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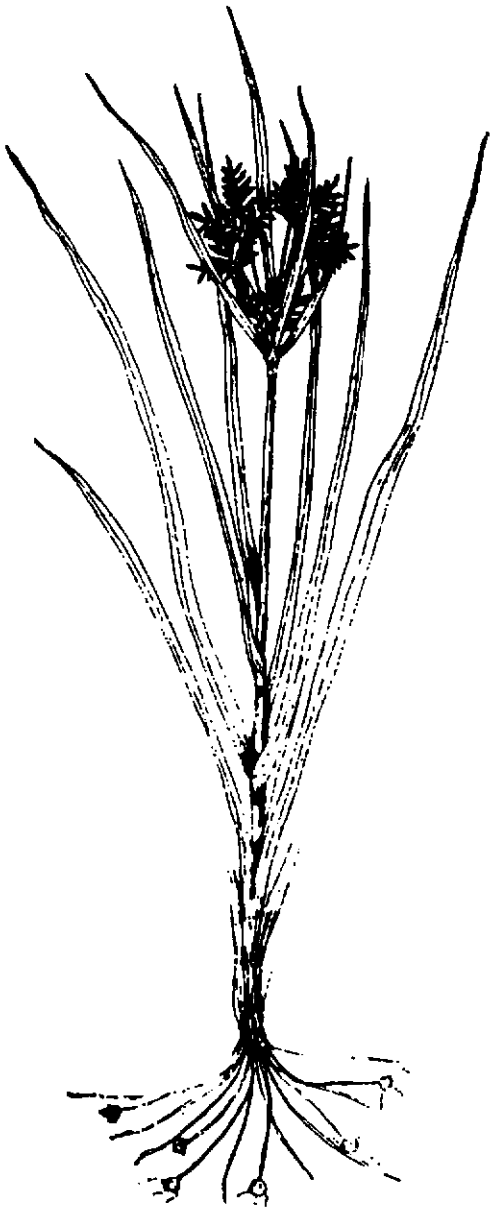
LIFE HISTORY STUDIES AS RELATED TO WEED CONTROL IN THE NORTHEAST

1 -- Nutgrass



Northeast Regional Publication

Agricultural Experiment Station
University of Rhode Island

LIFE HISTORY STUDIES AS RELATED TO WEED CONTROL IN THE NORTHEAST

1. Northern Nutgrass

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The research reported in this bulletin was conducted as part of the investigations of the regional weed research technical committee under Northeast Regional Project NE-42 "Weed Life Cycles, Soil Micro-organisms and Light as Factors in the Control of Weeds in the Northeast", a cooperative study involving the experiment stations in the Northeastern region. The work concerned with soil micro-organisms and light was initiated on July 1, 1954 under Northeast Regional Project NE-12 "Influence of Environmental Factors on the Effectiveness of Herbicides", and was continued under NE-42.

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LIFE HISTORY STUDIES AS RELATED TO WEED CONTROL IN THE NORTHEAST

Northern Nutgrass

INTRODUCTION

Northern nutgrass, *Cyperus esculentus L.*, also known as yellow nutgrass or nutsedge, is a serious weed in the 12 Northeastern states. During recent years this weed has become widespread in good agricultural land. It has even invaded lawns where its rapid growth and color are objectionable.

Nutgrass is a serious pest in many crops, but particularly in potatoes, corn, beans, tomatoes, peppers and nurseries. Nutgrass not only reduces yields and increases production costs due to increased cultivation and hand-weeding, but also lowers crop quality and increases harvesting and processing costs. For example, nutgrass rhizomes grow into and through potato tubers, causing them to be graded as culls. In the case of lima beans grown for processing, clumps of nutgrass going through the viners cause break-downs. In addition, nutgrass tubers become mixed with the shelled beans necessitating costly hand-sorting.

A regional study of the life cycle of northern nutgrass as affected by various environmental factors was begun July 1, 1958, by the Northeast Regional Weed Control Technical Committee (NE-42). Since little was known of the life cycle of this serious pest, it was considered necessary to conduct this study before planning experiments on its control. The findings of the four state experiment stations (Delaware, Massachusetts, New York and Rhode Island) who cooperated in the nutgrass study are brought together in this bulletin.

REVIEW OF LITERATURE

Description of northern nutgrass

Georgia (11) describes the northern nutgrass plant (*Cyperus esculentus* L.) in the following way: "Culms stout, 15 to 30 inches high, 3-sided, light yellowish green. Leaves about the same length, one-fourth to one-half inch wide, with heavy mid-vein and slightly roughened edges. The involucre has 3 to 6 leaf-like bracts extending much beyond the rays of the umbel, which are often compound. Spikes are straw-colored or pale yellow-brown, the whole plant being conspicuous for its light coloring, plainly visible at a distance among grasses. The scales of the spikelets are oblong-ovate, appressed at the base but loose at the tip, 3 to 5 nerved, with narrow scarious margins. Achenes small, oblong ovoid, three-sided, light yellowish brown." Drawings of the seeds and spikelets of *Cyperus esculentus* L. are shown in figure 1.

No botanical description of the nuts was found. If mentioned at all, they are referred to as tubers. Killinger and Stokes (15) of Florida described them

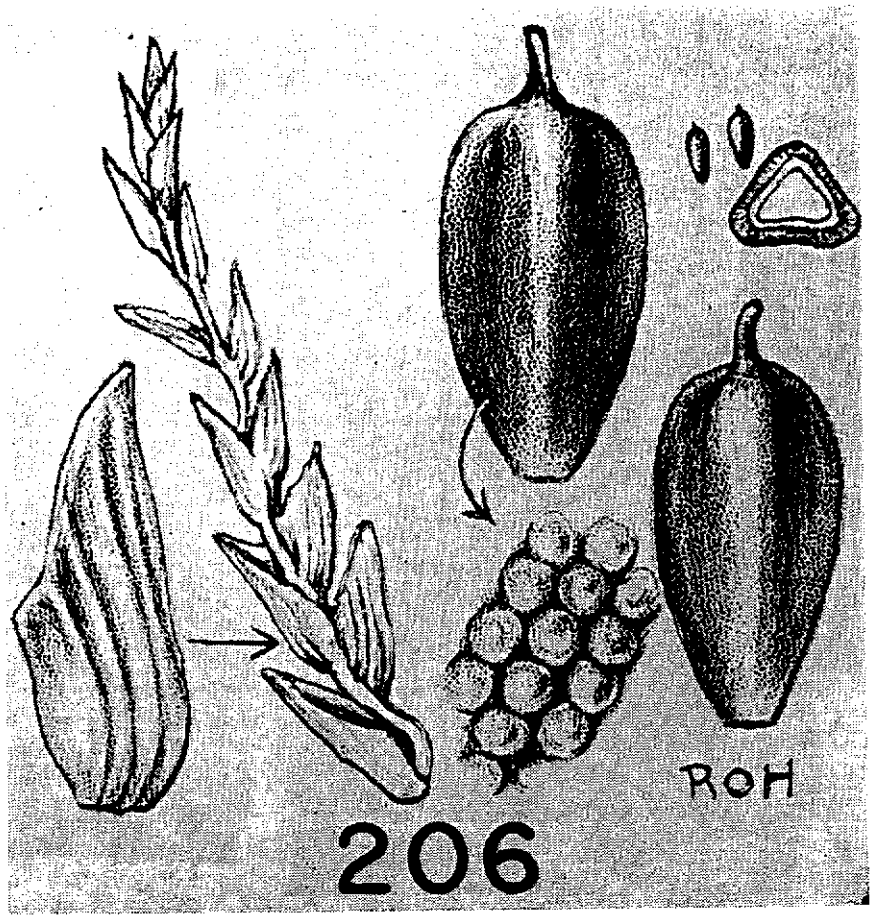


Figure 1. Details of seeds and spikelets of yellow (northern) nutgrass, C. esculentus L. (206), from USDA Handbook No. 30, plate XII. 1952.

as "small sweet tubers commonly called nuts". In this manuscript the words nut, nutlet and tuber will be used synonymously to refer to the underground storage organ. Morrison (17) describes them as "small chaffy tubers that remain in the ground uninjured over winter". In the South they are used to fatten swine, but produce a soft carcass which must be hardened by feeding corn. They analyze 0.7% protein, 6.6% fat, 10.5% carbohydrates and 20.5% dry matter. The tubers are usually oval and may attain a maximum size of one-half by one inch. Nutlets grown against a plowsole in potato fields may be flat on the lower side. The tubers are covered with a brown skin with many root-like projections over the surface. The interior is a hard white material which can be cut with a sharp knife.

When a tuber germinates one or more slender rhizomes originate from the buds at the apical end. As this rhizome nears the soil surface, a plant develops with a crown, topgrowth and roots. The new plant then produces many slender rhizomes which terminate in vegetative growth during a long photoperiod and in tubers, with less than a 12 hour day, or as the plant approaches maturity.

The crown at the base of the nutgrass plant is an important zone for re-

generation of new growth. Bell and Bannister (2) found that regrowth occurred from this area when the nutgrass was killed back by contact with herbicides. A small percentage of parent tubers will also resprout when the topgrowth is killed by herbicides or tillage.

The extensive infestation of the poorly drained soils of Minnesota was recently reported by Tumbleson and Kommedahl (23). One tuber in the field produced 1900 plants and 6900 tubers in a patch 6.5 feet across in one year. The most shoots were produced on peat, less on sandy loam, and least on sand. Shoots developed from nuts planted 20 to 32 inches deep in the greenhouse. Fallowing for 4 years did not completely eliminate viable tubers from a peat field. Tillage operations that exposed nutlets on the soil surface for 2 days lowered germination 80 percent.

Nutgrass maturing in cropland in September produces abundant seed. Justice and Whitehead (14) reported in 1946 that seed grown in Maine gave a high percentage of germination in laboratory tests. The importance of seed in the natural distribution of this weed was unknown. Orsenigo and Smith (18) of Cornell University made preliminary studies of factors connected with the germination of tubers and seed. Saidak (22) of Cornell reported a study to determine why dalapon produced variable field control of yellow nutsedge. Investigations using C^{14} labeled dalapon indicated negligible basipetal movement of leaf absorption while there was excellent distribution after root absorption. Little C^{14} accumulated in the parent tuber, indicating that under certain conditions limited dalapon translocation could account for variable field control.

PROCEDURES, RESULTS AND DISCUSSION

The life history studies consisted of germination tests with seeds and tubers after subjecting them to various chemical and temperature treatments. The effect of the photoperiod and light quantity on growth and development of shoots, tubers and seed were examined. The response of nutgrass plants to certain herbicides and other cultural treatments also received attention.

SEED STUDIES

Germination in the laboratory, greenhouse and field

In the laboratory tests 100 seeds were placed on moist filter paper in glass petri dishes. Each dish represented one treatment and there were 4 replicates of each. The tests with total darkness were conducted in aluminum weighing cans with moist filter paper in the bottom. The covers were tight-fitting and extended down $\frac{1}{4}$ inch around the edge of the can.

The germinators used in the laboratory tests were standard table models, with thermostatic control of electrical heating units. Diffused light entered

through a window in the door. When an alternating temperature range such as 70-90°F is mentioned, it should be interpreted to mean 70°F at night and 90°F during an 8-hour day. Additional tests were conducted in the greenhouse, either in petri dishes or in 6-inch clay pots of loam soil.

The germination tests were also conducted in the seed laboratory at the University of Massachusetts in the manner prescribed by the Official Seed Analysts (1). All treatments were replicated 4 times with 100 seeds in each replication. The substrate consisted of 2 discs of germination blotters placed in the bottom of covered petri dishes. The seeds were sprouted in standard seed germination chambers for a period of 45 days. All germinated seedlings were counted without regard for normal and abnormal seedlings. The seeds were dusted with arasan seed protectant before each treatment. Unless otherwise specified all tests were subjected to 16 hours of darkness and 8 hours of light. When an alternating temperature was used the seeds received 8 hours at the high temperature and 16 hours at the low temperature.

Inflorescences and seeds of northern nutgrass were obtained from several parts of the Northeast. All inflorescences obtained were identified as *Cyperus esculentus* L. The research personnel at Rhode Island and Massachusetts conducted comparable tests with seeds of the various regional strains of this weed. The results were similar in most instances. In the following pages each type of test will be summarized briefly with a minimum of tabular material.

Drying and cleaning seeds

Exposing the nutgrass inflorescences for a few hours at 100-120°F in an oven before drying at room temperature prevented a moldy condition which sometimes occurred when room-dried. Moldiness reduced the percentage germination. Massachusetts reported that temperatures up to 158°F for 3 hours did not affect germination.

The seeds were cleaned by screening them and subjecting them to an air blast which separated the heavier seeds from the lighter ones. The heavier seeds were used in the germination tests. Five lots of Massachusetts nutgrass seed weighed as follows per 100 seeds— 18.4, 19.9, 16.5, 14.8 and 15.2 milligrams. The mean germination, respectively, for each weight group was 74.2, 84.1, 44.1, 31.5, and 28.6 percent with an r value of 0.9992 for poor germination of light weight seed. Similar results were obtained in Rhode Island.

Temperature

From preliminary tests at Rhode Island, temperature seemed to be a critical factor. The first tests were attempted in 1957. Germination did not take place at constant temperatures of 75°F, 85°F or 95°F, but did occur when the temperatures were dropped to 70°F between 5 p.m. and 8 a.m.

Chemical treatments

Massachusetts workers soaked seed in concentrated sulfuric acid for 2, 5, and 10 minutes, then rinsed with water before placing them in petri dishes. The check seed germinated 72 percent after 18 days, while the germination of the acid treated seeds ranged from 88 to 91 percent. After 45 days in the germinator the differences were not as great.

Freshly harvested seeds were subjected to ethylene chlorohydrin vapors of several different concentrations for 24 hours. The results are in table 1. Concentrations of 0.2% and 0.5% increased germination significantly. The results suggest that the fresh seed was partially dormant and that the ethylene chlorohydrin overcame this condition since in a later test no improvement in germination was found. Subjecting seeds to a 12.5 M solution of sodium hydroxide, 0.1 M potassium permanganate or 0.1 M pyrogallic acid, from 2 to 10 minutes, did not inhibit nor improve seed germination.

Table 1. Effect of ethylene chlorohydrin on seed germination. (Mass.)

Treatment	% Germination
Check	29.7
0.2% ethylene chlorohydrin	50.7
0.5% ethylene chlorohydrin	46.0
1.0% ethylene chlorohydrin	8.7
2.0% ethylene chlorohydrin	0.0
5.0% ethylene chlorohydrin	0.0
LSD 0.05	4.9
LSD 0.01	6.8

Further results of chemical tests at Massachusetts (9) are presented in table 2. The freshly harvested seed used in this test was grown in Massachusetts from Rhode Island seed. The germination medium was saturated with potassium nitrate, ammonium nitrate, and combination of these with manganese sulfate. The average germination for seeds moistened with water was 47.7 percent. The 0.1 percent potassium nitrite and the 0.1 and 0.2 percent ammonium nitrate solutions increased germination significantly. The others produced no benefit or were definitely detrimental. Soaking seeds in solutions of potassium gibberellate for 2 hours, or initially moistening the filter papers with this solution increased the average germination of nutgrass seed from 46 to 67 percent. In general, 10 ppm was as effective as 1000 ppm of material. The seedlings receiving the gibberellate were 3 to 7 mm taller than the checks.

Germination media

In an experiment with seeds from Rhode Island (1957) and New York (1958) filter paper was compared to potting soil as germination media in petri dishes. The test was conducted in diffused daylight in a greenhouse with 85°F day temperature. The night temperature ranged from 60 to 70°F. Water and

O.1 and 0.2 percent KNO_3 solutions were compared. The percent germinations are shown in table 3.

Table 2. Effects of various chemicals on the germination of a R. I. strain of nutgrass grown in Massachusetts.

	% Germination	Treatments	% Germination
Check	47.7	0.2% $MnSO_4/KNO_3$	46.5
1.0% KNO_3	0.0	0.1% $MnSO_4/KNO_3$	49.5
0.5% KNO_3	4.7	1.0% $MnSO_4/NH_4NO_3$	1.0
0.2% KNO_3	49.0	0.5% $MnSO_4/NH_4NO_3$	40.2
0.1% KNO_3	56.0	0.2% $MnSO_4/NH_4NO_3$	43.5
1.0% NH_4NO_3	26.0	0.1% $MnSO_4/NH_4NO_3$	44.0
0.6% NH_4NO_3	53.2	1.0% KNO_3	42.0
0.2% NH_4NO_3	57.2	0.5% KNO_3	45.5
0.1% NH_4NO_3	54.2	0.2% KNO_3	45.7
1.0% $MnSO_4/KNO_3$	33.2	0.1% KNO_3	47.7
0.5% $MnSO_4/KNO_3$	46.7		
LSD 0.05	5.9	LSD 0.05	5.9
LSD 0.01	7.8	LSD 0.01	7.8

Table 3. Effect of media and KNO_3 solution on percent germination of 2 nutgrass strains at 85°F day temperature and 60-70°F at night. (R. I.)

Solution	Potting soil		Filter paper		Av. sol. & media	
	%	Arc-sine	%	Arc-sine	%	Arc-sine
			Rhode Island 1957			
Tap water	79	62.5	68	55.4	73	59.0
0.1% KNO_3	86	68.1	75	61.0	80	64.6
0.2% KNO_3	88	69.9	65	54.0	76	62.0
Average	84	66.8	69	56.8	76	61.9
			New York 1958			
Tap water	74	59.4	85	68.0	79	65.7
0.1% KNO_3	86	68.3	91	72.7	88	70.5
0.2% KNO_3	78	62.3	84	67.0	81	64.7
Average	79	63.3	87	69.2	83	66.3

LSD 0.05 Solution = 4.2 arc-sine values.
LSD 0.05 Strain x media = 4.9 arc-sine values.
LSD 0.05 Strain x media = 6.4 arc-sine values.

Statistical interpretation of the arc-sine values shows that the Rhode Island strain germinated significantly better on soil than on filter paper, the average for soil being 84 percent compared to 69 percent for filter paper. Comparing soil to paper, with New York seed, the average germinations were 79 and 87 percent, respectively. In this particular test, germination was statistically superior where 0.1 percent KNO_3 solution was used. With average germinations as high as 85 percent for water, these differences are probably not of practical importance as far as the potential infestation of fields by this weed is concerned.

Light quality and quantity

Tests were conducted in the seed laboratory (Mass.) to determine the effect of light quantity and quality on germination of nutgrass seed. Four

hundred seeds from each of 4 separate lots were subjected to each test in this experiment.

The seed from all treatments were alternated between 8 hours under the appropriate light treatments at 86°F. and 16 hours of darkness at 68°F. The amount of water used to moisten the germination blotters was kept constant.

Light quality was controlled by wrapping DuPont colored cellophane over the germinating dishes. Sylvania daylight fluorescent bulbs were used as the source of light and these were suspended 22 inches above the surface of the germinator. Light intensities were maintained by means of 2, 4 and 8 bulbs which produced 65, 140 and 280 foot candles of light, respectively.

Eleven treatments with light included the following colors: red ,pink, light yellow, dark yellow, light green, dark green, orchid, light blue, dark blue, red plus dark blue, and clear. An analysis of the data revealed no significant differences among the following treatments: red, pink, light yellow, dark yellow, light green, orchid, light blue, clear and the check. Seeds under dark green, red plus dark blue and dark blue, however, germinated significantly poorer than the check; seeds under dark blue germinated 48 percent less than the check. Light intensity resulted in a variation of results with poorest germination at 140 foot candles.

Interaction of temperature, light and moistening agent

Results of two typical experiments with temperature variations, KNO_3 as compared to water as a moistening agent, and light and dark versus complete dark, are presented in tables 4 (Rhode Island) and 5 (Massachusetts).

The germination (R. I.) was poor at 75°F and the figures were not included in the statistical analysis (see table 4). Germination at 95°F temperature was significantly better than at 85°F at the 1 percent level. Germination was also better in the glass petri dishes than in the aluminum cans. Even in the cans the percent of germination ranged from 65 to 85. This indicates that continuous darkness, *per se,* was not a particularly depressive factor, but that the environment in the darkened cans was not as favorable as in petri dishes. Potassium nitrate solutions were no more favorable than water in this test. The experiment described above was repeated in April 1959 with similar results.

The Massachusetts workers in 3 tests found that continuous darkness interfered with germination in the 68-86°F range but not in the 68-95°F range (see table 5). They used the Massachusetts seed and seed from plants which originated from the seed grown in Rhode Island. Apparently, when conditions are quite favorable for germination, complete darkness is not an inhibiting factor.

The effect of continuous light versus the normal diffused light which penetrates the germinators during the daytime was examined. The germinations for

continuous versus normal light were 67 and 70 percent, respectively. Under bright light, seedlings were short and dark green, while under diffused light they were tall and yellowish. Similar results were obtained with germination tests in the greenhouse where the seeds in one case were exposed to sunlight, while another set was shaded. No significant difference in germination was found. The shaded seedlings ranged from 15-32 mm, while those in direct sunlight were 2 to 10 mm in length 4 weeks after planting.

Table 4. Effect of light, temperature and KNO_3 solutions on the percent germination of northern nutgrass seed. (R. I.)

Solution	75°F*	85°F		95°F		Av. both temp.	
	%	%	Arc-sine	%	Arc-sine	%	Arc-sine
		Alternate light					
Water	0	73	58.6	96	78.1	84	68.4
0.1% KNO_3	1	76	60.7	93	74.3	84	67.5
0.2% KNO_3	2	69	56.4	85	60.0	77	58.2
Average		73	58.6	91	70.8	82	64.7
		Continuous darkness					
Water	1	68	55.6	82	65.8	75	60.7
0.1% KNO_3	7	65	54.1	80	63.6	72	58.9
0.2% KNO_3	13	66	54.5	85	67.9	75	61.2
Average		66	54.7	82	65.8	74	60.3

LSD 0.05 Temperature = 2.4 arc-sine values.
LSD 0.01 Temperature = 3.1 arc-sine values.
LSD 0.05 Light-darkness x solution = 4.1 arc-sine values.

Table 5. Effects of light, darkness, KNO_3 and temperature on percent germination of seed of a Rhode Island strain of nutgrass grown in Massachusetts.

Temperature	Check	Dark	0.2% KNO_3	Stratified at 50°F		Means
				5 days	30 days	
68-86°F	36.0	1.5	45.0	55.0	37.7	68.8
68-95°F	59.2	46.2	70.0	63.5	66.2	59.3
Total means	47.6	23.9	67.5	59.2	52.2	
LSD 0.05 Treatments						4.7
LSD 0.01 Treatments						6.3
LSD 0.05 Temp. x treat.	6.6	6.6	6.6	6.6	6.6	3.0
LSD 0.01 Temp. x treat.	8.9	8.9	8.9	N.S.	8.9	4.0

*Not used in statistical analysis.

Herbicidal Treatment

Two groups of seed were exposed to EPTC vapor (ethyl di-n-propylthiocarbamate) for periods of 0, 2, 4 and 8 hours. One lot was moistened 24 hours before treatment. The other was dry. Both groups of seeds germinated well, but showed damage shortly thereafter.

In another test dry seeds were given a similar exposure to vapor and were washed afterward, first in 95% alcohol, and then in water before being placed in the germinator. Seeds not exposed to EPTC germinated 92% while the exposed seeds were 85% viable.

Washing the seeds after treatment did not remove the toxic principle. In both these tests seedling damage was proportional to the length of exposure to

EPTC vapor. Shorter coleoptiles, burned and wilted tips, and thick, short roots which ended in a lump from which smaller and thinner roots grew, were characteristic of the damaged seedlings.

In a germination test in the greenhouse, New York (1958) seed was sown in potting soil in petri dishes and exposed to EPTC vapor for 0, 2, 4, and 8 hours. In half of the petri dishes the soil was kept dry (15% moisture) during the treatment; in the other half the soil was saturated with water. The dry soil was saturated with water after the vapor treatment.

The seedlings in the treated dishes showed an increased damage the longer the seed was exposed to the EPTC vapor. From the 8-hour treatment the seedlings were very short, thick and with a brown wilted tip. Even the seedlings from the 2-hour treatments were harmed. The damage was slightly less when the soil was dry during exposure to the vapor.

Good germination was obtained in all treatments, but there was a clear difference in the heights of the seedlings, which at the end of the third week were as follows:

	no treatment	2.5 cm
from	2-hour treatment	1 to 1.5 cm
moist	4-hour treatment	1.0 cm
seed	8-hour treatment	0.7 cm

The seedlings from dry-heated seed were a little longer than the seedlings from the moist-treated seed:

from	2-hour treatment	2.0 cm
dry	4-hour treatment	1.5 to 1.8 cm
seed	8-hour treatment	1.0 cm

Three weeks from seeding the growth of vapor-treated seedlings stopped. During the following two weeks they shriveled and mostly disintegrated. Only short stubs of the stems were left. After 8 weeks from seeding even the stubs of the stems disappeared and only small residues could be found. The check seedlings grew well.

In Rhode Island tests no differences in germination were found between seeds from plants sprayed with sodium arsenite vine killer and unsprayed plants.

Maturity of seed

Five collections of seed were made at the Gardner farm in Rhode Island, starting August 12, 1959 which was 3 weeks after pollination of the nutgrass flowers. The seed heads were green at the early harvests, but seed could be threshed out by rubbing them between the hands. Each batch of seed was stored at room temperature until November 18, 1959 when the germination test was started. The results are presented in table 6. The percent germinations

ranged from 17 to 55 percent. The average percent germination was considerably higher for seed harvested in September. This undoubtedly reflects more mature seed at the later harvests.

Table 6. Average germination of seed from different 1959 harvests from the Gardner farm. The test started November 18, 1959. (R.I.)

Date of Harvest	Germination %	Arc-sine
August 12	22	27.6
August 25	37	37.3
August 31	17	24.3
September 8	41	39.5
September 14	55	47.8
LSD 0.05 = 5.7 arc-sine values		
LSD 0.01 = 7.9 arc-sine values		

Storage conditions

Effect of wetting and drying seeds planted on filter paper and stored at 70°F or 54°F for a 60-day period was studied at Rhode Island. Alternating wet and dry periods did not prevent germination. Overall germination was somewhat less for some treatments at the 70°F temperature. It may be inferred from this that wetting and drying under field conditions will not materially reduce the viability of nutgrass seed when the temperatures are lower than necessary for germination. Experience has shown that after germination, seedlings are severely damaged from being dry for 24 hours.

Massachusetts tested seed stored at 5°F for a month before germination. Seed grown during 1958 in Massachusetts and Rhode Island was divided into three lots, one at room temperature, another at 5°F but dry, and a third at 5°F and wet. The germination of the dry seed was no different than the check, approximately 80 percent. The germination of the wet, cold seed was reduced to 34 percent.

A similar experiment carried out at Rhode Island with 1960 seeds from Massachusetts, NewYork and Rhode Island produced similar results. See table 7. Seeds were planted on moist filter paper and held for three months at either 0°F or 50°F. A third set was alternated weekly between 0°F and 50°F and a fourth between 50°F and 70°F. The check was from seed stored in a dry room. Fifty degrees appeared to be a favorable temperature for the storage of seed, since the best germination for each variety was obtained with this treatment, although the room-stored seeds were nearly as good. Holding the seeds wet at 0°F or at the alternating temperatures reduced seed viability considerably, but did not eliminate it. This suggests that some nutgrass seed will overwinter in soil and survive fluctuating temperatures.

Dry seeds of 4 strains of northern nutgrass were refrigerated at 36°F for 3 years. A comparable group was held at room temperature. In general, germination was equally good. The Massachusetts strain for example was 94 and 86 percent respectively, for the warm versus cold storage.

Table 7. The effect of 3 month storage temperatures on the viability of 3 strains of moist northern nutgrass seed. (R.I.)

		CK	0°F	50°F	50-70°F	0-50°F
R. I.	% germination	93	62	98	59	31
	Arc-sine	75.1	52.2	81.2	50.0	33.8
Mass.	% germination	50	21	53	27	9
	Arc-sine	44.7	27.5	46.7	31.3	17.2
N. Y.	% germination	64	36	83	27	12
	Arc-sine	53.4	36.9	65.9	31.3	20.6
LSD 0.05 Treatment			= 7.3 arc-sine values			
LSD 0.01 Treatment			= 9.8 arc-sine values			
LSD 0.05 State			= 5.7 arc-sine values			
LSD 0.01 State			= 7.6 arc-sine values			
LSD 0.05 Treatment x state			=12.6 arc-sine values			
LSD 0.01 Treatment x state			=16.9 arc-sine values			

Depth of seeding

Seed of northern nutgrass was sown at different depths in pots of sandy loam using 100 seeds in each. The planting depths were $\frac{1}{4}$, $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2 and $2\frac{1}{2}$ inches. There were 4 replicates for each depth. After the seeds were planted, the pots were plunged in soil on the Peckham farm. They were fertilized at the rate of 1500 pounds per acre with 10-10-10 fertilizer, and prevented from drying out by irrigation. The test was started May 27, 1959 and the results are presented in table 8.

Table 8. Germination of nutgrass seed planted at 4 depths in pots of soil. (R.I.)

	Depth of seeding			
	¼ inch	½ inch	1 inch	1½ inch
Percent germination	31	21	6	0
Days to emergence	12	14	19	. .

The results indicate that seed $1\frac{1}{2}$ inches or deeper below the surface of the soil was not able to come up. It was not determined whether the seed remained dormant or whether the seedlings died after germination at the lower depths.

Field plantings

The soil on the Peckham farm is sandy loam with pH 5.5. Plots were established in a field free from nutgrass and were fertilized with 1500 pounds per acre of 10-10-10 fertilizer.

Seeds of the 1958 harvest from New York, Rhode Island and Massachusetts were used. Twelve hundred seeds from each state were sown in 4 replicates. Each row was 9 feet long and 300 seeds were planted in each. The seeds were sown May 26, 1959 and were irrigated as often as necessary to keep soil moist. Throughout the growing season the plots were kept clean by hoeing.

The first seedlings emerged 15 days after sowing. Total germination on July 6 for the New York, Massachusetts and Rhode Island seed, respectively,

was 33, 15 and 0.8 percent. Flowering began August 26, which was 92 days after seeding. The best growth occurred during July, which was a warm, humid month with rainfall above average. The New York strain grew faster than those from Massachusetts and Rhode Island. All plants were green until the middle of September. On September 16, 113 days after sowing, the New York plants had 31 seedheads with mature seed. The Massachusetts and Rhode Island plants had 9 and 4 inflorescenses, respectively. On September 28 the plants turned a brown-yellow color and only younger stems were still green. The following night the plants were destroyed by frost.

A second field trial started July 6, 1959. The plots were established in the same field as before. The same strains, amount of seed and planting procedures were used. The first seedlings were observed July 20 (14 days after sowing) and when counted July 29, an average germination of 28, 18 and 2 percent was recorded for New York, Massachusetts and Rhode Island, respectively.

The plants grew until the middle of September and stopped with the advent of cold weather. The tallest plants, $1\frac{1}{2}$ feet, were the Massachusetts strain. The strains from Rhode Island and New York averaged one foot. Only one inflorescence was produced from the three strains and that was from a Rhode Island plant. On September 28 the plants were frosted and deteriorated rapidly.

On October 28, 1960 Rhode Island seed from the 1957 harvest and seeds from Massachusetts, New York and Rhode Island for the years 1958, 1959 and 1960 were seeded one-half inch deep in four replicates of 300 seeds each. Unfortunately, considerable washing occurred due to unusually heavy rains during the winter and spring of 1961. Counts in June 1961 showed the total nutgrass seedlings for four replicates ranged from 5 to 106. A good stand of seedlings also developed along the edge of the field where soil from the plots was deposited. This was ample proof that nutgrass seed of varying ages can survive winter conditions and germinate the following season.

Growth rate of seedlings

A growth rate test with New York strains of nutgrass was initiated July 17, 1959. One seedling was established to a 6-inch pot of soil, with 6 pots for each date of harvest. The harvest dates, average stem, and root plus rhizome weights as well as heights, and number of stems and nutlets per plant, are shown in table 9. The vegetative development slowed after 2 months as the days became shorter but nutlet production increased steadily. Eleven weeks after planting the yields of tubers from individual seedlings averaged 152 per pot.

TUBER STUDIES

Distribution in the profile

Tubers were counted in soil taken from 2 fields heavily infested with

Table 9. Average weight in grams and production per seedling of a New York strain of northern nutgrass. (R.I.)

Date of Harvest	Stems			Roots and rhizomes			Height of plants	No. of stems	No. of nuts	Total flower heads
	Wet gm.	Dry gm.	Moist. %	Wet gm.	Dry gm.	Moist. %	feet			
Aug. 12	0.6	0.05	91	0.1			0.4	2		
Aug. 24	13.5	1.57	88	3.2	0.38	88	1.5	21		
Sept. 3	55.2	5.47	90	18.2	1.96	89	2.6	23	11	
Sept. 14	62.8	10.02	84	56.8	9.98	82	2.6	21	51	2
Sept. 24	64.3	11.45	82	92.4	18.19	80	2.6	21	79	1
Oct. 5	65.8	11.75	82	105.3	29.47	72	2.8	20	152	

nutgrass. The first field, near Georgetown, Delaware, was sampled on April 10, 1958. It was planted to corn in 1957 and to rye cover in the fall of 1957. The second field, near Dover, Delaware, was sampled on October 2, 1958. It was cropped with tomatoes in 1957 and potatoes in 1958.

Samples were taken from 3 locations in each field, each of which were 2 square feet in area. Layers of soil were taken at the following depths: 0-3, 0-6, 6-9, 9-12, and 12-18 inches. Soil was washed through a screen and firm and soft tubers were counted. Soft tubers were those that could be crushed in the hand with moderate pressure, and were presumed dead.

Results are presented in table 10. They indicate that most tubers were in the top 6 inches of soil; that rarely are firm tubers found below 9 inches; that mortality during the winter was quite high. In the October sampling at Dover only 15 percent of the tubers were soft and presumed dead while in the April sampling at Georgetown 75 percent of the tubers were soft and presumed dead.

Table 10. Distribution of nutgrass tubers in the soil profile at Georgetown, Delaware, spring 1958, and Dover, Delaware, fall 1958.

Soil depth inches	Average* no. of tubers per 2 square feet					
	Georgetown**			Dover***		
	firm	soft	total	firm	soft	total
0- 3	43	90	133	47	7	54
3- 6	50	120	170	79	9	88
6- 9	2	74	76	22	11	33
9-12	0	6	6	0	0	0
12-18	1	1	2	0	0	0
Total	96	291	387	148	27	175

* Average of 3 samplings
** Sampled April 10, 1958
*** Sampled October 2, 1958

Depth of placement in soil

Firm overwintered tubers were placed in plastic-screen bags in a well-drained Sassafras sandy loam in the field in Delaware on June 26, 1958 at depths of 3, 6, 9, 12, and 18 inches. Twelve bags each containing 15 tubers were placed at each depth. One month later the emerged shoots were counted. It was assumed that no more than one shoot came from each tuber. This assumption may not be quite correct, since it has been observed that occasionally two shoots come from a single tuber. The germination percentages for the

3, 6, 9, 12, and 18 inch depths were 32, 24, 11, 3, and 0 percent, respectively.

In Rhode Island, depth of germination of nutlets was estimated by measuring the length of the slender rhizomes between the nutlet and the crown of the plant. Of the 461 plants dug from Bridgehampton silt loam soil, 302 had rhizomes of 2 inches or less, 134 were in the range of 2.25 to 4.0 inches and 25 possessed rhizomes from 4.25 to 7.0 inches. In loose, friable soil germination and emergence of plants from nutlets buried 7 inches deep is entirely possible.

Dormancy

The dormancy of nutlets received considerable attention from the regional research team. In Massachusetts, for example, freshly dug tubers appeared to be dormant and neither constant nor daily alterations of temperature in range from 50°F to 95°F induced germination. Tubers stored on moist blotter paper at 50°F for one month and then at alternating temperatures of 68-86°F for 48 days, germinated at 42 percent. When held for two months at 50°F the germination was 77 percent in only 13 days. Nuts dug from the field after overwintering showed sprouts in as little as 7 days from time of planting when placed at the 68-86°F temperature.

In Delaware the germination of 4 lots of newly formed tubers was 4, 8, 16, and 28 percent. These percentages were greatly increased by certain pregermination temperature or chemical treatments. Sprouting of the lot germinating 4 percent was increased to 94 percent by 50°F storage for 1 month; to 32 percent by soaking in a 5 percent thiourea solution for 1½ hours; and to 24 percent by momentarily dipping in a 1 percent ethylene chlorohydrin solution. Germination of the lot germinating 8 percent was increased to 91 percent by 50°F storage for 1 month; to 26 percent by exposure to 100°F for 36 hours; to 48 and 34 percent, respectively, by the thiourea and ethylene chlorohydrin treatments. Sprouting of the lot germinating 16 percent was increased to 54 and 46 percent respectively, by the same thiourea and ethylene chlorohydrin treatments. Germination of the 28 percent lot was increased to 100 percent by storage for 1 week at either 32°F or 38°F.

In Delaware, three lots of firm tubers that over-wintered and were taken from the soil in February 1958 germinated 32, 50, and 69 percent. Presumably the dormancy of these tubers had been broken by overwintering in the soil.

Durfee (9) of Massachusetts tested the following chemicals for breaking the dormancy of freshly harvested nutlets — potassium thiocyanate, ethylene chlorohydrin, thiourea and ethyl ether. The quantities used and the effects upon sprouting and growth are shown in tables 11 and 12. The most pronounced results were obtained from tubers treated with 0.5 percent solution of ethylene chlorohydrin and a 4 percent ethyl ether solution. The ethylene chlorohydrin not only promoted good germination but also excellent shoot and root

growth. This material had practically no effect on the apical dominance of the terminal bud.

Table 11. Average germination and growth obtained from several chemical treatments on dormant northern nutgrass tubers. (Mass.)

Treatment	Shoot length cm.	Root length cm.	Sprouts per tuber	Percent germination
Check	2.35	4.19	1.05	15.0
Check*	3.45	3.36	1.00	13.3
Check**	3.59	5.15	1.00	15.8
1% KSCN	0.58	1.96	1.28	79.2
2% KSCN	0.54	1.52	1.67	90.8
4% KSCN	0.49	0.41	1.47	65.8
0.5% ethylene chlorohydrin	5.59	5.68	1.14	100.0
1% ethylene chlorohydrin	4.63	5.10	1.17	90.0
2% ethylene chlorohydrin	3.20	3.36	1.07	65.0
4% ethylene chlorohydrin	1.32	1.03	1.12	36.7
1% thiourea	2.29	2.18	1.22	80.0
2% thiourea	0.96	0.18	1.97	97.5
4% thiourea	0.52	....	2.27	86.7
8% thiourea	0.50	....	2.23	34.2
LSD 0.05	1.06	1.12	0.14	22.6
LSD 0.01	1.42	1.51	0.19	30.3

* Tubers soaked in water for 1 hour.
** Tubers dipped in water then placed in an airtight jar for 24 hours at 86°F.

Potassium thiocyanate and thiourea solution broke the dominance resulting in up to 4 vegetative sprouts per tuber. The latter two chemicals retarded root and shoot growth after germination. The 4 percent ethyl ether allowed 100 percent breaking of dormancy, but severely retarded root and shoot elongation. Somewhat similar results were obtained in Delaware with thiourea and ethylene chlorohydrin. Rahn reported that EPTC prevented germination of tubers without killing them. Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) did not stop germination but eventually killed young plants.

Table 12. Average germination and growth of northern nutgrass tubers stored in soil at 50°F. for 2 months followed by treatment with ethyl ether. (Mass.)

Treatment	Shoot length cm.	Root length cm.	Sprouts per tuber	Percent germination
Check	3.86	4.76	1.12	48.35
0.1% ethyl ether	4.30	4.59	1.08	60.00
0.2% ethyl ether	5.08	4.95	1.05	65.00
0.5% ethyl ether	5.50	5.23	1.01	50.82
1.0% ethyl ether	5.83	5.67	1.04	61.67
2.0% ethyl ether	6.25	6.15	1.08	59.17
4.0% ethyl ether	3.84	3.79	1.78	100.00
LSD 0.05	0.77	0.84	0.12	12.28
LSD 0.01	1.06	1.15	0.17	16.82

Soil Compaction

The effect of degree of soil compaction on tuber germination was studied in the greenhouse. Soils having 4 levels of compaction as indicated by bulk densities of 0.97, 1.17, 1.36, and 1.68 were prepared and placed in nine-inch clay

pots. Fifty tubers were planted 3 inches deep in each pot. Treatments were replicated 3 times. A bulk density of 0.97 was obtained by mixing a loamy sand with peat moss in a ratio of 4 to 1, followed by subirrigation. A loosely packed clay loam which was subirrigated had a bulk density of 1.17 while a loamy sand compacted when dry and subsequently surface watered had a bulk density of 1.36. A loamy sand compacted when wet and subsequently surface watered had a bulk density of 1.68.

Nutgrass did not emerge from the most-compacted soil for a month. Nutgrass started to grow from the other 3 less-compacted soils after 10 days. After 4-months the germination was 96, 93, 67, and 47 percent, respectively, for the soils with bulk densities of 0.97, 1.17, 1.36, and 1.68. Both rate and percentage of germination of nutgrass was greatly reduced by heavily compacted soils.

Exposure to low temperatures and drying

Newly formed tubers were placed in refrigerators at approximately 5°F and 20°F. The dormancy of these tubers was previously broken by placing them at 38°F for one month. They had a germination percentage of 50 percent at the start of the test. When tubers from this same lot were pre-exposed to 20°F for 1, 3, 5, and 7 days and 2, 3, 4, and 5 weeks, no tubers germinated after 3 days exposure, at which time the germination was 8 percent.

When tubers were pre-exposed to 5°F for the same lengths of time, no tubers germinated after 3 days exposure, at which time the germination was 16 percent. Most tubers rotted during the germination test.

Samples from the same lot of tubers were placed on the soil surface in the field on October 9, 1958 to see what exposure to winter conditions would do to percentage germination. Samples withdrawn at monthly intervals germinated 32, 20, 20, 10, and 12 percent respectively. The last sample was withdrawn on March 9, 1959.

During this winter, 1958, monthly minimum temperatures for October through March were 31°, 17°, 6°, 3°, 3°, and 19°F, respectively. This indicates that exposure of tubers to freezing and drying conditions of winter would not be an effective method for eradication of nutgrass. A possible explanation for the short life of tubers placed in refrigerators at 20° and 5°F is that they were unable to become hardened by gradual reduction of temperature, as was the case in the field.

Herbicides applied to soil

The effect of atrazine and EPTC on germination of tubers was studied in the greenhouse. Atrazine at 3 and 6 lb/A and EPTC at 6 and 9 lb/A was incorporated in the top 4 inches of Norfolk loamy sand placed in 9-inch pots. Then 50 tubers, whose dormancy was broken by low temperature treatment,

were placed 3 inches deep in each pot. Three replicates were used. Results with atrazine are presented in table 13. Atrazine had no significant effect on germination, but did subsequently kill 86 and 100 percent of the resulting plants at the 3 and 6 lb/A levels, respectively.

Table 13. Effect of atrazine on germination of nutgrass tubers. (Del.)

Treatment	Germination after 6 weeks, %	Plant mortality after 11 weeks, %
Atrazine, 3 lb/A*	88	86
Atrazine, 6 lb/A*	87	100
Check	93	0
LSD 0.01	N.S.	15

*Pre-plant incorporated 4 inches deep.

Where EPTC was applied, no tubers germinated after 6 weeks. At this time, half the tubers were removed from each pot, were washed with water, and were replanted in untreated soil to see whether EPTC had killed them. These tubers sprouted readily giving germination percentages 5 weeks later of 79 and 77 for the 6 and 9 lb/A levels, respectively. At this time no tubers had germinated in the EPTC treated soil, whereas 93 percent of the tubers had germinated in the untreated soil.

The above results indicate that atrazine did not prevent germination but EPTC did. EPTC, however, did not kill the tubers, but kept them dormant.

Researchers in New York found that herbicidal chemicals did not kill dormant tubers. The materials tested were methyl bromide, substituted ureas, triazines, TCA, dalapon, EPTC and its analogs. The following season tubers sprouted and grew to maturity unless residually active amounts of the chemical were present. In this case, the plants usually were 2 to 6 inches tall before showing damage. When sufficiently large amounts of chemical were present the plants died.

Herbicides applied to mother plants

The herbicides listed in table 14 were applied to foliage of vigorous, 2-foot high nutgrass plants growing in 9-inch pots in the greenhouse. These plants bore numerous tubers. The objective was to determine whether these herbicides, following foliage applications would be translocated to intact tubers and kill them. One month after application, the potted plants were placed outdoors for 30 days, to break tuber dormancy since night temperatures were below freezing. Tubers were then removed and graded into small and large groups by sifting through a one-fourth inch screen. It was assumed that the large tubers were older and probably were mature at time of herbicide application, while the small tubers were still actively growing with carbohydrates being transported into them, possibly associated with herbicides. Tubers were then germinated for 6 weeks in perlite in the greenhouse.

Table 14. Effect of foliage applications of amitrole, amitrole + 2,4-D, amitrole-T, atrazine, and dalapon on germination of intact tubers of nutgrass. (Del.)

Herbicide	Rate lb/A	Percent germination	
		Small tubers	Large tubers
Amitrole*	5	2	1
Amitrole	10	0	0
Amitrole + 2,4-D	5 + 2	1	0
Amitrole—T*	2½	1	7
Amitrole—T	5	0	3
Atrazine	5	43	76
Atrazine	10	32	66
Dalapon**	10	56	81
Dalapon	20	55	67
Check		43	82
LSD 0.01		8	10

*Amitrole = 3—amino—1,2,4—triazole; Amitrole—T = Amitrole + ammonium thiocyanate mixture.
**Dalapon = 2,2 — dichloropropionic acid.

Amitrole was the outstanding chemical tested. Small and large tubers from untreated plants germinated 43 and 82 percent, respectively. Small and large tubers from plants sprayed with amitrole, 5 lb/A, germinated only 2 and 1 percent, respectively. No tubers from plants sprayed with amitrole, 10 lb/A, germinated.

Amitrole-T and a combination of amitrole and 2,4-D gave a more rapid top kill, but were essentially equal to amitrole. Atrazine and dalapon, were effective in killing the nutgrass foliage, but not in reducing the viability of intact tubers.

Longevity

In February, 1958, tubers were taken from a field heavily infested with nutgrass and placed in 50°F storage. During June, 1958, a number of plastic screen bags, each containing 15 tubers, were buried in a Sassafras sandy loam in the field at depths of 3, 6, 9, 12, and 18 inches. At intervals of 1, 3, 12, and 18 months two bags (30 tubers) at each depth were removed and taken to the greenhouse where germination tests of the firm tubers were run. It was assumed that when these tubers were placed in the soil in June, 1958, they were already approximately 10 months old, and that most of them had been formed during August and September, 1957. Their viability at time of burying in the field was 50 percent according to a greenhouse test.

A number of tubers remained firm after 18 months burial at depths of 9, 12, and 18 inches (table 15), but no tubers remained viable after 12 months burial. Assuming that these tubers were 10 months old when they were buried, this means that sometime between 13 and 22 months these tubers lost their viability completely. This suggests that few, if any, tubers will survive two winters in Delaware. Observations at Cornell and Rhode Island suggest that some tubers will remain viable in the soil for more than two years.

Table 15. Percentage of tubers that remained firm* after being buried in June, 1958 at varying depths in the field for varying lengths of time and their percent germination. (Del.)

Burial depth inches	Percent firm tubers and percent germination							
	1 mo.		3 mo.		12 mo.		18 mo.	
	tubers	germ.	tubers	germ.	tubers	germ.	tubers	germ.
3	83	17	63	7	0	0	0	0
6	90	13	60	7	13	0	0	0
9	77	20	73	24	20	0	3	0
12	....	....	73	15	13	0	7	0
18	....	....	80	14	23	0	10	0

*Tubers that had not rotted or germinated in soil.

GROWTH AND DEVELOPMENT

Photoperiod

The response of northern nutgrass to environmental factors was studied at the 4 cooperating stations including Massachusetts (6). The photoperiod had a pronounced effect on the vegetative growth and tuber production. Results from the Delaware tests are typical. Single tubers were planted in 8-inch pots of Norfolk loamy sand and subjected to 8, 12, and 16 hour photoperiods. When the day length was decreased from 16 to 8 hours, tuber formation was earlier and the numbers per plant increased also. Figure 2 shows that under the 8 and 12 hour exposure, plants averaged 30 tubers each at 10 weeks, with only 7 for the 16-hour treatment. At 12 weeks, when the 16-hour plants reached a maximum vegetative growth, nearly 60 nutlets per plant were recorded.

This indicates that while short days stimulate early nutlet formation at the expense of topgrowth, a bountiful crop of tubers is still produced as the plant matures. It is also evident that in a program of eradication by tillage, it is very important to prevent growth of nutgrass plants during the fall months.

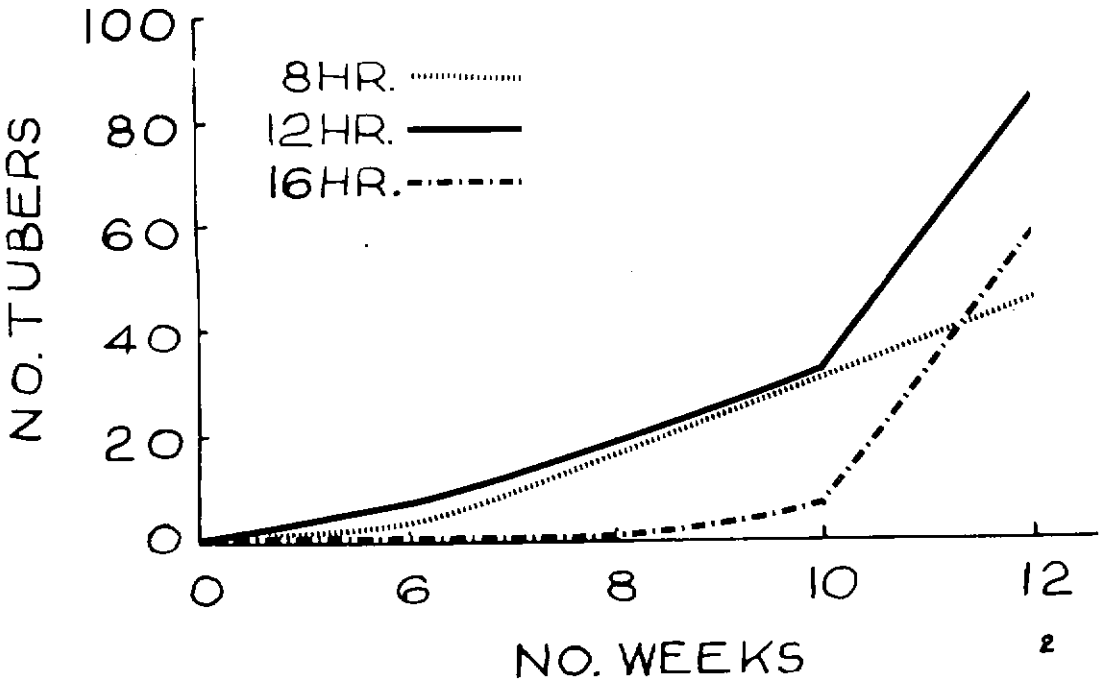
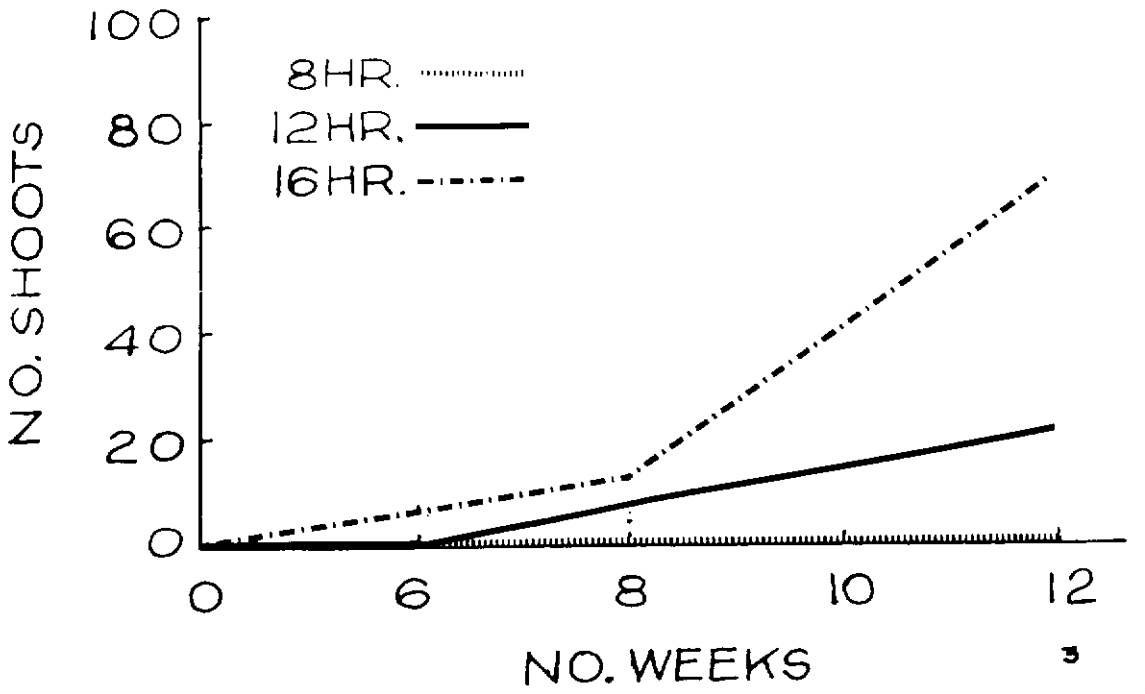
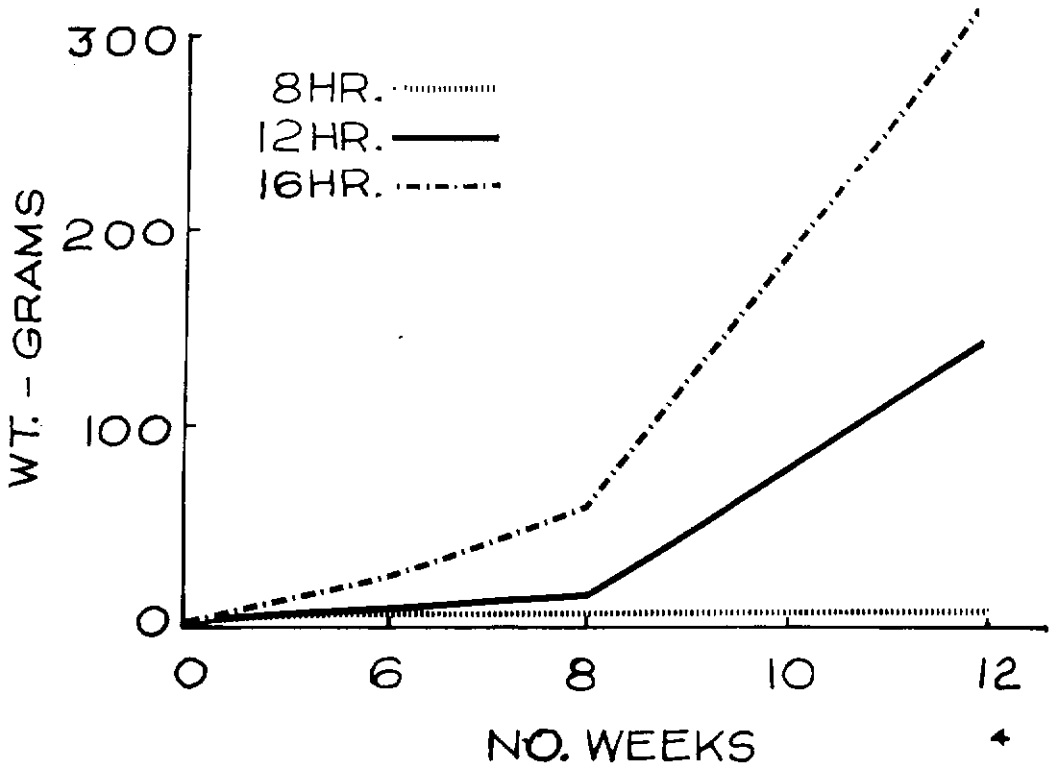


Figure 2. a. Number of tubers per plant as affected by 8, 12 and 16-hour photoperiods.



b. Number of vegetative shoots per plant as affected by 8, 12 and 16-hour photoperiods.



c. Weight per plant as affected by 8, 12 and 16-hour photoperiods.

In New York, tillage late in the season usually prevented tuberization. During 1960, however, tubers germinating about September 10 had formed 1 to 3 new tubers in three weeks. Foliage was 2 to 6 inches high at that time. Rhode Island workers found late fall tubers with an air dry weight as low as 0.1 gram produced vigorous plants the following season.

The total number of vegetative shoots and total weight in grams is also depicted in Figure 2. No subsidiary plants were developed under the 8-hour photoperiod, but under the long day treatments there were about 60 shoots per plant. The effect of photoperiod on size was apparent soon after the plants emerged. The weight of plants at the shorter day lengths was virtually unchanged over the first 8 weeks after which some increase occurred at the 12-hour exposure.

Effect of photoperiod on the growth of seedlings

In December, 1958 and January, 1959 two photoperiod experiments were conducted in a greenhouse at the University of Rhode Island. Seedlings from germination tests were transplanted into 6-inch pots of soil. Half of the pots in each test were placed under lights for 16 hours; the other half received the normal light of the short days of December and January.

In the first test all seedlings which were given a short day died. In the second test the survival of seedlings in short daylight was 70 percent. In both tests all the seedlings placed under extra light survived. The growth of the plants given short day was poor, while the plants receiving a long photoperiod grew rapidly. The light was turned off on May 5. At that time the heights of the plants were approximately 1 and $2\frac{1}{2}$ feet for short and long days, respectively.

Light Intensity

Nutgrass tubers were planted in 8-inch pots in the greenhouse in March and grown for a 12-week period at three light intensities. These were 8, 48, and 100 percent of the normal light in the greenhouse. It was assumed that light intensity in the greenhouse was 20 percent less than that outside which was approximately 165 gram calories per square centimeter per week for that time of year. The 8 and 48 percent levels were attained by shading with plastic screens.

Reduction in light intensity greatly reduced plant size as well as formation of tubers and vegetative shoots. For example, at 12 weeks, the respective values for the 8, 48, and 100 percent levels were 5, 25, and 135 grams for average weight of plants; 9, 18, and 34 for average tubers per plant; and 1, 2, and 22 for average number of vegetative shoots per plant. Tubers started forming 2 weeks earlier at the highest light intensity.

These results suggest that if a crop were grown that provided much shade,

the growth and development of nutgrass would be greatly inhibited. For example, in a spacing experiment practically no nutgrass was formed where lima beans were planted 2" apart, where they were 4" and 6" apart, the nutgrass was moderate and heavy, respectively.

Interaction of soil temperature, photoperiod, and light intensity

Two experiments involving the use of 2 soil temperatures (65°F and 85° F) and 3 photoperiods (14, 15, and 16 hours) were conducted for 12 weeks. A soil temperature of 65°F approximates the soil temperature during May and June, while 85°F approximates the soil temperature during July and August in Delaware. Photoperiods of 14, 15, and 16 hours approximates the effective daylight periods for September 2, August 7, and June 21, respectively, in Delaware. The main objective was to determine the date when tubers would be formed in the field. This would aid in prescribing control measures. The results are photographically shown in Figure 3.

Figure 3. Development of nutgrass plants after 14 weeks under varying photoperiods and soil temperatures at low light intensities. Left to right are 14, 15 and 16-hour photoperiods. The smaller plants at the left from 65° F soil, larger on the right from 85°F soil.

The first experiment was run during the winter months when light intensity was relatively low (approximately 165 gm cal per cm^2 per week), while the second experiment was run during late spring and early summer when light intensity was relatively high (approximately 444 gm cal per cm^2 per week).

Results from the 2 experiments were quite different. When light intensity was high, growth as well as formation of tubers and vegetative shoots was much more rapid, and variation in photoperiod had little effect. Lowering soil temperature from 85°F to 65°F reduced tuber formation greatly, but had little effect on vegetative shoots. When light intensity was low, growth and formation of tubers and vegetative shoots was at a much reduced rate, es-

pecially at the 65°F soil temperature. Furthermore, when light intensity was low, photoperiod had a significant effect: tubers formed earlier and in greater amounts at the shorter photoperiods, vegetative shoots formed earlier and in greater amounts at the longer photoperiods, and plant size was greater at the longer photoperiods.

Under field conditions, growth and formation of tubers and vegetative shoots should therefore be quite rapid during July and August. This is usually the case. Tubers will start forming 6 weeks after a plant starts to grow according to experimental results. Then during September and October, as days become shorter, with less light intensity and lower temperatures, plant growth and formation of vegetative shoots slows up greatly, while tuber formation continues or is enhanced.

Effect of soil moisture, fertility and pH

Three levels of available soil moisture were maintained in pots of Norfolk loamy sand, 35, 75, and 100 percent. In this coarse soil, growth of both tops and tubers showed a direct relationship to moisture levels. After 12 weeks, tuber production was 78, 32 and 17 per plant for high, medium and low soil moisture. Comparable numbers of vegetative shoots were 59, 14 and 2 respectively. The Rhode Island workers (3) using pots of Bridgehampton silt loam which holds considerably more available moisture than the Norfolk type found that plants grown at the 100 percent available moisture produced significantly more tubers and vegetative material than those at 50 percent moisture.

In this same test nutgrass produced equally well at pH levels of 5, 6 and 7 but its production was increased significantly when a 19-28-14 fertilizer was increased from 250 to 500 pounds per acre. Experiments in Delaware and Florida (15) with the Norfolk sand produced no significant increase from the use of fertilizer.

ERADICATION IN THE FIELD

Many attempts have been made in recent years to eradicate northern nutgrass from cultivated land. Some of the failures are due to the distribution of tubers throughout the plowed layer and sometimes below it, so that some plants show up every year. If they are not quickly eliminated, more viable tubers are produced.

Workers at Cornell kept land infested with nutgrass fallow for 4 years. At the end of the fourth year the average number of tubers per square foot was determined as shown in table 16. At this time 11 tubers per square foot were found in the top 6 inches of soil compared to 539 in the check. In the fall of 1960 tubers germinating about September 10 formed 1 to 3 new nutlets in 3 weeks.

Tubers usually failed to absorb herbicides applied to soil. The New York

Table 16. Numbers of tubers per square foot after 4 years of tillage. (N.Y.)

Depth	Fallow	Control
0- 6"	11	539
6-12"	2	222
12-18"	0	19
18-24"	0	16

(Cornell) station reported that the following chemicals did not kill dormant tubers, methyl bromide, substituted ureas, -triazines, TCA, dalapon, EPTC and its analogs. The tuber sprouted and grew to maturity unless residually active amounts of chemical remained. New plants usually grew from 2 to 6 inches before showing symptoms, if sufficient toxic residues remained. The nutgrass may be killed to the ground, but recovers and continues to grow. In a recent test in Rhode Island, 21 pounds of atrazine 80W were applied per acre in September, 1960. The potato crop was eliminated the following season, but the nutgrass grew well. In a similar test, atrazine, at 12 pounds per acre, eliminated a hay seeding but permitted a normal growth of nutgrass. These tests were in a Bridgehampton silt loam soil. Bell and Gardner (5) found that atrazine will control nutgrass in corn when applied at normal rates, providing there is enough rainfall to keep the corn growing rapidly. Rapid competition from corn seemed important in suppressing nutgrass with atrazine.

Durfee, Lachman and Lincoln (10) found that 20 to 40 pounds per acre of EPTC reduced the stand of nutgrass materially with little regrowth the following year after the higher rate of herbicide.

Researchers in Delaware (18, 20, 21) reported considerable success in eradication of heavy stands of northern nutgrass in the field on loamy sand or sandy loam. Some of the more recent treatments and results are shown in table 17. Clean cultivation from August 10 to killing frost in 1959, caused a 41 percent reduction in nutgrass emergence the following May. A 91 percent reduction was obtained by clean cultivation from August 1959 until frost 1960.

Amitrol-T at 5 pounds per acre applied to the foliage of a dense stand of nutgrass on August 10, 1959 produced an 83 percent reduction in emergence the following May. This was more effective than clean cultivation because it killed the intact tubers attached to the mother plants. Experiments with radioactive material has shown amitrole translocates to attached tubers following foliar applications. August applications of amitrole-T or atrazine at 5 pounds per acre gave a 77 percent reduction in stand. Dalapon at 10 pounds per acre was equally effective. Six pounds of EPTC, incorporated in April, produced a 67 percent reduction in stand.

Much can be done to reduce the stands of nutgrass, but nothing short of eradication can give permanent relief from this pest.

Table 17. Emergence of nutgrass in May as affected by clean cultivation and application of certain herbicides the previous years. (Del.)

Treatments	Pounds per acre	Method of application	Percent reduction of Nutgrass plants May 1960	May 1961
Check[1]		....	....	....
Clean Cultivation[1]		....	41	91
Amitrole—T	5	Foliar spray whenever 6" tall	....	95
Amitrole—T[1]	5	Foliar spray in August only	83	77
Atrazine[2]	5	Foliar spray whenever 6" tall	. .	90
Atrazine[1]	5	Foliar spray in August only	37	77
Atrazine[2]	5	Spray, pre-emergence in April	....	69
EPTC[2]	6	Spray, pre-emergence in April incorporated	....	67
Dalapon[3]	10	Foliar spray in August only	....	75
LSD 0.05			23	7

[1]Treatments started August 10, 1959.
[2]Treatments started April, 1960.
[3]Treatments started August, 1960.

RADIOACTIVE AMITROLE, ATRAZINE, AND EPTC

Effect on tubers

Autoradiography was employed in Delaware to study the absorption and translocation of radioactive amitrole[1], atrazine[2], and EPTC[3] in nutgrass following both root and foliage applications at varying stages of growth. Corn, which is highly tolerant of atrazine, was included in the atrazine studies. Irish potato, which is highly tolerant of EPTC, was included in the EPTC studies. Foliage and root applications were made to plants at 2 stages — plants 2 and 12 inches tall. In addition, herbicides were applied to germinating seed or tubers.

The techniques used were essentially those described by Yamaguchi and Crafts (24). When the radioactive herbicides were applied to 12-inch plants, a droplet of the solution having an activity of one millicurie was placed in a lanolin ring near the tip of the leaf on the adaxial surface. Amitrole was allowed to remain on the plants for 5 and 9 hours and 1, 3, 5, and 7 days before the plants were killed by drying in an oven at 80°C for three hours. Atrazine and EPTC were left on the plants for 2 and 7 days before the plants were killed. Application to 2-inch plants was made by momentarily dipping the shoot tip in the radioactive herbicide solution to a depth of one centimeter. The herbicides were allowed to remain on the plants for 2 and 7 days before they were killed. Applications to plant roots and germinating seeds and tubers, which were planted in sand, were made by including the radioactive herbicides in nutrient solutions (13). Crocks containing the sand were subirrigated daily with these solutions for either 2 or 7 days.

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[1]Supplied by the American Cyanamid Company.
[2]Supplied by the Geigy Chemical Corporation.
[3]Supplied by the Stauffer Chemical Company.

Radioactive amitrole, or a degradation product thereof, was readily translocated both upward and downward in plants and accumulated in daughter plants and tubers following application to 12-inch plants (Figures 4 and 5). Within 3 hours there was much translocation upward and slight translocation downward. One day after application, however, a considerable amount of amitrole was in the tubers. Translocation and accumulation continued to increase for 3, 5, and 7 days after application.

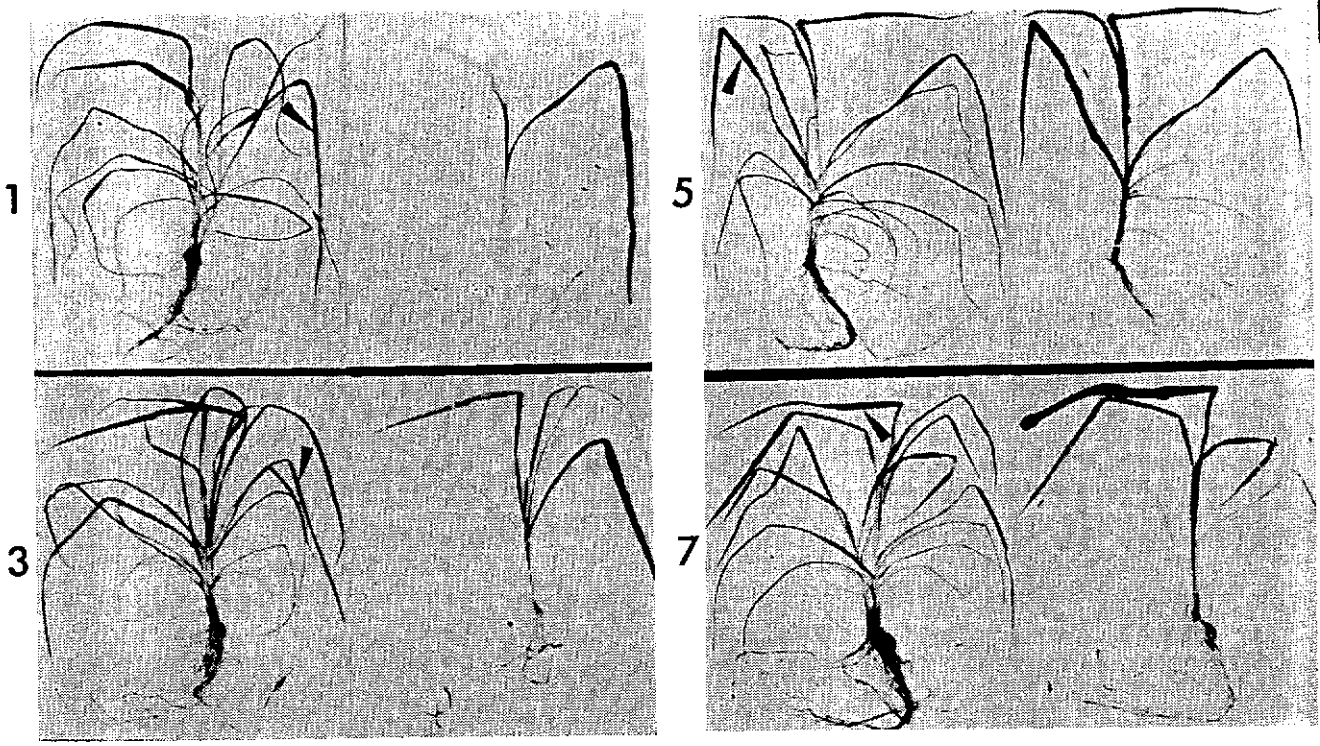

Figure 4. Composite photograph and autoradiograph of 12-inch plants that received radioactive amitrole at areas indicated by arrows (photograph-left, radiograph-right) for 1, 3, 5 and 7 days after treatment

Accumulation in young and old tubers appeared to be equal. Rate of accumulation of amitrole in tubers appeared to be correlated with the number of tubers borne on a particular plant. The more tubers there were the slower the accumulation. Accumulation in daughter plants was slightly less rapid than in tubers. But after 7 days, amitrole was widely distributed throughout nutgrass plants and had accumulated mostly in the growing points of the daughter plants, as well as tubers.

This is of great practical significance, provided this herbicide is highly toxic to nutgrass for then this chemical, by killing daughter plants and tubers, would greatly reduce the ability of this pest to reproduce and over-winter.

Absorption and translocation of atrazine by both nutgrass and corn, and EPTC by both nutgrass and potatoes, was rapid following root application. Therefore, selectivity of these herbicides cannot be based on differences in absorption and translocation. Absorption and translocation of these herbicides

upward or acropetally following leaf application was moderate, but translocation downward or basipetally following leaf applications, was very slight. Atrazine did not enter germinating nutgrass tubers but did accumulate in the embryo and to a lesser degree in the endosperm of germinating corn seed. EPTC did not enter germinating nutgrass tubers, but did enter germinating potato seed pieces especially through the cut surface.

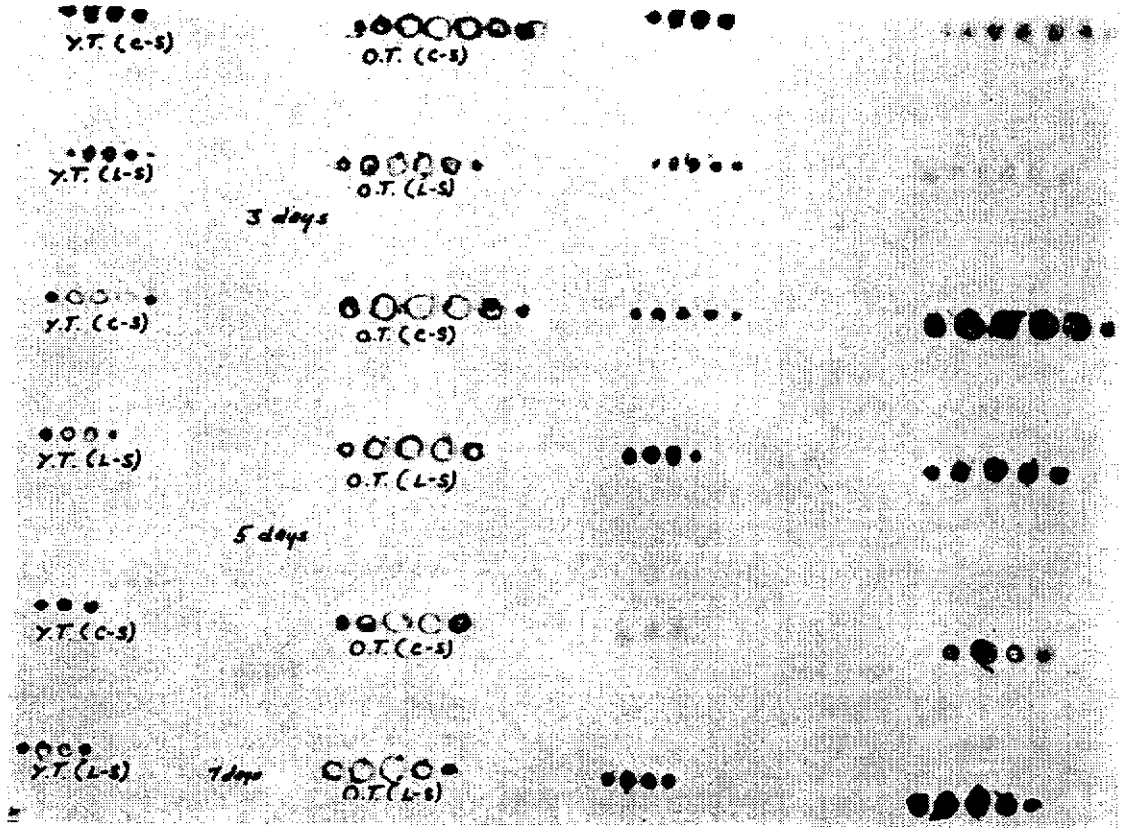

Figure 5. Photograph (left) and autoradiograph (right) of tubers removed from 12-inch nutgrass plants. Young tubers (Y.T.) and old tubers (O.T.) are shown in sections made both perpendicular and parallel to this axis. Black area represents accumulation of radioactive amitrole.

Effect on seeds

Massachusetts conducted tests to determine whether foliar applications of amitrole were translocated to the infloresence and if this treatment affected seed germination. Autoradiograms showed that tagged amitrole applied to the flower stem moved into the bract leaves and spikelets. These studies also indicated that the chemical had also been translocated to individual nutgrass seeds.

Amitrole at the rate of 2, 4 and 8 pounds was also applied to nutgrass growing in field plots. It was apparent that the chemical had a deleterious effect on seed germination. The plots treated with eight pounds of the chemical yielded only 25 percent as many seed as the 2 pound treatment, and in addi-

tion, seed samples from these plots germinated only 25-30 percent as well as those from the check plots.

SUMMARY

Northern nutgrass produces an abundance of viable seed as well as tubers. The tubers are the chief means by which this weed is disseminated in cultivated land. Nutgrass seedlings are easily destroyed by cultivation. In an undisturbed seedbed, seedlings produce both seed and tubers the first season of growth.

Germination of nutgrass seed is favored by alternating daily temperatures of 85°-95°F for 8 hours and 70°F for 16 hours. Seeds stored at room temperature or refrigerated for 3 years had a high percentage of viability. Alternating freezing and thawing or wetting and drying reduces the percent germination but does not kill all the seed. Germination will take place without special chemical treatment. In certain instances the use of KNO_3 solutions increases the percentage of sprouting seeds. Light or absence of light has little effect on germination when temperature conditions are optional.

The tuber production is hastened by a short photoperiod but as nutgrass plants mature under long day conditions, tubers are also formed. Shade (low light intensity) severely reduces the growth and tuber development of northern nutgrass. Competition with rapidly growing crops has a similar effect.

In an eradication program it is important to prevent tuber production during the late fall as well as during the early part of the season. Most tubers are produced in the upper 6 inches of soil and under favorable conditions tubers may germinate from this lower depth. Two years of mechanical or chemical fallow are usually necessary to get a 90% reduction of the viable tubers in the soil.

Tubers are dormant when freshly harvested. The dormancy is easily broken by low temperatures for a few days or by such chemicals as ethylene chlorohydrin.

Autoradiographs show that amitrole is translocated into the tubers and seeds. Tubers containing amitrole rarely grow and seed germination is decreased. EPTC promotes dormancy in nutgrass tubers. Atrazine like most chemicals tested injures new plants from germinating tubers but not dormant tubers.

LITERATURE CITED

1. Association of Off. Seed Analysts. 1954. Rules for testing seeds. Proc. Assoc. Seed Anal. 44: 31-78.
2. Bell, R. S. and E. J. Bannister. 1955. Chemical control of northern nutgrass in potato fields. Northeastern Weed Control Conference 9: 231-234.
3. Bell, R. S., and E. J. Bannister, and T. Tisdell. 1959. Effect of soil reaction, moisture, and fertility on the response of northern nutgrass to monuron. NEWCC 13: 444-449.
4. Bell, R. S. and E. Larssen. 1960. Experiments with germination of northern nutgrass seed. NEWCC 14: 45-48.
5. Bell, R. S. and P. B. Gardner. 1962. Experiments with control of nutgrass in silage corn with atrazine. NEWCC 16:
6. Bundy, Otto M. 1960. Growth and development of northern nutgrass as affected by certain environmental conditions. Master's thesis, University of Delaware.
7. Bundy, O. M., W. F. Donnalley and E. M. Rahn. 1960. Growth and development of northern nutgrass as affected by certain environmental conditions. (Abstract) NEWCC 14: 44.
8. Donnalley, William F. 1961. Translocation of amitrol, atrazine, dalapon and EPTC in northern nutgrass. Master's thesis. University of Delaware.
9. Durfee, J. W. 1960. Life history and the control of northern nutgrass, *Cyperus esculentus* L. Master's thesis. University of Massachusetts.
10. Durfee, J. W., W. H. Lachman and W. C. Lincoln, Jr. 1960. Control of northern nutgrass with EPTC and atrazine. NEWCC 14: 214-216.
11. Georgia, A. 1919. A manual of weeds. The MacMillan Co., New York.
12. Hill, E. R., W H. Lachman, D. N. Maynard, W. C. Lincoln, Jr. 1962. The effect of foliar applications of amino triazole on the germination of northern nutgrass seed. NEWCC 16: 64-68.
13. Hoagland, D. R. and D. I. Arnon. 1950. The waterculture method for growing plants without soil. Cal. Expt. Sta. Cir. 347.
14. Justice, O. L. and M. D. Whitehead. 1946. Seed production, viability and dormancy in the nutgrasses *Cyperus rotundus* and *C. esculentus*. Jour. Agr. Res. 73: 303-318.
15. Killinger, G. B. and W. E. Stokes. 1946. Chufas in Florida (*Cyperus esculentus*). Agr. Expt. Sta. Bul. 419.
16. Larssen, E. R. 1960. Factors influencing the germination and growth of northern nutgrass (*Cyperus esculentus*). Master's thesis. University of Rhode Island.
17. Morrison, F. B. 1947. Feeds and Feeding (20th Ed.). Ithaca, New York.
18. Orsenigo, J. R. and O. Smith. 1953. The chemical control of northern nutgrass *Cyperus esculentus*. NEWCC 7: 329-339.
19. Rahn, E. M. 1959. Control of northern nutgrass and other weeds in potatoes and tomatoes in 1958. NEWCC 13: 80-83.
20. Rahn, E. M. and W. F. Donnalley. 1961. EPTC for nutgrass control in potatoes. NEWCC 15: 54.
21. Rahn, E. M. and D. J. Fieldhouse. 1960. Evaluation of several herbicides for strawberries. NEWCC 14: 55-59.
22. Saidak, W. J. 1961. Translocation of dalapon in yellow nutsedge. Weeds 9 (4): 626-633.
23. Tumbleson, M. E. and T. Kommedahl. 1961. Reproductive potential of *Cyperus esculentus* tubers. Weeds 9(4): 646-653.
24. Yamaguchi, S. and A. S. Crafts. 1958. Autoradiograph method for studying absorption and translocation of herbicides using C^{14}-labeled compounds. Hilgardia 28: 161-191.