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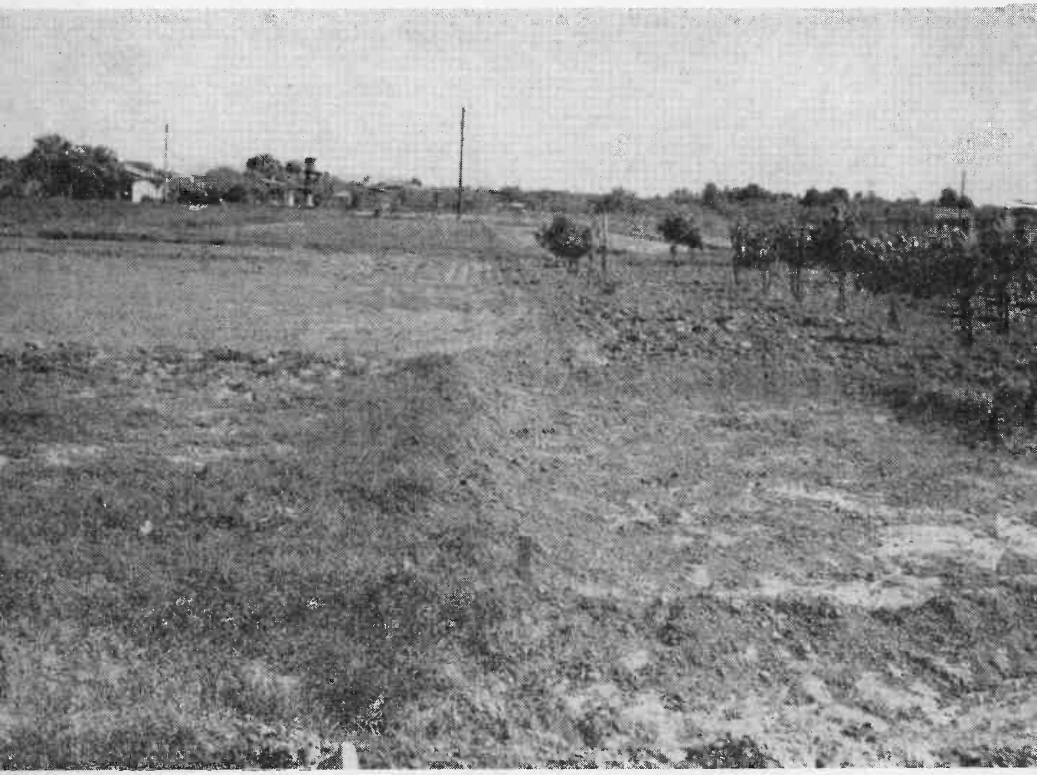
ERADICATION AND CONTROL OF NUT GRASS



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ERADICATION AND CONTROL OF NUT GRASS

By C. H. Davis and R. S. Hawkins

INTRODUCTION

Two species which are commonly called nut grass occur in Arizona. *Cyperus esculentus L.* is the more widely distributed and occurs in northern Arizona and at higher elevations than *Cyperus rotundus L.* The latter species is the more serious pest where both species occur and appears to be an introduced weed, whereas *C. esculentus* may be indigeneous. Specimens of *C. esculentus* in the University Herbarium have been collected before the likelihood of the introduction of *C. rotundus* as a weed and from areas in which the introduction of the plant was unlikely. The two plants grow to a similar height under the same conditions, but the *C. esculentus* leaves which first appear are narrow, 3/32 inch wide, while the first leaves of *C. rotundus* are 3/16 inch wide. The umbels of the two species are similar in shape but the scales of *C. rotundus* are more closely appressed, and the heads are reddish in *C. rotundus* and yellow in *C. esculentus.* However, the umbels of *C. rotundus* become bleached in southern Arizona so that at maturity the color difference is not striking. The greatest difference between the two species is in the tubers. Those of *C. esculentus* are about the size of a pea, rarely over ¼ inch in diameter, while the tubers of *C. rotundus* reach a length of 1 inch and a diameter of ¾ inch.

Nut grass rarely grows more than 18 inches high and damages crops to a great extent by competition with the emerging crop plants for water, thereby reducing the stand. Winter crops are rarely affected by nut grass except when planted before frost, as beets for seed or barley for pasture. The reduction in the stand of crops by nut grass is very important for crops planted on infested areas between May and November. Grain crops planted after the first killing frost of the fall or cotton planted before the rapid growth of nut grass begins usually escape damage and can be used advantageously on infested land if fertile and properly watered to avoid the damage done by the weeds. Nut grass is usually distributed by cultivating implements in balls of transplant material from infested nurseries and in water from ditches where the tubers drift along the bottom.

Experiments to test the effect of chemicals and cultural treatments on nut grass were started in Arizona in 1937. Complete eradication was sought in all chemical tests, although this was not obtained. The physiology of the plant was studied in the greenhouse to determine possible field methods of eradication. Nut

grass early showed a decided response to soil moisture differences; this was the object of much study in the greenhouse and in the field. The inability of nut grass tubers to withstand drying on the surface of the soil as shown by Smith and Fick[1] at Alabama was used in greenhouse and field experiments to arrive at practical methods of control.

VERTICAL DISTRIBUTION OF NUT GRASS TUBERS

The tubers of *C. esculentus* rarely are found more than 10 inches deep and usually are less than 4 inches below the soil surface. Tubers of *C. rotundus* have been found at 30 inches and commonly below 1 foot. Figure 1 shows the vertical distribution of *C. rotundus* tubers as found at the University Farm at Tucson. Fifty-seven per cent of the tubers buried 24 inches deep were able to send shoots to the surface in 4 months. Nut grass is able to spread quite rapidly, and under favorable conditions a single tuber of *C. rotundus* can infest an area 12 to 14 feet in diameter in one season.

DAMAGE DONE BY NUT GRASS

An illustration of the damage done by this weed was found in a field at Tucson where the nut grass was introduced from an infested ditch bank when the field was releveled in the fall of 1938. Very little nut grass could be seen in 1939 when the field was in Sudan pasture. In 1940 well-defined patches could be seen in the Sudan grass, and in that winter brown areas in the barley pasture were easily seen where the nut grass had killed out the barley seedlings. The field was plowed and after the usual preparation planted to hegari for silage on July 4, 1941.

On July 10 a good sorghum stand was present over all the field, both in the patches of nut grass and in the nut-grass-free areas. Although some differences occurred in the density of nut grass in the patches, twenty-one rows of 10 feet or more were found in which the stand of nut grass was very heavy and uniform. The patches sometimes extended over several rows and were of varying length in the rows. Each of the selected rows continued from the infested area into a weed-free area of 10 feet or more, although it was sometimes necessary to leave from 1 to 3 feet of partially infested row between the weed-free and nut-grass-infested rows. Soil samples for moisture determinations were taken in the hegari row on July 10, 18, and 26. The top inch of dry soil was discarded, and the second inch in which the hegari seed had been planted and the remainder of the top foot were sampled separately.

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[1]Smith, E. V., and Fick, G. L. Nut grass eradication studies: I. Relation of the life history of nut grass, *Cyperus rotundus L.* to possible methods of control. *Jour. Amer. Soc. Agron.* 29: 1007-1013, 1937.

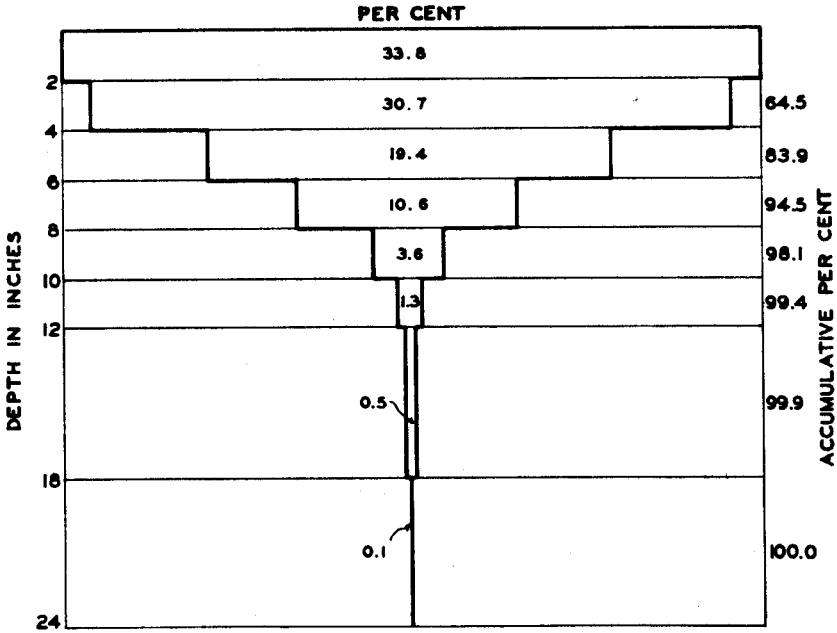

Figure 1.—Distribution of nut grass tubers in the top 24 inches of soil at the University Farm, Tucson.

The average moisture percentages for the nut grass areas and those free of nut grass are given in Table 1. A light shower wet the surface soil between July 18 and July 26 so that no differences occured in the moisture in the upper soil samples on July 26.

The surface soil in which the seed was planted was significantly drier in the nut grass patches 6 days after planting and remained drier than the soil in the same rows where there was no nut grass. The soil in the 10 inches below the seed was similarly drier in the nut grass areas than in those free of nut grass. The moisture loss, greater in the infested areas than in the free areas, took place before July 10 and was naturally more in the surface soil containing the seed than in the soil below the seed. The increased moisture loss was caused by transpiration of the small nut grass plants which started growth after the preplanting irrigation and appeared 3 to 4 days before the hegari seedlings. The wilting coefficient of this soil is 9.11, and the second inch of soil in which the hegari had been planted was not lowered to this point until July 18. The soil immediately below the seed, in which roots occurred even as early as July 10, had 12.1 per cent of moisture, well above the wilting coefficient on the second date of sampling.

Stand counts were made of the hegari plants on the dates indicated in Table 2. Some tillering increased the number of shoots counted by July 26 on the areas free of nut grass, and by August

TABLE 1.—AVERAGE PERCENTAGE OF SOIL MOISTURE AT TWO DEPTHS IN ROWS OF HEGARI INFESTED WITH NUT GRASS COMPARED WITH THOSE FREE OF NUT GRASS.

Date	Depth of sample			
	1 to 2 inches		2 to 12 inches	
	Free	Infested	Free	Infested
July 10	13.3	11.6	15.2	13.8
July 18	11.8	9.1	13.9	12.1
July 26	11.2	11.2	14.0	13.3

1 on areas infested with nut grass, although the amount of tillering could not be determined without pulling the plants.

The data for stand were analyzed by variance methods. The difference in stand on July 10, although in favor of the rows free from nut grass, is not significantly different. By July 18 the stand of hegari had been reduced significantly in the infested areas, but no significant reduction occurred in the areas free from nut grass. The reduction in stand on the infested areas was due to the drying up of the small plants which were evidently unable to compete with the nut grass.

The field was harvested for silage on October 8, 1941, and the rows which had been counted in July were harvested by weighing separately the heads and stalks from each row and combining the two weights for the yield of fresh silage. The yield data, which were analyzed in the same way as were the moisture and stand data, are given in Table 3.

The differences in yield are highly significant. There was no apparent advantage in pairing the rows, since yield from paired rows showed the same average difference per foot of row and a highly significant difference. The detrimental influence of the nut grass carried into the fall, although by October the hegari was 5 to 6 feet tall and the nut grass was 18 inches or less. Also the shade offered by the hegari had apparently reduced the stand of nut grass in October to 61 per cent of the counts made in July. Some spread from adjacent areas had occurred on the nut-grass-free plots but to the extent of less than 1 per cent of total area. Although a large part of the difference in yield was probably the

TABLE 2.—STAND OF HEGARI SHOOTS PER FOOT OF ROW IN NUT-GRASS-INFESTED AREAS COMPARED WITH THOSE FREE FROM NUT GRASS.

Date	Free	Infested
July 10	3.2	2.9
July 18	3.1	2.5
July 26	3.4	2.4
August 1	3.5	2.7

TABLE 3.—INFLUENCE OF NUT GRASS ON THE YIELDS (GREEN WEIGHT) OF HEGARI.

	Pounds per foot row		Reduction per acre due to nut grass (lbs.)
	Free	Infested	
Heads	0.589	0.524	944
Stalks	1.880	1.527	5126
Silage	2.469	2.051	6070

result of the reduction in stand in the early summer, the competition of soil nutrients through the growing season when the hegari apparently shaded the nut grass should not be entirely discounted.

Another part of the same field was used in 1942 further to check the influence of nut grass on the growth and yield of hegari. Plots were irrigated 9 days after planting to check against plots having similar stands of nut grass, but were not irrigated until 23 days after planting. Rains totaling 0.40 inch fell within 36 hours after the irrigation, so that no differences in moisture occurred between the irrigated and nonirrigated plots in the surface 2 inches. Likewise there was no significant difference in the stand of sorghum on the two treatments. The yield was slightly higher, though not significantly so, on the plots that were given the extra irrigation. The stand of nut grass per 10 square feet of row averaged 19.6 for forty rows which were not irrigated and 70.7 for the irrigated rows. The increase in nut grass stand was overcome by the end of the season. The sorghum shaded the nut grass completely, and after silage harvest in October no nut grass occurred in the rows in either treatment.

METHODS OF ERADICATION

SYSTEMATIC HOEING

Continuous cultivation will eventually kill any weed, but the optimum time and number of cultivations required to eradicate it most economically will vary with different weeds. A series of experiments designed to determine eradication requirements for nut grass was started in 1938 at the University Farm at Tucson. Plots 12 x 18 feet were laid out in an area heavily infested with nut grass. One series was hoed 1 to 2 inches deep each week and another each 2 weeks. The heavy work involved in the first three hoeings necessitated starting the plots at different times during the summer. The first plots were hoed on April 15 when the nut grass first appeared; the next were started June 1, the third series July 1, and the fourth on August 1. One half of the plots were not irrigated after hoeing started, and the others were irrigated each month in order to determine the influence of soil moisture on the time required for eradication. Two replications for each treatment

TABLE 4.—AVERAGE NUMBER OF HOEINGS NECESSARY TO ERADICATE NUT GRASS AT THE UNIVERSITY FARM AT TUCSON WHEN STARTED IN DIFFERENT MONTHS OF 1938.

Irrigated	Hoed	Month started				Average
		Apr.	June	July	Aug.	
Each month	Weekly	47	40	37	44	42
Each month	Biweekly	28	30	34	32	32
None	Weekly	54	52	56	53	53
None	Biweekly	41	40	38	32	38
Average		42	40	41	40	

TABLE 5.—AVERAGE NUMBER OF WEEKS NECESSARY TO ERADICATE NUT GRASS ON THE UNIVERSITY FARM AT TUCSON WHEN STARTED IN DIFFERENT MONTHS OF 1938.

Irrigated	Hoed	Month started				Average
		Apr.	June	July	Aug.	
Each month	Weekly	94	94	82	106	93
Each month	Biweekly	118	116	121	121	119
None	Weekly	126	119	112	108	116
None	Biweekly	129	123	162	134	137
Average		117	113	119	117	

were provided. At the conclusion of the experiment in 1941 there was no significant difference in the number of hoeings and the weeks taken to eradicate when started at different seasons of the year (Tables 4 and 5). This same lack of difference was found in two other series of plots cultivated which were started at different seasons with a one-horse cultivator equipped with sweeps. On the average, the plots which were started late the first season required more time to eradicate in the third season. The similarity in number of hoeings is more striking than in the number of weeks to eradication, because at the end of the second season nut grass was eradicated from the plots with moist soil by hoeing each week, while on others a few shoots appeared through the season of 1940. The shoots in 1940 required only a few hoeings but greatly extended the number of weeks.

Irrigation materially reduced the time and also the number of hoeings required for eradication. Weekly hoeings on moist soils eradicated the nut grass in two seasons, except for a few shoots which appeared to grow during the season of 1940 from tubers buried more than 18 inches deep. These few deeply buried tubers make careful watching necessary in the third season of the erad-

ication program. Eradication was not completed by August 13, 1940, on the dry plots when a flood covered the entire area. On that date all the dry plots had some nut grass showing. After the first hoeing subsequent to the flood nut grass failed to appear on three of the sixteen dry plots. Occasional shoots of nut grass appeared on three of the remaining plots in the fourth season, 1941. The last soil moisture samples taken before the flood were typical of the moistures determined just before an irrigation. The top 5 feet of soil was relatively uniform, averaging 8.40 per cent moisture on the dry plots and 10.30 on the wet ones. The standard error of the difference between these moistures on the wet and dry plots is 0.172 per cent moisture.

GREENHOUSE EXPERIMENTS WITH MOISTURE VARIATIONS

An experiment in the greenhouse was used to check the differences found in the field to determine whether the differences in moisture could account for the differences in the rates of tuber eradication. Pots were started at different seasons of the year and so subjected to different temperatures and lengths of days. Two moisture levels were maintained. For the low moisture series (Series B) the pots were not wet until the soil was below 9 per cent soil moisture. The wilting coefficient was 9.11. The soil was never below this point for as long as 24 hours. The high moisture series (Series A) was wet before the soil moisture was depleted below 11 per cent. The average minimum for this treatment was 11.4 per cent soil moisture. Three months after planting one tuber in each pot, the nut grass had become well established and the pots in each of the two series were divided at random into four lots, each lot consisting of four pots. Lot 1 of each series was used as a check, and the tops and tubers were counted and weighed for green and dry weight. The plants in Lot 2 of each series were clipped each week, those in Lot 3 clipped at 2-week intervals, and those in Lot 4 allowed to grow without clipping. After 3 months of clipping treatments the tops and tubers were harvested, counted, and weighed, as had been done previously with the plants in Lot 1. New plantings were made each 3 months until a total of eight experiments of four replications each had been completed. Table 6 shows the average weights and numbers of tubers for each lot. The numbers of shoots were determined weekly for each and are presented graphically in Figure 2. But slight and statistically nonsignificant differences occurred in total weights and numbers at different seasons of the year. The averages of all pots receiving the same moisture and clipping treatments are shown in Figure 2 and Table 6. Moisture differences were more important than seasonal differences in the greenhouse, which results agree with those obtained previously in the field.

Under higher moisture more nut grass shoots were produced than under the lower moisture treatment; however, the shoots in

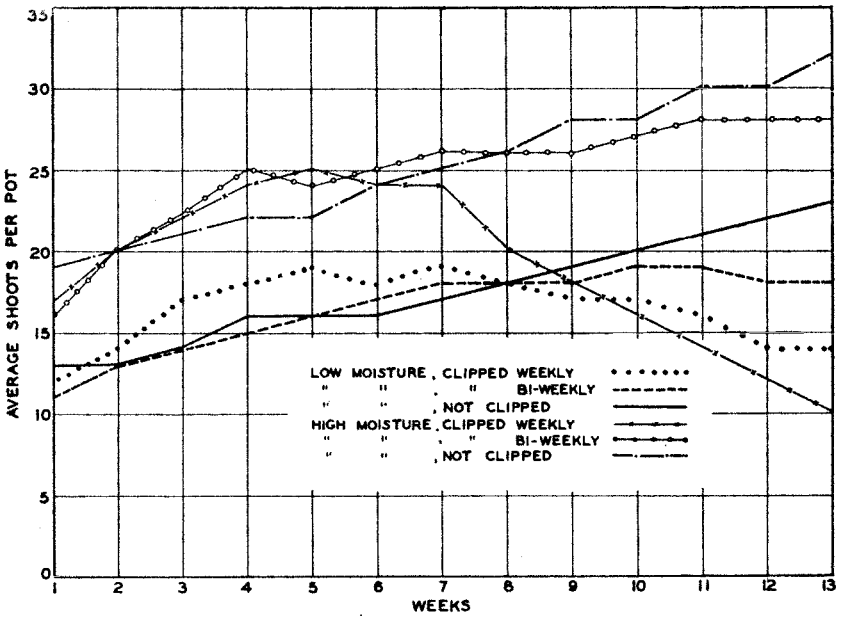

Figure 2.—Effect of clipping treatments and two moisture levels on the production of nut grass shoots in greenhouse pots. The soil moisture in the low moisture series was allowed to drop to the wilting coefficient 9.11 each time before wetting. That in the high moisture series never went below 11 per cent.

the high moisture pots disappeared more rapidly when clipped each week than plants started and maintained on a lower moisture level. Nut grass tended to maintain itself when clipped each 2 weeks on the high soil moisture but did not increase as rapidly as plants which were not clipped. Nut grass on the lower moisture level showed a tendency to level off at the end of 13 weeks' clipping and may have been maintaining the original reserves. These data indicate that under high moisture conditions nut grass is stimulated to make rapid growth so that by clipping it can be killed more rapidly than it can under low moisture conditions.

TABLE 6.—AVERAGE NUMBER AND WEIGHT OF NUT GRASS TUBERS FOUND IN GREENHOUSE POTS BEFORE AND AFTER CLIPPING ON TWO SOIL MOISTURE LEVELS, TUCSON, 1938-39.

Moisture	Treatment	Weight (grams)	Number
Low	3-months' check	25.4	20.3
Low	Clipped weekly	22.1	24.7
Low	Clipped biweekly	29.0	28.4
Low	6-months' check	59.1	56.7
High	3-months' check	38.3	27.5
High	Clipped weekly	27.0	27.2
High	Clipped biweekly	43.8	39.0
High	6-months' check	100.9	76.6

TABLE 7.—WEEKS REQUIRED TO ERADICATE NUT GRASS BETWEEN THE ROWS OF A VINEYARD WITH A CULTIVATOR EQUIPPED WITH SWEEPS. STARTED IN 1940 AT TUCSON.

Frequency of cultivation	Month cultivation was started			
	April	June	July	Average
Semiweekly	66	59	55	60
Weekly	66	57	59	61
Average	66	58	57	60

Under high moisture, however, an increase in the interval between clippings will result in more rapid regrowth than under a low moisture level.

SYSTEMATIC FIELD CULTIVATION

Semiweekly cultivations were no more effective than weekly when sweeps were used rather than the hoe. Two seasons were required for eradication in each case, as indicated in Table 7. Any eradication program must be followed by at least 1 season of checking in a cultivated row crop, and the best interval between cultivations seems to be 1 week rather than twice weekly or each 2 weeks.

The best time of year in which to start nut grass eradication was checked in three experiments. In the hoeing experiment cited in Table 5, the plots were located in an area receiving no treatment the year before. The experiment cited in Table 7 had received some cultivation the previous year but still had a heavy stand of nut grass. In another experiment on plots which had received three or four diskings in the season of 1939, the cultivation with sweeps was started on the first of each of 4 months in 1940. The average number of weeks required for eradication on four replicated plots for each month was as follows: June, 79; July, 97; August, 93; and September, 89. The nut grass was eradicated in the least time on the plots started in June in two of the three experiments and required but 1 more week than the July plots in the other experiment. However, in no case did an analysis of variance show a statistically significant difference in favor of any particular month. These data indicate that any season at which the work of eradication could be most readily initiated would be satisfactory for the control of nut grass.

DRYING TUBERS

Buried at varying depths

Exposure to the sun will kill tubers in a few days. Since all the tubers cannot be brought to the surface by practical field methods, experiments were designed to determine the rate in loss of viability through drying at various depths near the surface of dry soil.

Tubers were buried 1, 2, 3, and 6 inches deep with soil thermograph tubes. One hundred tubers were taken to the greenhouse from each plot at 3-day intervals for 3 weeks. These were planted in moist sand to determine their viability. A comparison of the viability of the tubers after one such experiment is presented in Table 8.

TABLE 8.—PERCENTAGES OF VIABLE TUBERS AFTER BURIAL IN THE FIELD AT DIFFERENT DEPTHS AND FOR VARYING PERIODS OF TIME. AVERAGE OF TWO 50-TUBER SAMPLES BURIED MAY 20, 1940, AT TUCSON.

Depth (inches)	Percentages by days in field							Average maximum temperature
	3	6	9	12	15	18	21	
1	90	63	24	0	0	0	-	120.3
2	82	76	38	6	0	1	0	106.2
3	92	82	72	55	20	4	0	100.6
6	94	86	78	55	54	86	-	87.7

Tubers which had been subjected to extreme temperatures reaching as high as 130 degrees F. and averaging 120.3 degrees in the surface inch rapidly lost their viability. In general, viability decreased with the extension of time as the position of the tubers approached the surface. None of the tubers sprouted after 12 days when buried 1 inch deep and none after 21 days when buried 2 and 3 inches deep. Viability still remained strong on the eighteenth day with tubers at the 6-inch level. An insufficient number of tubers remained at this level to run determinations the twenty-first day.

The maintenance of viability in the tubers at the 6-inch depth may have been the result of lower temperatures or higher moisture or, more likely, a combination of these factors. Previous experiments had shown that tubers would not be killed in moist soil, and moisture samples taken from the plots had shown as high moisture at 6 inches deep in the 6-inch plot as in the 1-inch. The soil in that plot had been removed to a depth of 6 inches and screened to take out all tubers and then replaced, so some moisture loss was expected. The soil in the 1-inch plot had not been disturbed below 1 inch. Since the death of the tubers was related to drying, it was important to determine what the effect would be if air-dry soil from the surface were turned under with a plow and tubers covered 5 or 6 inches.

In another tuber-drying experiment, soil was screened and spread in a layer 1 inch thick to dry for a week. It was then rescreened into previously prepared plots 2, 3, 4, and 5 inches deep and nut grass tubers placed in this air-dry soil at these depths with thermograph tubes. Viability decreased with decreased depth, as shown in Table 9, and decreased with increased time, as before. All the tubers had been killed at the 2-, 3-, and 4-inch levels by the twenty-first day and but 5 per cent of the tubers from the

TABLE 9.—PERCENTAGE OF VIABLE TUBERS AFTER BURIAL IN THE FIELD AT DIFFERENT DEPTHS AND FOR VARYING PERIODS OF TIME. AVERAGE OF TWO 50-TUBER SAMPLES BURIED JULY 2, 1940, AT TUCSON.

Depth (inches)	Percentage by days in the field							Average maximum temperature
	3	6	8	11	14	17	21	
2	51.0	5.0	0.0	0.0	0.0	0.0	0.0	123.1
3	71.2	59.5	40.2	20.2	9.0	4.0	0.0	110.6
4	100.0	84.2	44.2	23.5	15.2	7.0	0.0	108.5
5	92.0	95.0	89.0	87.2	80.0	20.2	4.8	100.2

TABLE 10.—SOIL MOISTURE PERCENTAGES IN PLOTS 3 WEEKS AFTER FILLING TO VARIOUS DEPTHS WITH LOOSE AIR-DRY SOIL. FILLED JULY 2, 1940, AT TUCSON.

Depth of sample (inches)	Moisture per cent in plots filled to depths indicated in inches				Average moisture percentage
	2	3	4	5	
0-1	0.33	1.09	0.55	0.46	0.61
1-2	0.47*	1.35	0.92	0.68	0.86
2-3	1.54	1.50	1.23	1.44	1.43
3-4	2.22	1.95	1.46	1.79	1.86
4-5	2.83	2.78	3.25	2.36	2.80
5-6	4.37	3.85	3.48	2.94	3.66

*Lowest depth disturbed. Soil samples above this line were taken from air-dry filled soil; those below from undistured soil.

5-inch level were still viable at that time. The viability of the tubers at the 5-inch level remained high for the first 2 weeks but dropped quite rapidly the third week. Average maximum soil temperatures ranged from 123 degrees F. at the 2-inch level down to 100 degrees F. at the 5-inch level. Soil moisture determinations were made of samples taken by inch depths in each of the four plots at the end of the 3-week period of tuber sampling (Table 10). These figures show that moisture must have come up from the undisturbed soil below as vapor, later condensing to increase the moisture of the uniformly air-dried soil used to fill the plots. The increase in moisture at the 5-inch level to about 2.36 per cent was of sufficient magnitude which, when accompanied by a drying temperature of 100 degrees F., enabled some tubers (4.8 per cent) to retain their viability beyond 3 weeks. The increase to 1.46 per cent moisture in the inch zone immediately above the 4-inch level, when accompanied by an average maximum temperature of 108 degrees, resulted in the death of all tubers by the end of the third week.

These results suggest the practicability of killing nut grass by successively deeper plowings at 3-week or longer intervals, bringing not to exceed 3 or 4 inches of new soil to the surface at each plowing. Previous reduction of moisture to a minimum by growing some such crop as a winter grain prior to initiating the plowing program might be necessary to insure the success of this method. Such an experiment is reported later in this bulletin.

Influence of size of tubers

Tubers buried in the field were not selected for size, but those which grew after longer periods were always large ones. Individual tubers of all sizes were weighed and dried in sand in the greenhouse at different intervals, then reweighed and planted to determine viability. Tubers of less than 0.10 gram dry weight did not grow after 2 days' exposure, as shown in Table 11. More of the tubers between 0.11 and 0.20 gram dry weight grew after 2 days' exposure than did the smaller tubers, but more grew after 3 days' exposure. Tubers of 0.21 gram or over retained viability for a longer period than smaller ones, but more over 0.31 gram dry weight retained their viability after 3 and 4 days than those of 0.21 to 0.30 gram dry weight. The percentage of dry weight is similarly related to viability. Practical application of these factors in the field will depend on the time taken to kill the large tubers which are mature. The factors which contribute to the loss in viability are loss in moisture and length of exposure to the high temperatures and drying conditions.

TABLE 11.—PERCENTAGE OF LIVE TUBERS BY WEIGHT CLASSES AFTER EXPOSURE TO DRYING IN THE GREENHOUSE.

Grams dry weight/100 tubers	Days' exposure in dry sand				
	1	2	3	4	5
10 or less	37	2	0	0	0
11 to 20	96	14	0	0	0
21 to 30	92	64	0	0	0
31 or more	100	96	54	58	0

Influence of temperature

The lowest average minimum temperature at which tubers were completely killed in all experiments was 100 degrees F. Air temperatures were recorded simultaneously with the soil temperatures. From these data the regression equation $X = 15.77 + 0.913A$ was calculated, where X is the maximum soil temperature at 3 inches deep and A the maximum air temperature. From the equation plus the error of the regression coefficient it was calculated that when the maximum air temperature reaches 94 degrees F., the maximum soil temperature 3 inches deep in dry soil of this type will be in excess of 100 degrees F. This relationship was borne out by examination of the daily records for the

2 seasons for which soil temperatures were available. The 3-inch depth was chosen for the determination of the soil-air-temperature correlation because 3 inches was the lowest depth at which tuber viability was destroyed in May soon after the spring dry season started.

The months of April, May, and June at Tucson have an average rainfall of 0.34, 0.19, and 0.28 inch, respectively. Maximum daily temperatures for the same months average 80.7, 89.3, and 98.8 degrees F. and are usually above 90 degrees F. after April 20 to May 1. These weather conditions indicate that the soil conditions necessary to kill nut grass tubers might be found in the field and are typical of irrigated valleys in southern Arizona.

Successively deeper turnings with shovel

Preceding trials having shown that exposure to intensive drying conditions for a few days will kill even the large tubers, an experiment was started April 21, 1940, to determine the practicability of controlling nut grass by successively deeper turnings of infested soil at systematic intervals. Two series of three plots each were used for the test. One series of plots was hoed 2 inches deep and left to dry for 2 weeks. At the end of this 2 weeks of drying, these plots were shoveled to a depth of 4 inches in an attempt to bring to the surface the tubers from 2 to 4 inches deep. At the end of the fourth week after the initial hoeing, the plots were shoveled to a depth of 6 inches. These treatments were continued at intervals of 2 weeks, the soil having been turned 2 inches deeper each time. The final turning to a depth of 12 inches was made at the end of 10 weeks. The second series of three plots was hoed at the same time as were the first series but to a depth of 3 inches and allowed to dry for 3 weeks, then turned 6 inches deep. These treatments were continued at 3-week intervals turning the soil 3 inches deeper each time until the final depth of 12 inches was completed at the end of 9 weeks. At the end of the twelfth week six areas of 1 square foot each were dug on each plot to a depth of 2 feet, and all the live tubers in the 2 cubic feet of soil were counted. The results as shown in Table 12 represent a very sizeable reduction when compared to adjacent check plots. Only 0.43 per cent of the tubers remained viable in the series turned at 2-week intervals to a depth of 2 inches at each turning and but 1.56 per cent in the series turned to a depth of 3 inches at each turning at 3-week intervals. Previous counts made in this soil (Figure 1) have shown that over 99 per cent of all tubers in the top 24 inches are located in the upper 12 inches of soil. These results indicate that systematic plowing at successive depths for 3 months during the hot summer period might very materially reduce the number of viable tubers in an infested soil and effect an excellent start toward control.

TABLE 12.—LIVE TUBERS PER SURFACE SQUARE FOOT ON JULY 25, 1942, AFTER SUCCESSIVELY DEEPER TURNINGS IN DRY SOIL IN THE FIELD AT TUCSON.

Thickness of layer turned each time (inches)	Weeks between turnings	Number of turnings	Numbers of live tubers per surface sq. ft. average of 6 replications			Average tubers sq. ft.	Percentage survival
			I	II	III		
2	2	6	6.13	0.0	2.13	2.75	0.43
3	3	4	26.0	0.0	3.67	9.89	1.56
Check	..	0	602	761	542	635	

Successively deeper plowing

Plowing experiments were run in a field at Mesa, Arizona, which had been in winter barley pasture and not irrigated after March 15. Three plots in a solid stand of nut grass were disked May 11 to a depth of 3 inches. On June 1 the plots were plowed with a disk plow to a depth of about 6 inches, and on June 21 the field was plowed to a depth of 10½ inches with a moldboard plow. Before plowing was started, counts of tubers were made on six areas of 1 square foot each, dug to a depth of 2 feet on each of the three plots. In August no live tubers were found in samples taken adjacent to the eighteen samples taken in May, but nine scattered patches of nut grass appeared in the three plots. In three of these patches, 18-square-foot areas were dug and viable tubers counted. Two live tubers and 23 basal bulbs were found in the 18 square feet taken to the plow sole, and a total of 65 live tubers were found in the soil below the plow sole. The original counts averaged 324 tubers per 2 cubic feet of soil. The final count, including basal bulbs which might have developed after the plowing stopped, represents 1.54 per cent survival. The surface soil at Mesa was dry, but the subsoil was wet enough to ball up in the hand.

Another experiment to determine the effect of successively deeper plowing to expose as many of the tubers as possible to drying between barley pasture and a sorghum crop was studied in the field at Tucson in 1942. The plowing and irrigation treatments used are given in Table 13. The July 21 irrigation, applied 9 days after planting, increased the number of nut grass shoots, as a comparison of Treatments B and C shows. However, the sorghum plants in Treatments A and B grew more rapidly and provided dense ground shade earlier in the season than those which did not receive the July 21 irrigation. Rains, totalling 0.40 inch, fell on July 21 and 22 and wet the soil to a depth of 2 inches, sufficient to accelerate sorghum growth temporarily on the unirrigated Treatment C plots but not enough to keep them growing rapidly.

The successively deeper plowings given prior to planting sorghum on the Treatment A plots undoubtedly killed most if not all of the tubers in the upper 10 inches. More than 99 per cent of the nineteen shoots per square foot which appeared by August 3 came from tubers in lower soil levels. On the other hand most of the twenty-one shoots found at that time on the Treatment C plots

TABLE 13.—INFLUENCE OF PLOWING AND IRRIGATION IN A SORGHUM FIELD ON THE APPEARANCE OF NUT GRASS SHOOTS. SEEDBED PREPARATION FOR ALL PLOTS THE SAME—IRRIGATED JULY 1; PLOWED 9 INCHES DEEP JULY 6; IRRIGATED JULY 8; DISKED, HARROWED, AND PLANTED JULY 12.

Treatment	Procedure prior to preparing seedbed for planting	Subsequent irrigations	Number nut grass shoots in 10 sq. ft. Aug. 3
A	Disked 3 in. May 12 Plowed 5 in. May 26 Plowed 10 in. June 11	July 21 Aug. 4	..... 19.1
B	None	July 21 Aug. 4	..... 52.1
C	None	Aug. 4	21.4

came from tubers in the upper 10 inches. Thus potential conditions for increased nut grass growth were greater on the C plots than on the A plots and not at all in proportion to the number of shoots which had appeared by August 3. The successive turning would facilitate eradication but the extra irrigation shortly after planting, as in treatment B, will insure the stand of the current crop and greatly reduce the detrimental effect of the nut grass.

SMOTHER CROPS

The possibility of combining a cropping program with nut grass control was tested for 2 years in experiments at Tucson and Mesa. Some plots were cultivated at weekly intervals between winter small grain crops, and others were cultivated between the time nut grass appeared in April and July 15, when hegari was planted. The growing of winter grain on infested land which had been systematically cultivated the previous spring and summer did not further reduce nut grass density the following spring when compared with areas receiving similar cultivations during the spring and summer but lying idle during the winter. Two or three hoeings in the growing hegari to supplement the cultivations were required for complete eradication. However, after 2 years of spring cultivation and hegari silage, less than 1 per cent of the nut grass tubers remained alive.

CHEMICALS

Because of high cost, the use of chemicals will necessarily be confined to small areas or areas inaccessible to cultivating equipment. However, widespread advertising relating to chemical control results in many ill-advised attempts to kill nut grass by chemical methods. Table 14 shows some of the results obtained with chemicals in Arizona in the eradication of nut grass.

TABLE 14.—PERCENTAGE OF NUT GRASS KILLED 1 YEAR AFTER FIRST USING VARIOUS CHEMICALS AT TUCSON.

Location	Chemical	Form applied	Pounds per sq. rd. by season of application			Per cent kill, av. 3 or more plots
			Fall	Spring	Summer	
Irrigation ditch	Sodium chlorate	dry	2	2	....	24
	Sodium chlorate	spray	2	2	....	14
	Sodium arsenite basic	spray	1	1	....	58
	acid	spray	1	1	....	22
	Carbon bisulphide	.....	..	2 gal.	....	24
	Weed torch	.....	..	weekly	....	0
	Hand hoeing	.....	..	weekly	....	94
Border over pipe line	Sodium chlorate	dry	..	4	2	68
	Potassium chlorate	dry	..	4	2	60
	Borax	dry	..	8	1.5	73
Fence line	Nelsite C	spray	..	..	0.5	50
	Nelsite additive compound plus	.....	..	..	....	....
Fence line	¼ lb. chlorate	spray	..	..	0.5	25
	¼ lb. chlorate/gal.	spray	..	..	0.5	25
	1 lb. chlorate/gal.	spray	..	..	2	25
	Sodium arsenite acid	spray	..	..	1	32
	Atlacide	dry	..	..	6	70
	Sodium chlorate	dry	..	..	6	50
	Borax	dry	..	..	6	65
	Borax	dry	..	..	8	65
	Fuel oil	spray	..	..	twice	20
	Kerosene	spray	..	..	twice	18
	Gasoline	spray	..	..	twice	48
	Burned	fire	..	..	twice	20

Chemicals have failed to give satisfactory control of nut grass. Although repeated treatments will eventually kill the plants in the same way that repeated cultivations will kill nut grass, the data given in Table 14 show that the chemicals are not very effective in one or two treatments. Repeated use of the arsenicals, sodium arsenite, either acid or basic, and Nelsite C have eradicated nut grass in a fence row almost completely. Repeated use of such chemicals cannot be recommended, however, because a ditch bank may be formed where the water might collect after passing through the treated weeds and later be used by animals for drinking. Burning when carried on for 1 year in the experiment cited in Table 14 resulted in an increase in the stand of nut grass. This was more the result of the eradication of other weeds than stimulation of nut grass because the second year of burning reduced the stand by about 25 per cent when compared with the original count. Hoeing at the same time other plots were burned was less expensive and much more effective than any of the other treatments. The first three hoeings cost more than the burning but became successively cheaper until at the end of the second season only an occasional weed was found to hoe, and none appeared the third season.

Until new and better chemicals are developed, none can be recommended for nut grass control unless they are to be used in areas where mechanical work is impossible.

Moving a ditch into a field already cleared of the weed, then plowing the old ditch and cultivating the weeds on the moist soil,

would be cheaper than attempting to eradicate the weeds on the ditch either by hand or by chemicals. Burning to control the set of seed, with a strip left below the ditch so that at least 10 feet could be kept plowed between the field ditch and the crop, would prevent the spread of nut grass from an infested ditch to a clean field.

SUMMARY AND CONCLUSIONS

A stand of hegari was reduced significantly in the rows containing nut grass during the period from 6 to 14 days after planting. During the same period the hegari stand was being reduced, the soil moisture continued lower in the nut grass rows than in the rows having no nut grass. The soil moisture at the depth of the hegari seed reached the wilting coefficient at the end of the period for which the hegari stand loss occurred. Tillering of the hegari plants failed to overcome the reduction in stand effects on grain or fodder yields by the time the field was harvested for silage.

Irrigation and rain, or rain alone 9 or 10 days after planting, overcame the detrimental effects of the nut grass in an Atlas sorghum crop, and in this experiment no significant yield differences were found. The heavy Atlas stand did more than the hegari to shade the weeds and overcome their effect in the nut grass patches. The competition for water supply seemed to be the most important factor in sorghum. Good cotton stands are often obtained on nut grass areas before the nut grass begins summer growth. The taller growing crops, such as hegari, Atlas sorgo, or cotton, will do much to control nut grass without additional work, beyond an extra irrigation to establish and maintain the stand while the crop plants are small. The same method may be applied to sugar beets and other late summer planted crops. The shade of competing crops may not kill all the nut grass, but it will control the weed and reduce the amount of work necessary for its eradication. Where the infestation covers entire fields or the hand labor for eradication is not available, a control program using summer smother crops with weekly cultivations between crops may be the most practical way of combating nut grass.

High temperatures in conjunction with low soil moisture will rapidly reduce the viability of nut grass tubers. These conditions are normally found in southern Arizona in the months of April, May, and June. The light showers which fall in these months rarely wet the soil below an inch deep, and the soil is seldom wet for more than a day or two. Temperatures as early as the last of April are usually sufficiently high to raise the soil temperatures above 100 degrees F. 3 inches beneath the surface. The higher temperatures reduce the time required to kill the tubers by increasing the rate of moisture loss. Moisture in the soil prevents the loss of moisture from the tuber and stimulates growth so that the tubers cannot be killed by near-surface exposure.

Drying nut grass tubers by bringing them within a few inches of the surface through successively deeper plowings at intervals of 2 to 3 weeks during the hot months of the year, followed immediately by a sorghum smother crop, successfully controlled nut grass in fields at Tucson and Mesa. The soil must be kept dry during the plowing treatments. Two or three hoeings in the sorghum row usually will hasten eradication very materially. Since but one extra plowing and perhaps two hoeings are involved in this method, the extra cost for nut grass control is comparatively small when one considers the large losses levied by a heavy stand of this pest. Two or 3 years of careful work will result in eradication and at the same time provide a cash or feed sorghum crop each year.

Soil moisture is necessary to stimulate nut grass growth, and cutting the shoots each week in moist soils destroys more food in the new shoots which are cut off than is produced by the shoots which are already at the surface. Thus, weekly cuttings will kill the weeds in moist soil. Cutting the shoots more frequently cuts off fewer shoots, and cutting at longer intervals allows some food to be stored by the older shoots in excess of that used by the new ones. If the soil moisture is lowered, the rate of growth is reduced so that less material is cut off at each clipping and the life of the weeds is extended.

Where nut grass is to be eliminated from permanent plantings, continuous cultivation is a practical method of eradication and must be carried on for 3 seasons to kill all the weeds around the trees or vines. A smother crop and early season cultivation might be combined in some orchards. Such a combination as early planted Sudan grass or cultivation each week until Sudan grass is planted in June will control nut grass and may reduce the amount of handwork necessary for its eradication.

Irrigation each month and cultivation each week was the most practical method of killing nut grass where no crops were to be grown; a cultivator with sharp sweeps, a good disk, or a hand hoe—in that order—were the most effective implements. Any tool which will cut the nut grass shoots an inch and a half or more deep will be effective.

No season of starting cultivation showed any advantage over others in reducing the time or number of cultivations necessary to eradicate nut grass. Any season in which the control methods can best be started will be effective. However, once eradication is attempted and after the first three cultivations when the weeds begin to disappear, any omission in the cultivation program will delay eradication by that much or more.

Nut grass is particularly resistant to chemicals, and except for repeated killing of the tops by use of oils, burning, or other chemicals, nut grass will not be eradicated by chemicals except where used in sufficient quantity completely to sterilize the soil. The

large amounts of borax, sodium chlorate, or arsenic which must be used for complete sterilization and the 3 years or more required for complete eradication make the cost of chemicals prohibitive except on permanent fence lines, around buildings and similar locations, or on small plots. Twenty-four hundred pounds of borax, 1,600 pounds of sodium chlorate, or 1,280 pounds of arsenic trioxide would be necessary to sterilize an acre.

RECOMMENDATIONS FOR ERADICATION AND CONTROL

I. Nut grass can be eradicated without excessive cost and still provide for the production of a cash crop each year if the following procedure is followed carefully and all operations are performed promptly and thoroughly.

1. Grow a winter crop from which irrigations are withheld sufficiently long before harvest to enable the plants to reduce the soil moisture as much as possible.
2. If daily maximum temperatures have reached 94 degrees F. or higher by the time the above crop is harvested, disk the field 3 inches deep and leave for 3 weeks of drying.
3. Plow 6 inches deep and allow 2 weeks for drying.
4. Replow 10 inches deep and leave for another 3 weeks of drying.

The success of this program of weed-killing operations depends upon the thorough drying of the tubers at high temperatures in the top 3 or 4 inches of soil as the successively deeper turned layers are brought to the surface. If rains should interfere with the drying program, an extra disking and subsequent lengthening of the period prior to the next operation might be required to facilitate drying of the tubers.

5. Irrigate, prepare seedbed, and plant to a heavy-producing, fast-growing sorghum such as hegari or Atlas. It will probably be too late to plant a long-season sorghum such as Manko.
6. Irrigate 7 to 10 days after planting. If nut grass appears in quantity along with emerging sorghum plants, the stand of sorghum will be reduced by the competing nut grass unless the growth of the sorghum plants is accelerated by this early irrigation.
7. Irrigate and cultivate during balance of season as often as needed for good crop growth and weed control.
8. Unless a good application of barnyard manure can be made following harvest of the sorghum, the land should lie fallow and no winter cropping be attempted.
9. Plow following sorghum harvest.

10. Following spring and early summer, disk or cultivate with sweeps, if sorghum stubs permit, as often as necessary to prevent regrowth of nut grass.
11. Prepare seedbed and plant to second year of sorghum.
12. Repeat irrigation and cultivation program as before.
13. Early season cultivation plus the digging of an occasional escaped nut grass shoot in the third year's sorghum or other row crop may be necessary for complete eradication.

II. Cultivate each week with sweeps or disk if thorough job can be done with no misses and irrigate each month during the summer. Plant only winter crops. Repeat for 3 years.

The success of this method of eradication is dependent upon keeping the soil moist to encourage germination of the nut grass tubers and systematic thorough cultivation to prevent top growth. Thus the old tubers will be destroyed through depletion of food reserves and the formation of new ones prevented.

III. Eradication along ditches or fences.

1. Hoe each week from last frost to first frost for 3 seasons, or until eradication is complete, or
2. Burn each 3 weeks to prevent seeding and cultivate weekly a strip 10 feet wide between the crop and the ditch or fence which is infested.
3. After cleaning a field, move the ditch or fence to clean soil and cultivate the old ditch or fence row.

IV. Control:

The damage done by nut grass is primarily the reduction of stand in field crops while the crop is becoming established. Crops can be grown on infested land where eradication is impractical, because of lack of labor or funds, by following these precautions.

1. Plant only tall-growing crops in the summer; cotton and sorghum are two examples.
2. Crops planted after the first of May will require an extra irrigation 7 to 10 days after planting, even though the soil seems moist and the nut grass occurs only in patches.
3. An extra hoeing may be required, particularly with cotton, to enable the crop to become sufficiently established to compete with the weeds.