whose further development repeats the pattern of the parent axis. Under normal field conditions, one plant can produce as many as 15 additional tillers of various orders.

The root system of a mature barnyardgrass plant consists chiefly of fibrous or adventitious roots (Figure 5). The primary root supports the young seedling only for the first few days following germination. The first adventitious roots arise from the segment between the scutellum and coleoptile known as the mesocotyl, at the time of seedling emergence. Primordia of these roots are

TABLE 1. Calendar of barnyardgrass development—field planting: 6/15/62; greenhouse: 6/17/62; Amherst, Massachusetts.

Days after germination[a]	Growth stage	Plant height, cm		Developmental morphology	
		Field	Greenhouse	Formation of primordia	Appearance of organs
0			0.1-0.2	3rd leaf	Primary root
1	Mesocotyl elongation		0.5	1st mesocotyl root	
2[b]			1.5	4th leaf; 1st tiller 1st coronal root	1st leaf
3		2	3		1st mesocotyl root
4				5th leaf; 2nd coronal leaf	
6	Vegetative growth				1st coronal root
7			4	2nd tiller	
9				6th leaf	2nd leaf
10		5	5		2nd coronal root
12				7th leaf; 5th tiller	3rd leaf
13					1st tiller
14					3rd coronal root
16			15		4th leaf; 2nd tiller
19				8th leaf	5th tiller
20			20	7th tiller	
21	Shoot apex elongation				
22	Infloresc. primordium	25	25		
30	Interdonal elongation	58			6th leaf
40	Heading	80			
60		135			8th leaf
64	First mature seeds				

[a] "Germination" is here intended to mean the reactivation of growth processes by the embryo in the grain as perceived by microscopic inspection.
[b] Day of emergence, i.e. the appearance of seedlings in the seed bed.

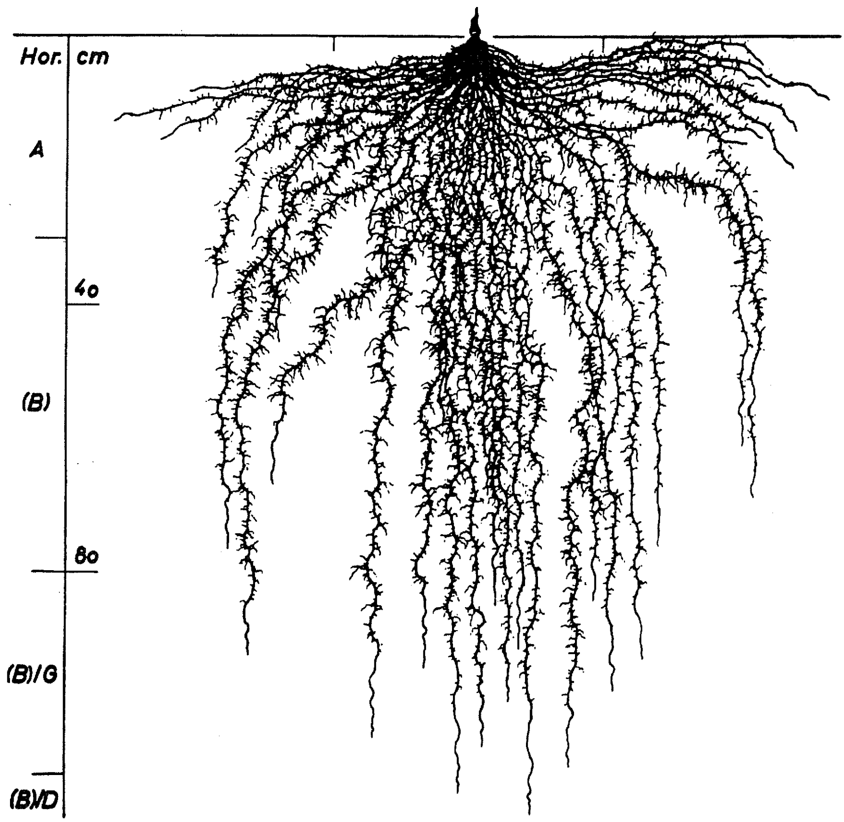

Figure 5. Distribution of barnyardgrass roots in soil (from Kutschera (27)).

initiated the first day after germination. Adventitious roots originating from the internodes above the mesocotyl appear the sixth day after germination from primordia initiated the day of emergence. The origin and development of root primordia in barnyardgrass conform to the characteristic pattern for grasses. The histology of the mature root is of a standard monocotyledonous type (26). The stele is polyarch with secondary roots developing from the pericycle. Root color is whitish. Root distribution is dependent on soil conditions. According to Kutschera (27), in a porous, well-aerated soil the roots may reach a depth of 116 cm while in wet, packed areas, the penetration is less. There is considerable spreading close to the soil surface around the main shoot as evidenced by the system being 106 cm in diameter.

SEED INVESTIGATIONS

Duration of Dormancy

Roger and Stearns (36) found that freshly harvested seeds of barnyardgrass germinated better than one-year-old seed, 55 percent and 4 percent respectively. Arai, et al. (2), working with *Echinochloa crusgalli,* var. *oryzicola,* found dormancy lasts about a year when seed was stored at room temperature. The dormant period was considerably shorter when seed was stored in soil.

Materials and Methods

In August of 1963 and 1964 seed was collected from the field in Delaware and stored at room temperature in the laboratory. In 1963, seed was also stored outdoors, 1½ inches deep between 2 layers of plastic screen, in steam sterilized soil. Seeds were withdrawn about every 2 weeks and 3 replications of 50 seeds each were placed in the germinator at 100°F in the dark. Final germination counts were made after 20 days.

Results and Discussion

Dormancy was found to exist. Freshly collected seed in August 1963 and 1964 germinated only 0.3 percent and 1.4 percent, respectively. Duration of dormancy for the 2 years varied considerably, for some unknown reason. Seed collected in August 1963 broke dormancy about December 30, approximately 4 months after collection, when 18.5 percent of the seed germinated. Seed collected in August 1964 broke dormancy by May 1, about 8 months after collection, when 44 percent of the seed germinated. The maximum germination of 1963 seed was 58 percent, which occurred roughly 8 months after collection. Dormancy of 1963 seed was broken by December 30, 1963, about 4 months after collection whether it was stored in the laboratory or 1½ inches deep in soil outdoors.

Breaking Dormancy

In Japan, Arai, et al. (2), working with *Echinochloa crusgalli,* var. *oryzicola,* found the following effective for breaking seed dormancy: storage at high temperatures, 40-50°C; moist storage at 5°C; freezing at -5°C; and storage in nitrogen at 30°C. They found alternating temperatures, per se, ineffective for breaking dormancy.

Materials and Methods

Seed was collected in Delaware in August of 1964. To break dormancy, a number of treatments involving changing the environment, or using certain chemical or physical means, were evaluated. Germination was measured by placing 150 seeds (3 x 50 seeds on filter paper in petri-dishes) in a germinator at 100°F. Final counts were made after 20 days.

Results and Discussion

Treatments found most effective for breaking dormancy are listed in Table 2. Untreated seed germinated only 1.4 percent. When the seed covering, or pericarp, was removed, germination was 87 percent, indicating that the seed covering, or some inhibitor in it, was the limiting factor. Apparently the seed covering was altered sufficiently by certain treatments to allow good germination. Treatments were exposing the seed to high, 120°F, and low, 40°F, temperatures, especially when the seed was moist; and soaking the seed in acetone for 20 min., in concentrated H_2SO_4 for 8 min., or in water for 4 days. Ineffective treatments were soaking in gibberellic acid, 10 ppm, for 2 days; and pricking seed coverings prior to soaking in water for 2 days.

TABLE 2. Most effective methods tested for breaking dormancy of barnyardgrass seeds.

Treatment	Germination after 20 days, %
Control	1.4
Seed covering removed	87
Freeze-thaw, moist, 4 days	68
120°F, moist, 5 hrs.	67
120°F, dry, 5 hrs.	25
Acetone, 20 minutes	60
Concentrated H_2SO_4, 8 minutes	40
Soaked in water, 4 days	38
40°F, moist, 14 days	31
40°F, dry, 14 days	21
LSD, 1%	14

Seed Maturity and Germination

Well-developed mature barnyardgrass seeds are dark grey or brownish and shiny. Immature seeds are light grey or strawlike and smaller in size.

Barnyardgrass seed samples collected at Amherst, Massachusetts, from the same plants at various dates in 1963, showed variations in germination. There is enough evidence that well-matured weed seeds are more viable than seeds at early stages of maturity. Some seeds may be viable even at milk or dough stages of ripening (18).

Materials and Methods

Tests were conducted at seed testing laboratories at the University of Massachusetts. In the germinator, seeds were kept moist between blotters. Temperature was set for 8 hr. at 86°F and 16 hr. at 68°F.

Results and Discussion

From a barnyardgrass seed sample collected in 1963, 4 x 100 dark grey, well-developed mature seeds and 4 x 100 light grey ones were taken. Ninety-four percent of the dark seeds germinated in 35 days as compared with 79 percent of the light ones. Statistically, differences were highly significant.

In life history studies, barnyardgrass was seeded in the field at various dates during the growing season. Plants which emerged at August 8, 1965 developed few immature seedheads until killing frost. At harvest time seeds were small, light grey and in the milk-dough stage of maturity. Interestingly enough, 35.4 percent of these seeds germinated in 30 days.

In the third test, 200 barnyardgrass seedheads were tagged at heading when they were about halfway out of sheathes. Close observation showed that these seedheads were at the anthesis stage of development. At random 20 tagged seedheads were collected 4, 12 and 20 days later. Seeds of each sample were separated into darker and lighter groups and germination tests were conducted. Results are presented in Table 3. The obtained data clearly verify previous results; the more mature the seed, the better the germination. On the other hand, barnyardgrass seeds at early stages of ripening can be viable and serve as source of infestations.

TABLE 3. Percent germination of barnyardgrass seeds collected at various dates after anthesis.

Days after anthesis	Seed color	Percent germination 5 days	10 days	15 days	20 days	25 days	35 days
	dark	0	0	0	0	0	0
4	light	0	0	0	0	0	0
	dark	4	9	9	9	9	9
12	light	2	3	3	3	3	3
	dark	10	12.4	12.4	12.4	12.4	12.4
20	light	10	11.0	11.0	11.0	11.0	11.0

Effect of Temperature on Germination

In Japan, Arai, et al., (3) working with *Echinochloa crusgalli,* var. *oryzicola,* found the maximum temperature for germination was 45°C, the optimum was 30-35°, and the minimum was 10-15°C. In Washington, Roche, et al., (35) obtained optimum germination with alternating temperatures of 20-30°C, with light.

Materials and Methods

In Delaware 2-year-old seed, with dormancy broken naturally, was run through a gravity separator. Only the largest seeds were used. To prevent seed decay, they were treated with Arasan seed disinfectant. Three replications of 50 seeds each were placed in the germinator in the dark at varying temperatures for 20 days. Germinated seeds were counted and removed at 2-day intervals.

Results and Discussion

The optimum temperature for 89 percent, or maximum germination, was 100°F, although at 90°F, germination was 75 percent, only slightly lower (Table 4). At 110°F, there was some development of the radicle and plumule on many seeds, but it was abnormal, and not considered as germination. No germination occurred at the lower limit of 50°F. Similar results were obtained by Vengris, et al. (44).

It appears, then, that relatively high temperatures are needed for rapid and high germination. This means seed will germinate better during hot weather, and when it is close to the soil surface where the soil is warm.

TABLE 4. Effect of temperature on seed germination.

Temperature, °F	Germination, percent[1] 4 days	10 days	20 days
110	0	0	0 a[1]
100	88	89	89 b
90	71	73	75 c
80	39	39	39 d
70	31	43	43 d
60	0	30	45 d
50	0	0	0 a

[1] Numbers followed by the same letter are not statistically different at the 5% level.

Effect of Light and Moistening Agent on Germination

In Washington, Roche, et al., (35) obtained 12 percent more germination with light at a temperature of 86°F.

Materials and Methods

In New Hampshire, seed from Delaware and Massachusetts was exposed to varying amounts of light and was germinated at alternating room temperatures of 70°F for 16 hr and 60°F for 8 hr (9). Distilled water and 0.2 percent KNO_3 were used as moistening agents, with 10 ml to each petri dish containing 2 layers of filter paper. Four levels of light exposures to cool white fluorescent lamps set at 100 fc were used: 0, 1 hr, 8 hr, and 168 hr (continuous). Each treatment consisted of 5 replications of 100 seeds each. Final germination counts were made at the end of 7 days (168 hr).

Results and Discussion

Exposing seeds in the germinator to light improved germination greatly (Table 5). For example, after 1 week, 60 percent of the seeds under continuous light germinated, whereas only 6 percent of those in continuous dark germinated. These were the results with 1-year-old Delaware seed, in which dormancy was broken naturally. Results were inconclusive with Massachusetts seed which was only 2 months old and in which dormancy was obviously not broken. After 1 week, maximum germination was only 1.6 percent and after 1 month, 3.4 percent. Exposure of the Delaware seed to 1 or 8 hours of light had intermediate effects.

TABLE 5. Effect of light and moistening agent on germination.

Light exposure hrs	Moistening agent Water	0.2% KNO_3
0	6%[2]	12%[2]
1	13	12
8	35	39
168	60	68

[1] Cool white fluorescent lamp at 100 fc.
[2] Germination after 1 week.

Using 0.2 percent KNO_3 solution as a moistening agent rather than distilled water had a slightly beneficial effect in most cases. For example, after 7 days of continuous light, 68 percent germinated with 0.2 percent KNO_3 solution and 60 percent with distilled water.

Longevity of Seed

In Japan, Arai, et al. (3), observed that seeds lived longer in poorly-drained paddy fields than in well-drained soils. However, when seed was buried for 8 years in submerged soil and then germinated, most of the seedlings had abnormal and shorter plumules compared to those from seed buried for only 1 year. When stored in fresh running water for 3 to 9 months, only 1 percent of the seed germinated. After 12 months in fresh running water, no seed germinated. In Washington, Roche, et al., (35) found no reduction in germination after seed was buried in submerged soil for 30 months, but when buried under normal soil conditions for the same period, germination was reduced by 67 percent at a depth of 10 cm and 20 percent at a depth of 20 cm.

Materials and Methods

In Delaware in November 1962, freshly collected seed was divided into 2 lots. One lot was stored in a glass jar in the laboratory at room temperature, and the other lot was buried in a Matapeake loam in the field at 2 depths, 3 and 10 in. The following technique was used: 400 seeds were placed between plastic window screen in soil at the midpoint of a number of 4-in clay pots. Pots were covered with inverted clay saucers and buried in the soil. In half the pots, the seed was 3 in below the soil surface and in the other half, seed was 10 in below the soil surface. Each year one pot from each depth was lifted, and germination tests run. For each treatment, 150 seeds (3 replicates of 50 seeds each) were placed in the germinator at 100°F (Except in 1963, when 80°F temperature was used.)

Results and Discussion

After 3 years, there was no evidence of deterioration of seed viability, either when buried in the field or stored in the laboratory (Table 6). In fact, there was a slight trend for the 3-year-old seed to germinate better than 1- and 2-year-old seed. Approximately 90 percent of the 3-year-old seed germinated no matter where it was stored.

TABLE 6. Germination of barnyardgrass seed after being buried in the field or stored in the laboratory for varying periods of time.

	Percent germination after[2]		
Treatment	1 yr	2 yrs	3 yrs
Buried 3 in.[1]	58	73	87
Buried 10 in.[1]	73	90	93
Stored in laboratory	58	74	89

[1] Seed buried in the field on November 2, 1962.
[2] Germination after 20 days at 100°F, except for the first year when 80°F temperature was used.

Effect of Planting Depth, Soil Type, and Soil Compaction on Plant Emergence

Barnyardgrass seedlings have emerged from depths as great as 6 in (35). However, greatest and most rapid emergence usually occurred from ½ to 1½-in depths. (12, 35) The soil type here was Sagemoor fine sandy loam. Few seeds on the soil surface in the field germinated, presumably due to unfavorable moisture.

In Germany, Hanf (21) reports that heaviest seed is better able to emerge from the lower depths, and that seedlings can emerge from greater depths in sandy soil than in clay soil. He also found soil pressure to be of little influence on emergence unless aeration was inadequate.

Materials and Methods

In a field near Georgetown, Delaware, in a Matawan sandy loam, 200 seeds, 4 replications of 50 seeds each, were placed at each of the following depths: On the surface, and ½, 1, 2, 3, 4, 5, 6, and 7 in.

In the greenhouse in Delaware, 150 seeds, 3 replications of 50 seeds each, were placed at each of the following depths: On the surface, and ½, 1, 3, 5, and 7 in. Two soil types were used: a light soil, Matawan sandy loam; and a heavy soil, Matapeake loam. In addition, 2 levels of soil compaction were used: loose soil, which was sub-irrigated to avoid compaction; and compact soil, which was tamped heavily and also surface-watered to increase compaction.

Results and Discussion

In the field, no barnyardgrass emerged from deeper than 5 in (Table 7 and Figure 6). At 5 in only 8 percent of the seed emerged. Highest emergence was at the ½-in depth where 63 percent of the seed emerged. Emergence was also fairly good from the 2, 3, and 4-in depths, where approximately half the seed germinated. Only 9 percent of the seed placed on the soil surface germinated. These results indicate that a soil-incorporated herbicide would likely be more consistently effective for control of barnyardgrass, since this weed can germinate from relatively deep in the soil. A surface applied herbicide would be dependent on heavy rainfall or irrigation soon after application to carry it down as deep as 5 inches to kill germinating seed.

TABLE 7. Depth of emergence of barnyardgrass in a Matawan sandy loam in the field.

Depth in inches	Percent Emergence[1] after 40 days
Surface	9 a
1/2	63 b
1	53 bc
2	47 c
3	42 c
4	29 d
5	8 a
6	0 a
7	0 a

[1] Numbers followed by the same letter are not significantly different at 5% level.

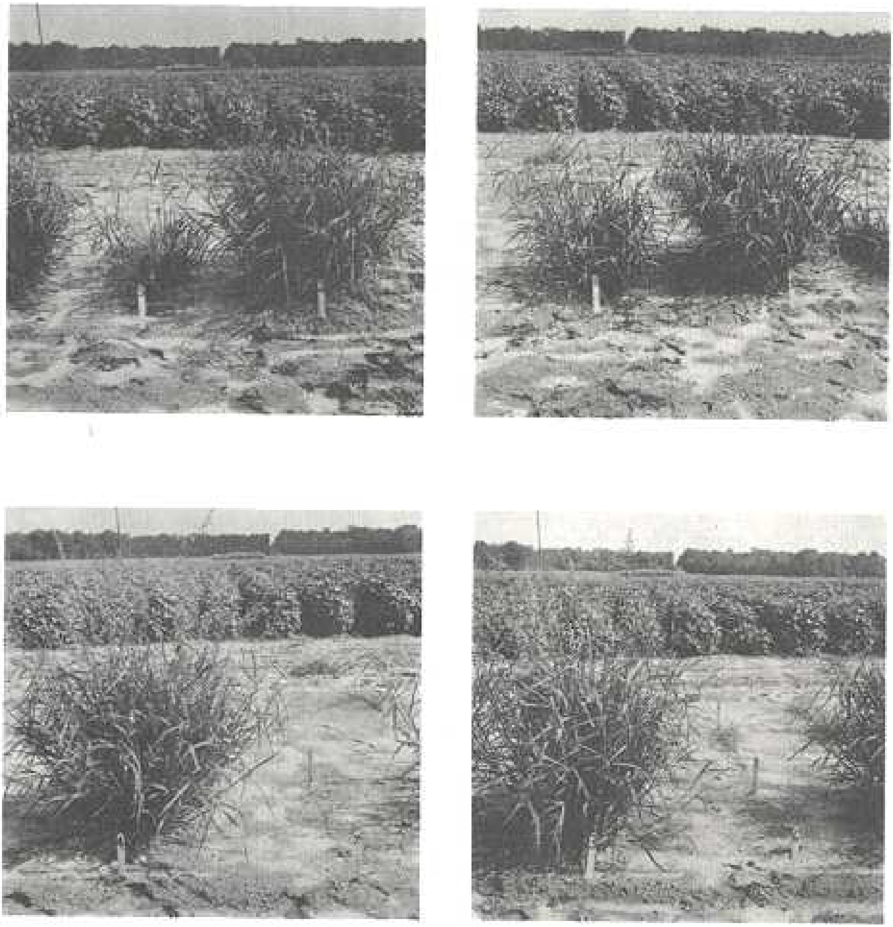

Figure 6. Emergence of barnyardgrass from varying depths in a Matawan sandy loam, Georgetown, Del., in 1965, showing relative plant growth and structure. Upper left, seed placed on soil surface and 2 in. deep; upper right, seed placed 5 and ½ in. deep; lower left, seed placed 4 and 7 in. deep; and lower right, seed placed 3 and 6 in. deep.

In the greenhouse, germination was best from seed placed on the soil surface (Table 8). This was contrary to results in the field, presumably because the soil surface did not dry up as readily in the greenhouse. Germination was somewhat more rapid in a sandy loam than in a loam. No seed emerged from the 5 or 7-in levels, even though about 25 percent of the seed germinated. Compaction of soil seemed to increase emergence (Table 9). This was especially true with seed placed ½ and 1 inch deep. At both these depths, 29 percent more seed germinated in the compacted soil as compared with the loose soil. This may have been due to better moisture relationships.

TABLE 8. Depth of emergence of barnyardgrass from two soil types in the greenhouse.

Depth in.	Percent Emergence after 10 Days: Sandy loam	10 Days: Loam	25 Days: Sandy loam	25 Days: Loam
Surface	70	28	80	54
1/2	23	5	41	32
1	14	8	33	21
3	7	3	9	6
5	0	0	0	0
7	0	0	0	0
L.S.D. at 5%	10		13	

TABLE 9. Effect of soil compaction on emergence of barnyardgrass from varying depths.

Depth in.	Percent Emergence after 10 days: Compacted[1]	10 days: Loose[2]	25 days: Compacted[1]	25 days: Loose[2]
Surface	41	57	71	64
1/2	11	16	51	22
1	9	13	42	13
3	3	7	8	7
5	0	0	0	0
7	0	0	0	0
L.S.D. at 5% level	NS		13	

1. Soil compacted by tamping and surface watering.
2. Soil kept loose by sub-irrigating.

Emergence under Field Conditions

Materials and Methods

In a heavily infested field of sandy loam near Milford, Delaware, a number of 3 x 3-ft plots were laid out on May 17, 1963. Treatments (Table 10) consisted of keeping the plots clean by hoeing for varying lengths of time, and then noting emergence of barnyardgrass after these periods. Treatments were replicated 4 times. Data so obtained might be used to adjust time of planting of a crop so as to avoid a heavy infestation of barnyardgrass.

Results and Discussion

Maximum emergence, 34 plants per 9 sq ft, was observed following the May 17 cultivation (Table 10). Emergence following successive cultivations, 2 to 3 weeks apart, decreased rapidly until there was no emergence, following the August 5 cultivation. According to this data, a crop planted on June 1 would have only 50 percent of the infestation in a crop planted on May 17, and a crop planted on July 5 would have only 13 percent of the infestation in a crop planted on May 17. This information can have practical value for the control of this pest.

TABLE 10. Emergence of barnyardgrass after varying periods of clean cultivation.

Date of last cultivation	Av. No. of plants per 9 sq ft	Percentage of 5/17 emergence
5/17	34 a	—
6/1	17 b	50
6/21	8 c	22
7/5	5 cd	13
7/23	3 cd	8
8/5	0 d	0

In Massachusetts, seasonal occurrence of barnyardgrass seedlings in potato fields was investigated in 1962, 1963 and 1964 (41). The barnyardgrass survey was made semi-monthly starting the first part of June and continuing until the harvest. Each year five, 2-to-4-acre potato fields were selected at random. Land was in an intensive agricultural area and heavily infested with barnyardgrass.

Seedlings of barnyardgrass began to emerge as soon as the potatoes or shortly after. Emergence continued throughout the growing season. With the advance of the growing season, barnyardgrass increased markedly. Weed plants were most noticeable in the field in August and September when the potato vines started to lodge and much of the grass was headed. A clean potato field at the beginning of the growing season may be so dominated by barnyardgrass in the fall that the field looks as if it were seeded to grass.

INFLUENCE OF CERTAIN ENVIRONMENTAL FACTORS ON GROWTH AND DEVELOPMENT OF BARNYARDGRASS

Light

Several aspects of light are well known to be important influences on the growth and development of plants including photoperiod, quality, intensity and total energy. The latter is a function of the combined influence of the first three. Temperature may or may not be a modifying influence depending on species and other factors. All of these aspects were investigated either in the field, greenhouse or laboratory in an attempt to determine their influence on barnyardgrass growth and development.

Photoperiod

Practically no specific literature on photoperiod and barnyardgrass existed at the time these studies were initiated. Dickerson (14) conducted greenhouse studies in Delaware designed to determine the influence of photoperiod on barnyardgrass. In the first test he used day lengths of 8, 12 and 16 hr and in a second test, 13, 14.5 and 16 hr. He worked in the winter period in regular greenhouses having average temperatures of about 70°F. All plants received full sunlight from 8 a.m. until mid-afternoon. Then they were either shaded or given artificial light from incandescent lamps depending on the photoperiod desired. Time clocks turned off the lights at the appropriate hour. About 55-60 foot candles at the soil level were provided those plants which required supplemental light.

Seeds were sown in clay pots 6 in. in diameter and were grown continuously under the particular photoperiod until harvest. When seedlings were thoroughly established, they were thinned to one vigorous seedling per pot. In the first test, a uniform harvest was made about 3 months after seeding. In the second, 6 plants were harvested from each photoperiod at intervals of 3, 6, 9 and 12 weeks following seeding. Data were recorded for several growth and development characteristics and analyzed by Duncan's Multiple Range Test.

Results

In the first test, plants receiving 8 and 12 hr of light were similar, while those receiving 16 hr were significantly taller and had greater fresh weight. However, to better understand the photoperiodic effect, it is more important to study the results from the second test in which day-lengths of 13, 14.5 and 16 hr were used, since photoperiods in this range are normal for the growing period. These results are presented in Table 11 and Figure 7.

TABLE 11. Development of barnyardgrass after 12 weeks under 13, 14.5 and 16 hr. photoperiods.

	Hours of Light		
Observations per plant	13	14.5	16
Height (cm)	71.5 b	148.9 a	152.9 a[1]
Top fresh wt. (gm)	5.0 b	31.8 a	32.5 a
Number of panicles	7.9 a	1.3 b	1.0 b
Number of primary tillers	3.3 a	.9 b	.6 b
Total number of tillers	7.1 a	1.1 b	.8 b
Leaves per main shoot	4.8 b	8.8 a	9.5 a
Total leaves	10.5 a	13.6 a	12.1 a

[1] Means that have the same letter following them are not significantly different at the 5% level.

It can be seen from the table that a photoperiod of 13 hr produced plants markedly different from those in the 14.5 and 16 hr treatments. Even though the shorter photoperiod plants had more tillers and panicles, they were only about one-half as tall and one-sixth as heavy as those receiving the longer day lengths. The results from the 13-hr treatment were very similar to those

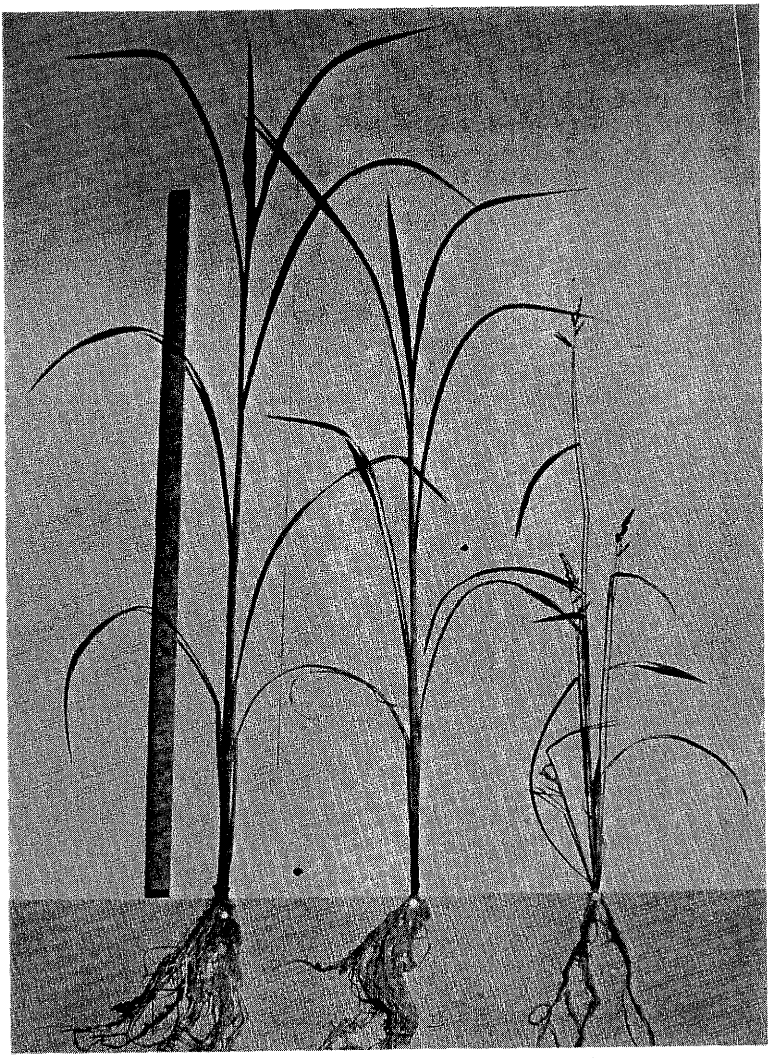

Figure 7. Barnyardgrass after 9 week exposure to day lengths of 16, 14.5, and 13 hrs. (left to right).

of the 8 and 12-hr treatments of the first experiment. It is obvious that the shorter day-length plants would have much less competitive influence on crop plants (see section on plant competition). The results from time of seeding studies (see later section) done in the field in Massachusetts, Delaware, Ithaca and Long Island tend to confirm the marked influence of photoperiod.

At the University of Massachusetts (44) the effect of photoperiod on growth and development of barnyardgrass was studied under controlled conditions in growth chambers. Two growth chambers were programmed for short-day conditions (11 hr) and two for long-day conditions (16 hr). Temperatures were maintained at or near 75°F from 6 a.m. until 6 p.m. and at 65°F from 6 p.m. to 6 a.m.

Barnyardgrass normally appears to be a short-day flowering plant (Figure 8). Plants under long-day conditions headed and produced mature seeds much later than similar plants under short-day conditions. The long delay in

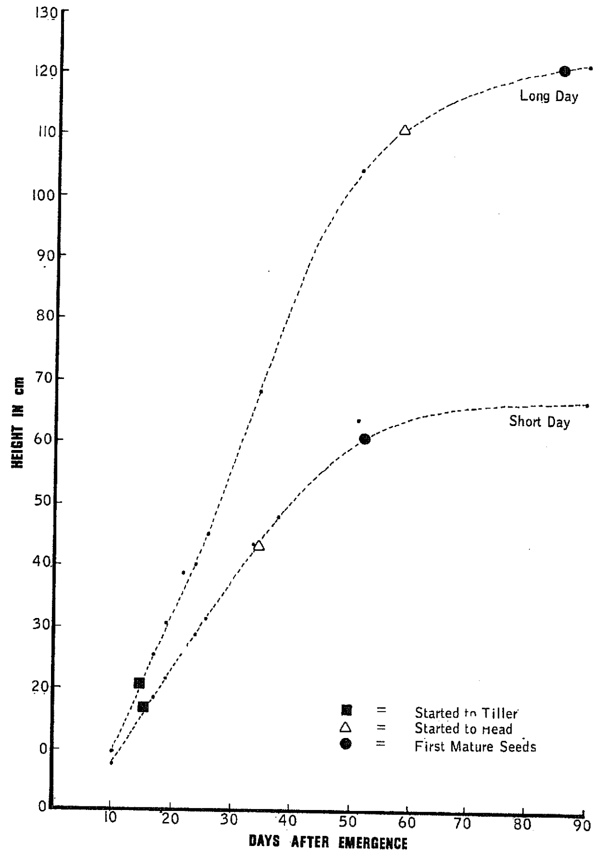

Figure 8. Growth and Development of barnyardgrass in growth chambers under 16-hr. (long-day) and 11-hr. (short-day) photoperiod.

flowering was associated with vigorous vegetative growth. Thus, at the time of heading, the long-day plants were over 100 cm tall, while plants under short-day conditions headed out about 3 weeks earlier at a height of only about 40 cm. This also was reflected in the field studies summarized in Table 18. Field plants emerging about June 10 and June 22 attained heights of approximately 150 cm in 6 weeks. Heading was similarly delayed, even when temperatures were favorable. Long-day conditions also produced much large inflorescences than those of short-day plants. Proportionally more seeds were produced by long-day plants. This grass apparently is adapted to a wide range of photoperiodic conditions. It flowers early under short-day conditions and thus appears to be a short-day plant. Under long-day conditions, barnyardgrass makes vigorous vegetative growth to produce extremely large plants with large inflorescence which produce many times more seed than comparable panicles grown under short-day conditions. The grass then appears to be a delayed long-day plant. Plants in the latitude of Massachusetts thus may be stimulated to large vegetative growth by exposure to long photoperiods. Southward, in latitudes of decreasing day length, the long photoperiod stimulation would not be noted and plants would be proportionately smaller, with each head producing fewer seeds. The observed combination of photoperiodic effects adapt barnyardgrass to essentially any photoperiod, fitting it for wide distribution as a nearly cosmopolitan weed.

Light Quality

Cilley and Dunn (8) in New Hampshire studied the influence of light quality on growth and development of barnyardgrass for 4 months under artificial conditions which permitted use of three light qualities.

Materials and Methods

The growth chamber, temperatures, lights, growing media, etc., were similar to those reported elsewhere in some detail (15, 32). Seeds were germinated in vermiculite and, after 4 weeks, were transplanted to plastic containers with similar media. Twelve plants were placed under each of three colors produced by fluorescent lights—red, white, and blue at equal intensities. Four months after seeding, plants were harvested and measurements made on stem length, stem number, fresh weight and dry weight.

Results

Blue light significantly reduced the height and weight of barnyardgrass when compared to white or red light (Table 12). However, no significant dif-

TABLE 12. Barnyardgrass growth under red, white, and blue fluorescent lights.

Observation	Light qualities: White	Red	Blue
Height of main stem (cm)	94.5a[1]	83.2a	67.3b
Number of tillers	4.2a	3.8a	3.7a
Fresh weight (gm)	34.2a	24.6a	11.4b
Dry weight (gm)	3.1a	1.9a	0.9b

[1] Values in the same row that have the same letter following them are not significantly different at the 5% level.

ferences were observed in the production of tillers. It was also noted that panicles were produced earlier under blue light. In general, the growth response of barnyardgrass to light quality is very similar to that of crabgrass (32).

Light Intensity

It has been shown with several grasses and sedges that shading has a profound effect on growth and development (5, 32). However, no research has been reported concerning this aspect of light and barnyardgrass.

Materials and Methods

Experiments were conducted at Newark, Delaware, and Ithaca, New York. Part of this research has been published by Bayer (4) and Dickerson (14). At both locations, special plantings were made in the field and various levels of shade applied. Commercially available Saran shade material was used over post and wire structures that held the material about 6-7 ft above the soil level. Plants received a given level of shade for the entire growing season. They were started in June and July and harvested September 16th at Ithaca and October 8th at Newark.

Results

The results of the shading treatments are summarized in Table 13. Interesting similarities as well as differences were found at the two locations.

Both the number of tillers and the number of panicles were always greater in full sunlight than in heavy shade, regardless of location or planting date. However, extended height, dry weight, and fresh weight showed considerable variation. In the test at Newark, Delaware, light to moderate shade dramatically increased height and fresh weight. Unfortunately, dry weights were

TABLE 13. The effect of shade on growth and development of barnyardgrass.

Percent shade	Extended height (cm)	Fresh weight (gm)	Dry weight (gm)	Primary tillers	Panicles
Newark, Delaware 1963 (Dickerson 1964)					
Planted July 11					
0	121b[1]	653b		102a	219a
25	163a	1420a		59b	229a
50	160a	789b		39c	117b
75	154a	277c		18d	41c
Ithaca, New York 1965					
Planted June 15					
0	153b	1152a	222a	51a	48a
30	163a	1115a	231a	44ab	44a
73	131c	580b	100b	29cd	26ab
Planted July 15					
0	85d	285c	32c	37bcd	44a
30	87d	240c	27c	32cd	34ab
73	77e	122d	14c	17e	9b

[1] Values followed by different letters within each experiment are significantly different at the 5% level.

not recorded. In contrast, at Ithaca, New York, low levels of shade had no marked effect on height or weight. At this location, the most significant changes in plant responses were due to differences in planting date (see Date of Planting section for more details).

It is believed that the differential responses to shade between Delaware and New York were associated with differences in air temperature and indirectly with soil type and water relations. Table 14 includes the monthly mean temperatures for the two locations. Throughout most of the experimental period there were 5-10°F differences in mean temperatures between the two locations as measured in the shade by official weather stations. It is likely that in full sunlight these differences would be even greater.

TABLE 14. Monthly average air temperatures at Ithaca, New York, and Newark, Delaware.

	June	July	August	September
Newark, Delaware—1963	70.1	76.2	71.7	64.0
Ithaca, New York—1965	62.3	65.6	67.1	61.9

Thus the plants in Newark undoubtedly had much higher water requirement than those in Ithaca. In addition, the Matapeake loam soil in Delaware was a relatively light soil of fairly low water-holding capacity, whereas that in New York was an Eel silt loam with a relatively high water-holding capacity. Probably the light shading in Delaware provided a climate that was comparable to that of full sunlight in Ithaca. This conclusion is substantiated by the fact that both plant height and fresh weight in light shade at Delaware were similar to that of plants in Ithaca under either full sun or light shade.

Effect of Nitrogen, Phosphorous and Potassium on Growth

The response of barnyardgrass to high levels of fertility is implied by its vigorous growth in crops under intensive cultivation. Several workers indicate that it is more serious in soils of high fertility (26, 38, 39).

Bayer (4) conducted a factorial experiment with nitrogen, phosphorous and potassium on two soil types: a Howard gravelly loam in a high state of fertility, and an Eel silt loam at a relatively low level of fertility. Significant linear responses in dry weight were observed on both soil types when nitrogen was added at rates of 50 to 100 pounds per acre. However, similar increases from phosphorous and potassium were observed only with the Eel silt loam which was at a low level of fertility. He concluded that barnyardgrass responded to the three major fertilizer elements with increased yields. On the Eel soil, phosphorous gave the greatest increase per unit of fertilizer added, followed by nitrogen and potassium.

Moisture

Adair, et al., (1, 29, 33) and many others describe barnyardgrass as a serious competitor in situations with high soil moisture. Jones (25) reported that partial control of barnyardgrass was achieved by flooding the seed bed with 4 to 8 in of water. Some barnyardgrass, however, emerged from underneath as much as 10 in of water. Cannon (7) studied the effects of oxygen tension on barnyardgrass roots and concluded that it "should probably be classed among the species which require good conditions of soil aeration."

Materials and Methods

Dickerson (14) studied the effect of three levels of moisture on the growth and development of barnyardgrass. This study was initiated in the greenhouse in March using the Ap horizon of Norfolk loamy sand in 8-in clay pots. After the seedlings had emerged treatments were given as follows: (a) water added when the mean available moisture for all pots fell below 35 percent available, (b) water added when the mean fell below 65 percent and, (c) soil maintained at saturation at all times by subirrigation. Soil moisture was measured with Bouyoucos moisture blocks placed in the center of each pot, 2 in below the surface. Natural day length was supplemented by approximately 60 foot-candles of incandescent light to give at least 16 hr of light for the duration of the experiment.

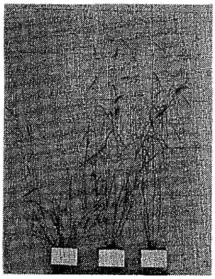

Figure 9. Barnyardgrass grown for 12 weeks under minimum available moisture levels of 35%, 65% and saturation (left to right).

Results

At the end of 12 weeks, 6 plants were harvested from each treatment and data obtained on extended height, fresh weight, number of panicle, tillers and leaves (Table 15). Plants that were watered when available moisture dropped below 35 percent were significantly shorter, but weighed nearly twice as much as those which were kept saturated. Similarly, plants from the saturated treatment produced less than one-half as many primary or total tillers as those from the 35 percent levels. It was interesting to note that, as the moisture increased, the growth habit of plants became more upright (Figure 9).

TABLE 15. Development of barnyardgrass after 12 weeks under three moisture levels.

Observations per plant	Moisture levels 35%[1]	65%[1]	Saturation
Height	175.2b	195.8a	203.4a[2]
Top fresh wt (gm)	202.0a	210.8a	108.0b
No. of panicles	6.8a	8.2a	7.2a
No. of primary tillers	10.0a	8.6a	3.2b
Total no. of tillers	18.8a	14.6ab	7.6b
Leaves per main shoot	20.6a	19.2a	16.2a
Total leaves	95.0a	81.4a	48.2b

[1] Watered when mean of available moisture for the treatment was below indicated percent as measured by Bouyoucos moisture blocks and meter.

[2] Values having the same letter following them are not significantly different at the 5% level.

These results indicate that barnyardgrass did not thrive under extremely high moisture conditions even though seedlings will emerge under conditions of low oxygen. Moisture conditions that are favorable for most crops are apparently optimum for barnyardgrass.

Growth and development of barnyardgrass also was studied in the field in Massachusetts under various soil moisture conditions. Barnyardgrass was seeded at South Deerfield farms on a loamy sand having excellent drainage. This area represents dry soil moisture conditions. For wet soil moisture conditions, plots at Amherst were on sandy loam. The "dry" area did not receive any irrigation; however, the "wet" area was irrigated as often as needed to keep soil moisture near field capacity. Each of these experimental areas was 30 x 80 ft. Branyardgrass was seeded in the middle of May in rows 2 ft apart. Each week, soil samples were taken for moisture content determinations. Data showing soil moisture conditions of these experimental plots are presented in Table 16. The relationship between foliage and root development on these plots was studied in 1962. To determine foliage to root ratios, plants were dug from two, 1-sq-yd areas in each field after tillering, but before elongation of internodes; after elongation of internodes, but before heading; and at maturity.

TABLE 16. Soils and soil moisture conditions used in studying growth and development of barnyardgrass in Massachusetts. Averages of 1962, 1963, and 1964.

Experiment areas	Soil text.	Field capacity	Soil moisture percent		
			Average	Range	Soil type
Dry	loamy sand	13.6	6.9	2.7-13.8	Hadley loamy fine sand
Wet	loamy	29.1	26.9	21.3-32.4	Merrimac fine sandy loam

Growth and development of barnyardgrass plants under wet and dry soil moisture conditions are presented in Table 17. Under wet conditions, average seedlings developed heads earlier, but this did not affect the date of plant maturity. Visual observations indicated that barnyardgrass grew and developed best under wet conditions. Dry soil conditions in particular depressed barnyardgrass height, yield and number of panicles per tiller. Observations in Massachusetts did not verify Hejny's (22) findings that barnyardgrass grown under wet conditions has longer awns. As one would expect, greater root to foliage ratio were found for plants grown under dry rather than wet soil moisture conditions. As development progressed, these differences decreased. In 1963 and 1964 plants growing under wet conditions were infested with leaf spot (*Helminthosporium spp.*)

TABLE 17. The influence of soil moisture conditions on growth and development of barnyardgrass. Average data for 1962, 1963, and 1964.

Soil moisture conditions	Seed. to emerg. days	Emerg. to tiller days	Emerg. to head days	Emerg. to maturity days	Main Tillers: Length in cm	Main Tillers: No. of elongated internodes
Dry	9	13	48	72	111	5.6
Wet	8	12	45	72	168	6.0

No. of tillers per plant	Av. length of a tiller in cm	No. of panicles per plant	Total yields lb/A[1]	Root/foliage ratio[2]: After tillering	Root/foliage ratio[2]: At elongated internodes	Root/foliage ratio[2]: At mature plants
11.8	85	0.5	4583c	.25	.21	.08
12.4	123	1.0	7560d	.11	.11	.07

[1] L.S.D. test. Values marked with different letters indicate significant differences at 5% level.

[2] Results of 1962 year only.

DATE OF PLANTING STUDIES

In the temperate regions, barnyardgrass can emerge throughout the growing season until killing frost in the fall. Growth, development and competition of a weed may vary considerably due to differences in time of emergence. Knowledge about these biological factors of weeds is limited. The objective of these investigations was to obtain specific information on growth and development of barnyardgrass emerging at various dates.

Materials and Methods

Special plantings were made at 2 week intervals in Delaware and Massachusetts and in two locations in New York, i.e. Ithaca and Riverhead, Long Island. These began in April or May and continued to late August or early September. Data were recorded on such aspects as emergence, rate of vegetative growth, extended height, tillering, number of panicles, heading, maturity of seeds, fresh weight and dry weight, etc. Not all measurements were made at all locations.

Results

Representative data on general growth characteristics from a few plantings in New York and Massachusetts are presented in Table 18. The most striking results from several experiments at the various locations were the drastic reductions in height, fresh weight and dry weight from seedings made the first week in July compared to those made earlier. In contrast, there was relatively little difference in growth and development between plantings made any time between April and early July. Also although remarkably similar trends in responses were observed at the different locations, the plants in Massachusetts were taller with fewer tillers. These differences are undoubtedly due to the much closer spacing used in Massachusetts than in New York or Delaware. The data are not presented here, but there was little variation at a given location from season to season in either growth, development, or maturity of barnyardgrass.

TABLE 18. Effect of date of planting and location on general growth and size of barnyardgrass.

Date of planting		Height (cm)		No. of. tillers		Dry wt.[1]	
N.Y.	Mass.	N.Y.	Mass.	N.Y.	Mass.	N.Y.	Mass.
5/8	5/2	120	167	28	9.7	71	3.97
6/4	6/1	110	153	37	9.7	88	3.90
6/19	6/16	103	150	29	9.6	58	2.87
7/3	7/2	70	116	22	12.2	16	1.65
7/18	7/16	22	80	17	12.0	3	0.84
7/30	8/1	10	33	3	6.1	1	0.21

[1] Grams per plant in New York; tons per acre in Massachusetts.

Germination and emergence of barnyardgrass (Table 19) varied from 11 days when planted in April to as short as 5 days when planted July 16. This is not a particularly striking difference for field conditions; however, these data are not based on percentage of emergence. Since an excess of seed was sown, as long as some plants emerged there was a sufficient numbr to permit thinning to the stand desired in these studies. In the laboratory, however, percentage germination at 60°F was reduced to about 40 percent of that at either 90° or 100°F. (Table 4)

TABLE 19. Influence of date of planting on the development of barnyardgrass.[1]

Date of seeding Del.	Mass.	Days to[2] emergence	Days to[2] tillering	Days to panicle	Panicles per plant	Days to maturity
5/9	5/2	11	25	68	8.7	88
6/6	6/1	9	22	63	9.6	81
7/4	7/2	7	17	47	12.5	74
8/1	8/1	7	23	44	5.4	74

[1] Data are averages from experiments at Massachusetts and Delaware except as noted.
[2] Massachusetts only.

Tillering initiation under field conditions appeared to be regulated by temperature and total day length rather than by photoperiod. As can be seen in Table 19, there was less time required for tillering to be initiated in the July plantings than in those made earlier or later. Tiller initiation ceased when the reproductive phase was reached. Plants changed to the reproductive stage sooner after seeding in August than when seeded earlier. In the field investigations, it is not possible to definitely ascribe this change to total light, temperature, or photoperiod. However, in the work in Delaware (Table 11) it was clearly shown that photoperiod had a marked influence on the reproductive development of barnyardgrass. The critical photoperiod was between 13 and 14.5 hours of light. The shorter days caused much more rapid change to the reproductive phase. This would strongly indicate that, in the field, lower temperatures in August are not as important as day length in changing plants to the reproductive phase. Furthermore, shading experiments (see earlier section) showed no relationship to time of tillering, but it did influence numbers of tillers.

Rate of vegetative growth, as measured by height, appeared to be directly related to temperature. Elongation was relatively slow in the early spring and until about June 25th. As can be seen in the graphs (Fig. 10), rates of extension increased dramatically in all plantings from late June until early August.

Discussion

Under field conditions very similar growth and development responses were obtained at 4 fairly widely separated locations. Furthermore, similar results were obtained in succeeding years. This clearly indicates the importance of photoperiod rather than soil, water, temperature, etc., in governing the growth, development, and reproduction of barnyardgrass. Controlled day length studies confirm the fact that photoperiod is exceedingly important in determining amount of tillering, tiller extension, etc. When the reproductive phase begins, essentially all further vegetative growth is stopped or drastically reduced.

These growth and development characteristics have a direct bearing on both the competitive ability of barnyardgrass and on the measures utilized to control it. For example, if good control in long season crops can be obtained

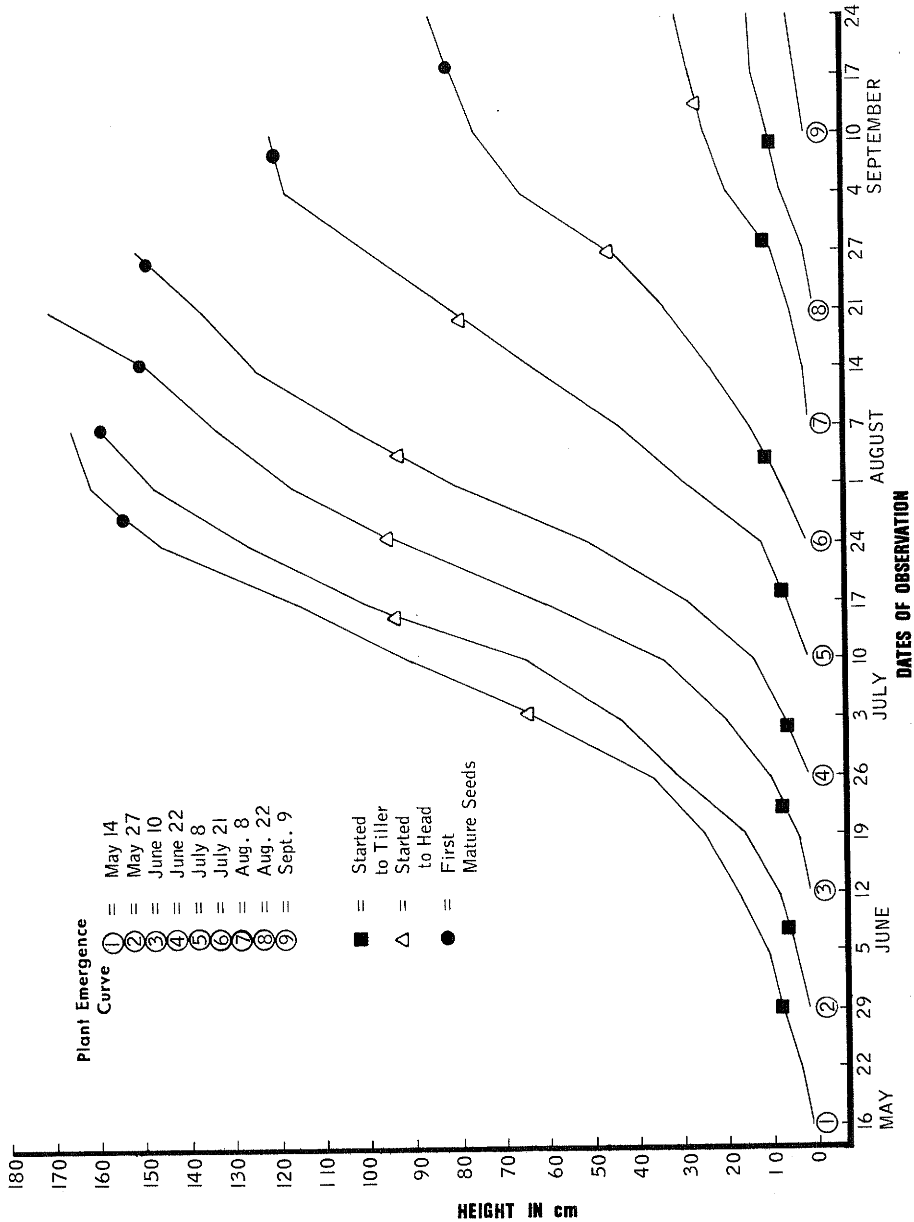

Figure 10. Growth and development of barnyardgrass emerging at various dates in Massachusetts. Averages of 1962, 1963 and 1964.

by mid-July, there is little need for specific control measures later in the season, since seedlings emerging after mid-July make only one-tenth to one-twentieth as much growth as those seedlings which emerge a month or two earlier. This reduction in growth of the late germinating plants is brought about by the marked sensitivity of barnyardgrass to photoperiod. As the days become shorter, reproductive rather than vegetative growth will occur so that, almost regardless of the date of emergence, seed heads will form during September. Furthermore, in crops such as corn, late-emerging seedlings will be heavily shaded by the crop and good control will occur naturally because barnyardgrass is exceedingly susceptible to dense shade (Fig. 11).

On the other hand, barnyardgrass, emerging in May, June, or early July, in crops that do not provide heavy shade, customarily makes very rapid and extensive vegetative growth provided adequate moisture and nutrients are present. Thus, it is likely to become a much more serious pest in intensively grown crops such as potatoes, snap beans, and other vegetables than in such crops as wheat, oats, and dry field beans.

COMPETITION STUDIES

Barnyardgrass grows tall, produces a large amount of foliage under favorable conditions (11, 30) and its competitiveness, if not controlled, is great. Competitiveness of barnyardgrass with potatoes (New York), beans (Delaware) and alfalfa (Massachusetts) was studied.

Potatoes

Materials and Methods

Bayer (4) investigated the competitive relationship between potatoes and barnyardgrass. Katahdin potatoes were planted in 3-ft rows with the seed pieces at 8-in spacings. Three rows of barnyardgrass were seeded in each row of potatoes, one directly in the plant row and the other two on each side of the hill. Barnyardgrass plants were spaced 6 in and 24 in apart in the row. The timing of barnyardgrass emergence was established by seeding it at various dates so that weed emergence would occur (a) at the same time as potatoes, (b) when potatoes were 2 to 4 in high, and (c) when potatoes were 12 in high. During the growing season, the plots were hand-weeded to remove any naturally occurring weed seedlings. The plants were irrigated as needed. The plots were dug by hand and the yield taken in total pounds of ungraded potatoes.

Results and Discussion

Potato yields decreased as barnyardgrass density increased and when the barnyardgrass emerged early in potato growth. (Table 20) Although the average effect of timing was less than the effect of spacing, potato yields were significantly higher in those plots where the weed emerged at the two later timings.

The average effect of spacing on barnyardgrass height and number of tillers was not significant. On the other hand, timing was significant; height and number of tillers significantly decreased from the early to the late plantings. Since barnyardgrass did not vary in height or number of tillers regardless of the spacings involved, while potato yields decreased with increasing barn-

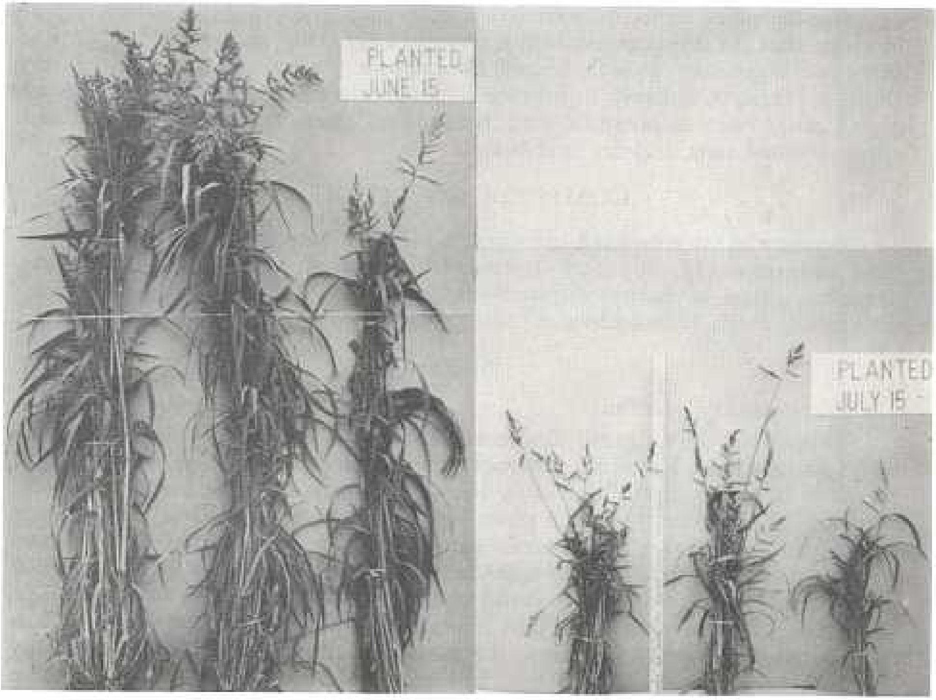

Figure 11. Effect of date of planting and shade on barnyardgrass, Ithaca, New York. Left to right in each series: zero, 30, and 75% shade.

yardgrass density, it is apparent that barnyardgrass was the successful competitor for the elements of growth. Light, water and mineral elements were undoubtedly involved to various degrees. The decrease in height and number of tillers of barnyardgrass with time of planting was apparently a photoperiodic effect plus the multiple effects of the established potato plants on seedling barnyardgrass.

TABLE 20. Pounds of potatoes per plot as affected by two levels of density and three times of emergence of barnyardgrass.

Spacing between barnyardgrass in inches	Time of barnyardgrass emergence: With Potatoes	Potatoes 2-4 in.	Potatoes 12 in.	Average effect of spacing
6	18.8	21.0	21.0	19.9
24	21.1	22.2	23.3	22.2
Average effect of timing	20.0	21.6	21.7	

Lima Beans and Snap Beans

Materials and Methods

Competition between barnyardgrass and Harvester snap beans and Thaxter lima beans were investigated in 1964 and 1965 in Delaware. The soil was a Matawan sandy loam. Barnyardgrass seed was planted directly on top of bean rows with Planet Jr. seeders. Rows were 3 ft apart. Beans were thinned during the second week and barnyardgrass plants were thinned during the fourth week after planting. The final plot consisted of a single row of beans spaced 2 in apart in the row overseeded with barnyardgrass 6, 12, 24, or 36 in apart. Also an experiment was conducted to find if increasing the population of bean plants would reduce barnyardgrass yields. In all trials four replicates were used. Plots were kept free of naturally occurring weeds by hand weeding. In 1965 irrigation was applied as needed.

Results and Discussion

When snap and lima beans were spaced at 2-in intervals in-the-row and barnyardgrass seedling spacings were varied from 36-in intervals down to 6-in intervals, bean yields were not significantly affected. These results were obtained in 1965 when soil moisture levels were maintained by irrigation and are in contrast to results from 1964 trials when soil moisture was limited to natural rainfall. Snap bean yields in 1964 were reduced by barnyardgrass plants growing at 6-in or 12-in intervals in the bean rows.

Lima beans had a significant effect on the size of barnyardgrass plants produced under irrigation in 1965 (Table 21). The closer spacings of lima bean plants greatly reduced the size and yields of barnyardgrass. This was not the case with snap beans. Differences in grass response to snap and lima beans can be attributed to the longer growing season required by limas. During the extra 4 weeks needed by limas, the closer spacings of beans slowed the growth of grass, keeping it at a size similar to that obtained by barnyardgrass in the snap bean plots. At a 6-in lima bean spacing, however, plant competition was such that grass continued growth and achieved much greater size.

Reduction in size of barnyardgrass plants is of great practical significance as large grass plants can cause much damage to mechanical harvesters. Under irrigation, whether snap or lima bean plants were spaced 1, 2, or 6 in. apart in the row, yields were not significantly affected by the presence of barnyardgrass at 6-in intervals in the row when compared with grass free plots. In the check plots where no grass was grown, yields were higher from the 1- and 2-in spacings than from the 6-in spacings of bean plants.

TABLE 21. Yields of beans and barnyardgrass as affected by various in the row spacings of beans in 1965 under irrigation. Barnyardgrass plants were spaced 6 in. apart. Weight lb./10 ft. row.

Spacing of bean plants	Weed Yields		Snap bean Yields		Lima bean Yields	
	With snap beans	With lima beans	Alone	With weeds	Alone	With weeds
1″	1.1a[1]	1.3a	6.6a	7.1a	2.5a	2.0a
2″	2.6a	2.1a	7.4a	6.2a	2.1ab	1.9a
6″	1.8a	6.7b	5.1b	6.1a	1.7b	1.2b

[1] Weights in the same column followed by the same letter are not different at the 5% level.

Alfalfa

Materials and Methods

Narragansett alfalfa was seeded in rows 1 ft apart and 10 ft long on May 4, 1963 and April 30, 1964. Barnyardgrass was seeded between alfalfa rows, the same day as the alfalfa and at 2 week intervals until August. Each time barnyardgrass rows were extended 10 ft beyond alfalfa seedings to make them 20 ft long with one-half growing between alfalfa and 10 ft alone in pure stands. The later ones served as checks in evaluating barnyardgrass response to the competition by alfalfa. Alfalfa grown alone in pure stands served as checks to evaluate alfalfa response to the competition by barnyardgrass. Plots consisted of four rows of alfalfa interseeded with 3 rows of barnyardgrass. After emergence, barnyardgrass was thinned to about 3 in between plants. Alfalfa stands were uniform and averaged 8 plants per foot row. All experimental areas were kept free of naturally occurring weeds by hand cultivation. In both years, the plots were harvested twice at the bloom stage of alfalfa. Dry weights of plants were used as a measure of yields. A randomized block design with four replicates was used.

Results and Discussion

The competition pattern between alfalfa and barnyardgrass was found to be similar in both experiments. The data of the 1963 and 1964 experiments are combined in Table 22.

Barnyardgrass emerging 2 weeks later than alfalfa significantly decreased yields of the first cuttings of alfalfa. The earlier the weed seedlings emerged, the greater the effect on alfalfa yields. The competition was found to be reciprocal—both species competed with each other. After the first cutting, both the alfalfa and barnyardgrass grew up and competition continued. Barnyardgrass seedlings that emerged July 8, about 2 weeks before the first mowing of alfalfa, became established and decreased yields of the second cutting of alfalfa significantly. At the first mowing, these barnyardgrass seedlings were stunted because they were suppressed by advance alfalfa plants; they did not produce any measurable yields. Alfalfa, after it was established, was more effective in suppressing the growth of the weed than the weed was in suppressing the growth of alfalfa. Total dry matter yields of alfalfa show that barnyardgrass seedlings emerging within 6 weeks after alfalfa emergence can decrease crop yields appreciably. Weed seedlings that emerged between June 24 and July 8 were suppressed the most. Their yields, compared with checks, were decreased up to 85 percent. Barnyardgrass seedlings emerging in August or later did not develop into large massive plants. They produced little foliage even when grown alone without any competition. The competition between alfalfa and barnyardgrass emerging in the fall decreases considerably. Thus, in the fall alfalfa yields are less affected by barnyardgrass, not only because of the increased competitive power of alfalfa but also because the competitiveness of the weed decreases significantly at this time.

TABLE 22. Yields of alfalfa and barnyardgrass in 1963 and 1964 as influenced by competitiveness of both plants when barnyardgrass was emerging at various dates.

Barnyard-grass Emergence dates month/day[1]	First mowing 7/20		Second mowing 9/10		Totals of both mowings	
	Barn-yardgrass	Alfalfa	Barn-yardgrass	Alfalfa	Barn-yardgrass	Alfalfa
5/14	66*[2]	70*[2]	74*[2]	36*[2]	70*[2]	59*[2]
5/26	64*	78*	63*	41*	64*	66*
6/10	30*	88	31*	54*	30*	77*
6/24	17*	99	16*	67*	16*	88
7/8			15*	73*	15*	91
7/22			38*	80	38*	93
8/7			58*	99	58*	99

[1] Alfalfa emerged May 9.
[2] Relative values alfalfa or barnyardgrass grown alone in pure stands=100.
* Indicates significant differences at the 5% level from checks, i.e. from barnyardgrass or alfalfa yields when these plants were grown alone in pure stands.

A plant which is able to establish itself first is usually a better competitor. (30, 31). Soil fertility and climatical conditions occurring in one growing season may favor one species; just the opposite may happen another year. Early seeding of alfalfa may be advantageous in its competition with naturally occurring barnyardgrass. Barnyardgrass is a warm season grass and usually emerges in Massachusetts later during the growing season.

Alfalfa seedlings, suppressed but not killed due to the competition from weeds, regained normal growth the following year. It is important to control barnyardgrass seedlings in the year alfalfa is established up to the time of the first mowing.

CONTROL OF BARNYARDGRASS

Chemicals

There are many chemicals[1] which are toxic to barnyardgrass, especially when in contact with the germinating seed or the emerging coleoptile. A partial list of these includes acetamides such as CDAA and diphenamide; benzoics such as amiben, dicamba and 2, 3, 6-TBA; thiocarbamates such as EPTC, pebulate and vernolate; triazines such as atrazine and simazine; substitute ureas such diuron, fenuron, and linuron; also amitrole, CIPC, dalapon, DPA, DCPA, Stoddard solvent and trifluralin. Successful utilization of these compounds is dependent on many factors i.e., crop tolerance, dosage, moisture, temperature, timing, placement, soil type,[2] etc. Unfortunately, only a few of these chemicals will kill established barnyardgrass plants, and it is particularly difficult to find ones which will remove them safely from established cultivated plants.

Dawson (9) did extensive work on the uptake of EPTC by barnyardgrass seedlings and showed the great importance of shoot uptake. Friesen, et al. (17) found similar results with uptake of CDAA by wild oats (*Avena fatua L.*). Bayer (4) studied the relative importance of shoots and roots of barnyardgrass in uptake of several herbicides in some detail. One of Bayer's techniques which proved highly successful involved spraying liquid latex on layers of treated and untreated soil as plastic pots were being filled and seeded. Barnyardgrass roots and shoot penetrated the latex layer readily. Subsequent bioassay tests of the various soil layers in the pot experiments showed that, except for EPTC, there was essentially no movement of any of the chemicals beyond the latex layer. Bayer concluded that for EPTC, linuron, dalapon, prometryne, and trifluralin shoot absorption was more important than root absorption whether the soil was moist or dry. However, with diphenamid root absorption was more important when the soil was relatively dry.

The importance of the coleoptile in herbicide absorption, and the lack of selectivity and/or the lack of activity of most post-emergence chemicals, make pre-emergence applications to barnyardgrass advisable. In fact, some compounds such as trifluralin, EPTC, and diphenamid are often incorporated prior to planting.

Frequently, reference in the field is made to the problem of barnyardgrass after lay-by and the statement made that "chemicals are not needed until lay-by." However, research by Bayer (4), Dickerson (14), and Vengris et al., (44), on growth and development indicate that only those seeds which germinate before the middle of July grow into plants capable of providing serious competition for most crop plants. Thus, the above generalizations regarding lay-by are evidently incorrect. While it is true that the problem of large barnyardgrass plants in crops does not become apparent until after lay-by, prevention nonetheless requires control of barnyardgrass during May, June and part of July. Pre-emergence chemicals applied after July 15 are not likely to be of much practical value in preventing large barnyardgrass plants at harvest time.

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[1] For specific research information on chemicals refer to the voluminous literature available in the proceedings of the several regional weed conferences and in *Weeds*, Journal of Weed Society of America.

[2] For current recommendations on control of chemicals, consult local agricultural authorities.

Cultural Practices

Cultivation.

Although cultivation has long been the only method available for controlling barnyardgrass in crops, it has een only partially successful. Where heavy infestations occur, such as in Delaware and Maryland and on the Eastern Shore of Virginia, fields are occasionally abandoned because cultivation failed to control this pest. In fields with moderate or light infestations, cultivation has proved more satisfactory. Bayer (4), working with tagged plants in potato fields having muck and loam soils, found higher final infestations in crop-plant rows than in areas between rows. This was a result of lack of removal by cultivation rather than increased emergence.

Even in areas with moderate infestations, cultivation has several important limitations. First, the crop must emerge well in advance of the barnyardgrass so that grass within the crop row can be covered with soil during cultivation without damage to the crop. Fairly large amounts of soil must be moved into the plant row because it has been observed that barnyardgrass which is only lightly covered will re-emerge. Second, since rainfall is erratic in the Northeast, cultivation cannot always be done at the most desirable time. In addition, some plants will survive if it rains soon after cultivation. Third, in many fields another flush of barnyardgrass seedlings will emerge a few days following cultivation if there is adequate soil moisture. Fourth, with large scale row-crop farming it is almost impossible, from a management standpoint, to cultivate each field at the most opportune time for good barnyardgrass control.

With the advent of herbicides effective on barnyardgrass and at the same time safe on crops, growers now use pre-plant or pre-emergence herbicides coupled with one or two cultivations. They are obtaining better results than with either chemicals or cultivation used separately. Many research workers confirm these results.

Crop Rotation

Crop rotations have not been of direct value in controlling barnyardgrass. To date, their principal advantage is that rotations sometimes permit planting the most severely infested fields to those crops having a high tolerance to chemicals that are effective against the grass. A few of the most outstanding field practices for controlling barnyardgrass are as follows: potatoes and snap beans treated with EPTC; lima beans, soybeans, and cole crops treated with trifluralin; tomatoes treated with diphenamid; carrots treated with Stoddard solvent; onions treated with CDAA; and sweet corn or field corn treated with atrazine or simazine. It is apparent that a wide choice of crops is available; most growers can select a rotation that will suit their soils, equipment, labor supply, and markets. They can readily plan a rotation that will materially reduce the chances of reduced crop yields due to heavy barnyardgrass infestations.

Sanitation

Although strict sanitation is of little value on fields where heavy infestations of barnyardgrass already exist, nonetheless it is of prime importance where an infestation is just starting. In fields where only an occasional plant occurs, farmers can well afford to remove them by hand before they have matured seeds. Bayer (4) calculated a potential yield of 900-1000 pounds per acre of seed from a solid stand of barnyardgrass since one fairly vigorous plant could produce 5000 to 7000 seeds. It is obvious that only one or two seasons of neglect will permit a light infestation to develop into a severe problem. In badly infested fields that are harvested early, a reasonable sanitation program of discing or plowing and seeding cover crops will tend to reduce the severity of the infestation. It is not known how long seed will remain viable in the field, but Rahn and Dickerson have studies underway in Delaware in which specially buried seeds are removed from the field at intervals and checked for germination. Good germination is still being obtained from seed buried four years ago when the experiment was started.

CLIPPING AND REGROWTH

Clipping and regrowth of barnyardgrass are of special interest since this occurs in the production of certain hay and forage crops. Also, one form of this grass, *Echinochloa crusgalli* var. *frumentacea* Roxb. Wright, Japanese millet, is used as a forage plant for silage and grazing.

Materials and Methods

In studying defoliation and regrowth of barnyardgrass, three separate field experiments were conducted during the 1962 and 1963 growing seasons at Amherst, Massachusetts (43). The experimental area was limed to pH 6.4 and fertilized with 44 lb of P and 83 lb of K per acre. Half of each plot received 150 lb. of N per acre at seeding and the other half received none. Clipping treatments were started at four different stages of barnyardgrass development: (A) before elongation of internodes, (B) after observable elongation of internodes but before heading, (C) at full heading, and (D) at maturity. The earlier the clippings were started, the more intensive the defoliation regime; plots of A, B, C, and D treatments were clipped on an average of 6, 4, 3, 1 times during the growing season, respectively. (Table 23). The second and all subsequent clippings were made at approximately uniform intervals and at the same stage of development as the first one.

TABLE 23. Pounds per acre of barnyardgrass* as affected by 4 clipping schedules, 2 cutting heights, and 2 nitrogen levels.

Clipping schedule	Clipping height, cm	Number of clippings	Yield, lb/A+ NO	Yield, lb/A+ N150
A) Before internode	5	5	2875 e	3046 e
elongation	10	6	3216 e	3905 d
B) After internode	5	3	3742 d	4286 d
elongation	10	4	4070 d	4583 d
C) At heading	5	2	6240 c	8503 b
	10	3	6056 c	7599 c
D) At maturity	5	1	8603 a	10380 a
	10	1	7625 b	9902 a

* Barnyard grass seeded 5-31-63.

+ Duncan's Multiple range test. Means with the same letters within a column do not differ significantly at the 5% level.

As the growing season progressed into late August and September, the regrowth shoots in treatments A and B, even though shorter, elongated and produced heads. Clippings were continued until killing frost.

After the killing frost, all plots were harvested for the last time and yields obtained were added to the total yields. Therefore, total yields in each case were for the entire growing season. Plant dry weights were used as a measure of yields. In each case a final plot consisted of a single row 10 ft long, with plots spaced 4 ft apart. Distances between rows were needed to exclude shading neighboring plots and possible effects on the regrowth. A randomized block design was used with 6 or 8 replicates.

Results and Discussion

The earlier the barnyardgrass clippings were started and the more often plants were clipped, the lower the total yields of dry matter (Table 23). Barnyardgrass yields were largest when mowed at maturity. This is in agreement with results of Mays and Washko (28).

The height of clipping was not, on the whole, an important factor in dry matter yields. Yield differences obtained between 5 cm and 10 cm height clipped plots were not statistically significant.

However, when comparing results of clipping treatments which were started before heading (clippings A and B) with those obtained at heading and at maturity (clipping C and D), significant differences were observed. When clippings were started early and an intensive clipping schedule employed, height of clipping was an important factor in regrowth (Table 23). Plants clipped at 10 cm recovered faster than those clipped at 5 cm. Total dry matter yields were consistently higher even though differences were not statistically significant in all experiments.

It is reasonable to assume that the higher clippings have less effect on the growing points concentrated in the grass crowns and that the taller stubble has more carbohydrates to instigate the regrowth of the plant. In treatments started at more advanced stages of growth, e.g. at heading or especially at maturity, regrowth did not play an important role in total yields produced. On the average, yields of plants clipped at 5 cm height were slightly greater (Table 23) than those cut at 10 cm height. Because of the shorter clipping, first cutting yields were higher and regrowth was too small to affect the results.

Additional N fertilization increased total dry matter yields (Table 24). Additional N significantly increased the yield of the first clipping but did not

TABLE 24. Seasonal yield distribution of barnyardgrass* as affected by 2 nitrogen levels and 2 cutting heights before internode elongation.

Clipping height, cm	N added lb/A	Yield, lb/A, of sep. clippings+ I	II	III	IV	V	VI	Total yield, lb/A
5[a]	0	487a	994a	732b	361c	304d	—	2875
	150	726b	1220a	561b	320c	219d	—	3046
10[b]	0	418a	561a	884a	618b	559c	177d	3216
	150	635b	714a	1107b	648b	602c	200d	3905

* Barnyardgrass seeded 5-31-63.

+ Means marked with a different letter in the same column are significantly different at 5% level between yields of N_0 and N_{150} within the same height of clipping.

[a]—Clipped 5 times.

[b]—Clipped 6 times.

in the following clippings. In some cases high N fertilization produced even lower aftermath yields. Results of clipping schedule A from experiment III illustrates this (Table 24). It is reasonable to assume that the liberal N fertilization stimulated the growth immediately after application and thus produced higher yields of the first cutting. This is in agreement with Dexter's findings (13) and apparently is caused by the upset of the nutrient balance of the plant. Reserve plant nutrients might be exhausted and plants weakened due to the stimulated growth immediately after application of nitrogenous fertilizers. Griffith et al. (20) found that nitrogen fertilization and close clipping were closely associated with severe stand losses.

Regardless of the clipping schedule, the barnyardgrass recovered and continued until the plants were killed by frost. Therefore, under normal field growing conditions in the Northeast region, defoliation to control barnyardgrass is of limited value. Exhaustion of the plants may, of course, decrease the competitiveness of the weed and probably contribute indirectly to the effectiveness of herbicidal treatments. Burt (6) found that herbicides as well as cultural control practices were more effective in controlling Johnson grass when the plants had been weakened by pasturing or mowing. This is a point that should justify further studies.

BIOLOGICAL CONTROL BY A WEEVIL

In 1962 in Massachusetts, the larvae of a weevil, *Hyperodes humilis, Gyll* (*Curculionidae*), was observed to feed on barnyardgrass (40). They usually attacked the growing points and the youngest tissue around them. As a result of injury, at first the youngest leaves usually wilted; then plants were stunted and more prolifically tillered. Plants infested at an early stage of growth usually died. The larvae caused greatest injury to the May 18 and June 1 seedings of barnyardgrass. July and August seedings were less affected. Field corn, crabgrass, and yellow foxtail growing nearby were not attacked.

SUMMARY AND CONCLUSIONS

This study consisted of many experiments covering various phases in the life cycle of barnyardgrass. The experiments were conducted cooperatively by the Delaware, Massachusetts, New Hampshire, and New York Agricultural Experiment Stations. Developmental anatomy and morphology were studied. Seed studies included duration and breaking of dormancy; effects of temperature, light, and moistening agent on germination; longevity; and emergence on varying dates and at varying depths. Environmental factors, such as day length, light quality and intensity, soil fertility and moisture and date of emergence, with their effects on growth of plants were explored. Competiveness of barnyardgrass with potatoes, lima beans, snap beans, and alfalfa was investigated. In studies on the control of barnyardgrass, herbicides, cultivation, crop rotation, and biological control by a weevil were evaluated.

As a result of these experiments, the following observations and conclusions were made:

1. Dormancy in freshly harvested barnyardgrass seed persists from 4 to 8 months.

2. The most effective treatments for breaking seed dormancy were removing seed covering; exposing seed to high (120°F) and low (40°F) tem-

peratures, especially when the seed was moist; soaking the seed in acetone for 20 min. in concentrated H_2SO_4 for 8 min, or in water for 4 days.

3. Even seeds harvested in the milk dough stage of development are able to produce new seedlings.

4. Optimum temperature for germination was 100°F.

5. Light was not necessary for germination, but it improved germination considerably.

6. After 3 years, there was no evidence of deterioration of seed viability, either when buried in the field or stored in the laboratory.

7. Greatest emergence in the field was from the ½ in depth. There was emergence, however, from as deep as 5 in. Soil compaction increased emergence.

8. In a heavily infested field, maximum emergence was just after the May 17 cultivation. Following successive cultivations, about 3 weeks apart, emergence decreased rapidly. Following the August 5 cultivation, no barnyardgrass emerged.

9. Short photoperiod, 13 hr, caused plants to be much smaller, but to bear many more tillers and panicles, compared with plants grown under photoperiods of 14.5 and 16 hr.

10. Blue light caused plants to be much smaller and to produce panicles earlier, compared with white and red light.

11. Shading caused a reduction in number of tillers and panicles. At Newark, Delaware, light to moderate shade, 25 to 50 percent, resulted in higher and heavier plants. At Ithaca, New York, this did not occur due, it is thought, to lower air temperature and higher moisture holding capacity of the soils in New York.

12. Barnyardgrass responded to additions of nitrogen on both high and low-fertility soils. Responses in additions of phosphorous and potassium occurred only on a low-fertility soil.

13. Barnyardgrass responded to high soil moisture, but growth was reduced when soils were kept saturated.

14. Seedlings that emerged after mid-July made only 1/10 to 1/20 as much growth as those emerging a month or two earlier.

15. Yields of potatoes were reduced in proportion to density and earliness of emergence of barnyardgrass. Yields of snap and lima beans were reduced in proportion to density of barnyardgrass when moisture was limiting, but not when moisture was optimum. Close in-the-row spacing of lima beans greatly reduced size of barnyardgrass plants. In newly seeded alfalfa, yields were reduced in proportion to the earliness of emergence of barnyardgrass. After alfalfa was established, it could successfully compete with barnyardgrass.

16. EPTC, linuron, dalapon, prometryne, and trifluralin entered barnyardgrass seedlings primarily through the coleoptile; diphenamid entered primarily through the root.

17. Clipping barnyardgrass, regardless of number of clippings and size of plants at time of clipping, did not adversely affect recovery of plants.

18. One example of biological control of barnyardgrass was observed in Massachusetts—a weevil that attacked the growing points and the youngest tissue around them. Field corn, crabgrass and yellow foxtail growing nearby were not attacked.

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