AN ABSTRACT OF THE THESIS OF

Karin Tanphiphat for the degree of Doctor of Philosophy in Crop Science presented on July , 1989 .

Title: Biology and Control of Tuber Oatgrass (Arrhenatherum elatius (L.) Presl. var. bulbosum (Willd.) Spenn.) .

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ARNOLD P. APPLEBY

Tuber oatgrass (Arrhenatherum elatius (L.) Presl. var. bulbosum (Willd.) Spenn.) is a perennial grass that often becomes a weed problem in Western Oregon. Control efforts using glyphosate often give unsatisfactory results. The effects of several factors on development of tuber oatgrass were investigated. Long days and cool temperatures (16/8h, 20/10C day/night) were favorable conditions for shoot growth in this study. Temperature increases from 20/10C to 30/20C day/night hastened corm formation in plants growing under short days (8/16h day/night), but not in those growing under long days (16/8h day/night). Vernalization was not required for plants to produce flowers. Tuber oatgrass seeds were not dormant and had a high germination percentage. Seed germination was most rapid at 15C; increasing the temperature to 25C significantly reduced total germination. Initial germination was delayed at 8 and 25C. The total

total number of corms that sprouted was the same at 8, 15, 25, and alternating 20/30C at 16/8h. Corms at different stages of maturity sprouted at different times. Immature corms sprouted more slowly and the time required for total sprouting was longer than that of mature corms. This variation in corm maturity would reduce the effectiveness of a single herbicide application.

Growth and development of tuber oatgrass was investigated in plants growing in the field and in outdoor pots. Under the mild climate of the Willamette Valley, Oregon, shoot emergence occurred in early fall, followed by vegetative growth during the winter and spring. In the summer, above-ground portions of the plant stopped growing and senesced. The highest absolute growth rate of the plants occurred in early May, shortly before the onset of the reproductive stage. In early May, the growth rate of corms was higher than that of the shoot.

The efficacy of glyphosate on tuber oatgrass was investigated in greenhouse and growth chamber studies. Glyphosate at 1.2 and 2.5 kg ae/ha significantly reduced new corm formation and corm viability. A 24-h period between glyphosate application and removal of the shoots was sufficient to cause maximum reduction in regrowth. Glyphosate applied at the 6- to 7-leaf stage controlled all of the tuber oatgrass. The total amount of ^{14}C translocated out of treated leaves did not differ among different growth stages, but more ^{14}C accumulated in the dormant corms when

applied in 10 ul droplets at the 2- to 3-leaf stage than at the 4- to 5- or 6- to 7-leaf stages. Most of the poor control in the field from glyphosate is probably due to dormant corms in the soil that are not connected with an emerged shoot.

BIOLOGY AND CONTROL OF TUBER OATGRASS

(*ARRHENATHERUM ELATIUS* (L.) PRESL. VAR. *BULBOSUM* (WILLD.) SPENN.)

by

Karin Tanphiphat

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DEDICATION

This thesis is dedicated to those individuals who directed my education to this point.

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INTRODUCTION

Tuber oatgrass (*Arrhenatherum elatius* (L.) Presl. var. *bulbosum* Willd. Spenn.) is a perennial grass that often becomes a weed problem. Although its geographic range is limited, it is difficult to control where present. In Western Oregon, tuber oatgrass has been reported to be a weed problem in many crops including winter wheat, annual ryegrass, and Austrian peas.

Glyphosate is a postemergence non-selective herbicide that has shown promising results for controlling many perennial weeds. Although effective control of other perennial grasses by glyphosate has been reported, researchers and growers in Western Oregon have observed that tuber oatgrass usually regrows after glyphosate application. The limited information on biology of this weed makes planning control programs difficult.

Research reported in Chapter 1 was undertaken to determine some factors influencing the development of tuber oatgrass.

Research in Chapter 2 was conducted to develop the morphological and phenological description of growth and

development phenomena in tuber oatgrass plants growing under normal field conditions and in the pots.

Research in Chapter 3 investigated the efficacy of glyphosate on tuber oatgrass and determined the translocation of ^{14}C-glyphosate into dormant corms.

Each chapter was written as a complete and self-contained manuscript. Detailed data are presented in the Appendix.

Chapter 1. Factors Affecting the Development of Tuber Oatgrass (*Arrhenatherum elatius* (L.) Presl. var. *bulbosum* (Willd.) Spenn.)

ABSTRACT

The effects of several factors on development of tuber oatgrass were investigated. Long days and cool temperatures (16/8h, 20/10C day/night) were favorable conditions for growth. Temperature increases from 20/10C to 30/20C day/night hastened corm formation in plants growing under short days (8/16h day/night), but not in those growing under long days (16/8h day/night). Vernalization was not required for plants to produce flowers. Tuber oatgrass seeds were not dormant and had a high germination percentage. Seed germination was most rapid at 15C; increasing the temperature to 25C significantly reduced total germination. Initial germination of seeds was delayed at 8 and 25C. The total number of corms that sprouted was the same at 8, 15, 25, and alternating 20/30C at 16/8h. Corms at different stages of maturity sprouted at different times. Immature corms sprouted more slowly and the time required for total sprouting was longer than that of mature corms. This variation in corm maturity would reduce the effectiveness of a single herbicide application.

INTRODUCTION

Tuber oatgrass (Arrhenatherum elatius (L.) Presl. var. bulbosum (Willd.) Spenn.) is a perennial grass that has become an increasingly serious weed problem. Its lowest stem internodes swell and form corms. These corms are readily separated by tillage, and each corm is capable of producing a new plant. In spite of its importance, not much is known about its biology, although some factors affecting corm formation have been studied. Corm formation is hereditary and independent of habitat (UNDERWOOD 1911). Soil conditions have no fundamental effect but merely modify the degree of corm development (JENKIN 1931). Plants grown under continuous illumination or long days produced corms more rapidly than those subjected to short days (LE CLERCH 1971). A similar result was found under normal field conditions (LE CLERCH 1976).

Besides vegetative propagation, plants also can become established from seeds. LE CLERCH (1976) found that tuber oatgrass seeds were produced in sufficient amount to ensure reproduction by that means alone. In his study, seeds showed little dormancy and had 65 to 80% germination as soon as they matured. Germination of freshly collected seeds could be stimulated by exposure to alternate temperatures (20/15C day/night) or chilling at 4C for 24h. Seed longevity varied, but it was very short in soil; it may be 2

years when stored in laboratory conditions.

Although the geographic range of tuber oatgrass is limited, it has been difficult to control in Oregon. Researchers and growers in Western Oregon observed that the weed usually regrows after herbicide application. The limited information on factors influencing the development of this weed makes planning control programs difficult. As a result, the objectives of this study were to investigate a) the effect of photoperiod and temperature on tuber oatgrass development, b) vernalization requirements, c) seed and corm germination requirements, and d) corm sprouting in response to different stages of maturity.

MATERIALS AND METHODS

Effect of photoperiod and temperature on tuber oatgrass development. Tuber oatgrass plants originating from corms were used to investigate the effects of light and temperature on subsequent plant development. Single corms were planted in 10 by 10 cm plastic pots filled with greenhouse soil mix (soil:peat:sand:pumice-1:1:1:2). The pots were placed in growth chambers under light intensity of 250 $uE \cdot m^{-2} \cdot s^{-1}$ with the following treatments:

1. 30/20C day/night temperature at 16/8h photoperiod.
2. 30/20C day/night temperature at 8/16h photoperiod.
3. 20/10C day/night temperature at 16/8h photoperiod.
4. 20/10C day/night temperature at 8/16h photoperiod.

The plants were subirrigated daily and fertilized weekly with a water-soluble fertilizer (N:P:K-20:20:20). Random samples of 10 plants were excavated at 2-week intervals and the number of tillers, shoot height, and shoot dry weight were determined. Plants also were evaluated for corm formation. T_{50} (time required to obtain 50% of plants forming corm), the parameter used by LE CLERCH (1975), was estimated from the graphs. The experiment was repeated using plants produced from seeds.

Vernalization study. A study was conducted to investigate vernalization requirements for flowering of tuber oatgrass plants started from seeds and corms. Seeds

and corms, which had not been exposed to chilling, were placed in 15 by 15 cm plastic boxes containing filter paper (seeds) or sponge (corms) moistened with distilled water. The boxes were kept in the refrigerator at 5C for 0, 1, 2, 3, and 4 weeks. After vernalization, both seeds and corms were allowed to acclimate at room temperature for 2 days prior to transplanting into the 3.7-L plastic pots and placed in the greenhouse. Greenhouse temperature was 18/15C day/night with 16/8h photoperiod maintained by supplemental lighting. The number of days to flowering and the number of panicles produced 6 months after planting were recorded. Data were analyzed by regression analysis.

Seed germination study. The seeds used in this study were collected from plants grown in the greenhouse. Germination tests were conducted on freshly harvested seeds. The experimental design was a completely randomized design replicated four times with 4 by 2 by 2 factorial arrangement of treatments. There were four temperature levels (8, 15, 25, and alternating 20/30C at 16/8h), two light treatments (light and dark), and two germination solutions (water and 0.2% KNO_3 (v/v)). The light treatment was approximately 250 $uE \cdot m^{-2} \cdot s^{-1}$. Twenty-five seeds were placed on blotter paper moistened with germination solution in covered plastic boxes. For the dark treatment, the boxes were wrapped in aluminum foil before being placed into the germinators. Radicle emergence was counted weekly and the experiment was

terminated after 8 weeks.

Corm sprouting study. The effect of light and temperature on corm sprouting was studied. Tuber oatgrass corms were collected from plants grown under normal field conditions. Strings of superimposed corms were sectioned into single corms. Ten corms were placed into sponge soaked with distilled water and put in plastic boxes before being placed in germinators. The treatments were similar to those used in the seed germination study except that no KNO_3 treatment was included. Shoot emergence was counted weekly.

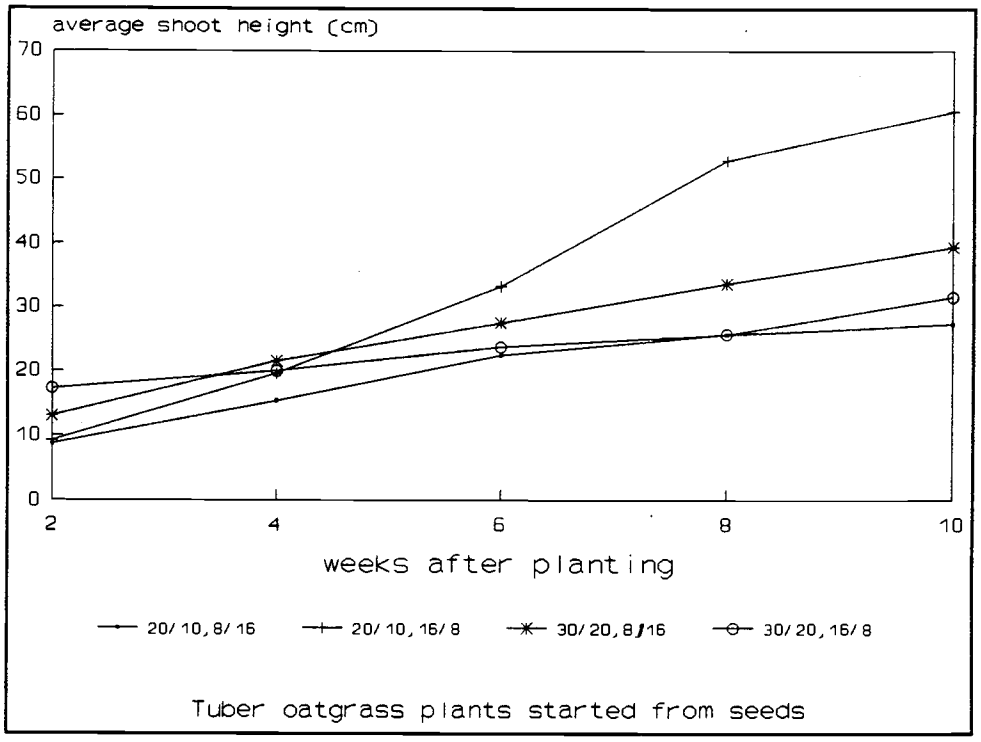
Sprouting of tuber oatgrass corms at different stages of maturity. Tuber oatgrass plants were collected from the field on April 1, May 16, June 24, and August 1, 1988. The shoots were clipped off above the top corms and corms were replanted using greenhouse soil mix (soil:peat:sand:pumice-1:1:1:2) in 28 by 53 cm plastic containers. Twenty-five corm units with equal numbers of superimposed corms were used to make up each replicate. The pans were placed in the greenhouse with an ambient temperature of 18/15C day/night. The pans were surfaced-watered daily and emerging shoots were counted at 2-week intervals. The experiment was terminated after 24 weeks. The percentage of corms that had sprouted after 24 weeks was subjected to analysis of variance.

RESULTS

Effect of photoperiod and temperature on tuber oatgrass development. Long days and cool temperature (16/8h, 20/10C day/night) were favorable conditions for tuber oatgrass growth as indicated by the higher shoot dry weight, shoot height, and number of tillers (Figure 1.1). Under short days and cool temperature (8/16h, 20/10C day/night), growth was slow. Plants started from corms grew faster than those started from seeds.

Corm formation was influenced by both photoperiod and temperature (Figure 1.2). Corm formation was most rapid in plants growing under long days and low temperature as indicated by the T_{50} values (Table 1.1). Increasing temperature hastened corm formation in plants growing under short days but not in plants growing under long days. The time required to obtain 100% corm formation was longest for plants growing under short days and low temperature, and shortest for plants growing under long days and low temperature. The delay in corm formation on plants growing under 30/20C at 16/8h was partly due to the delay in seed germination from this treatment. It was also observed that corms stored in total darkness formed new corms before new leaves were produced.

Vernalization study. Vernalization was not required for plants started from seeds or corms (Table 1.2). Both



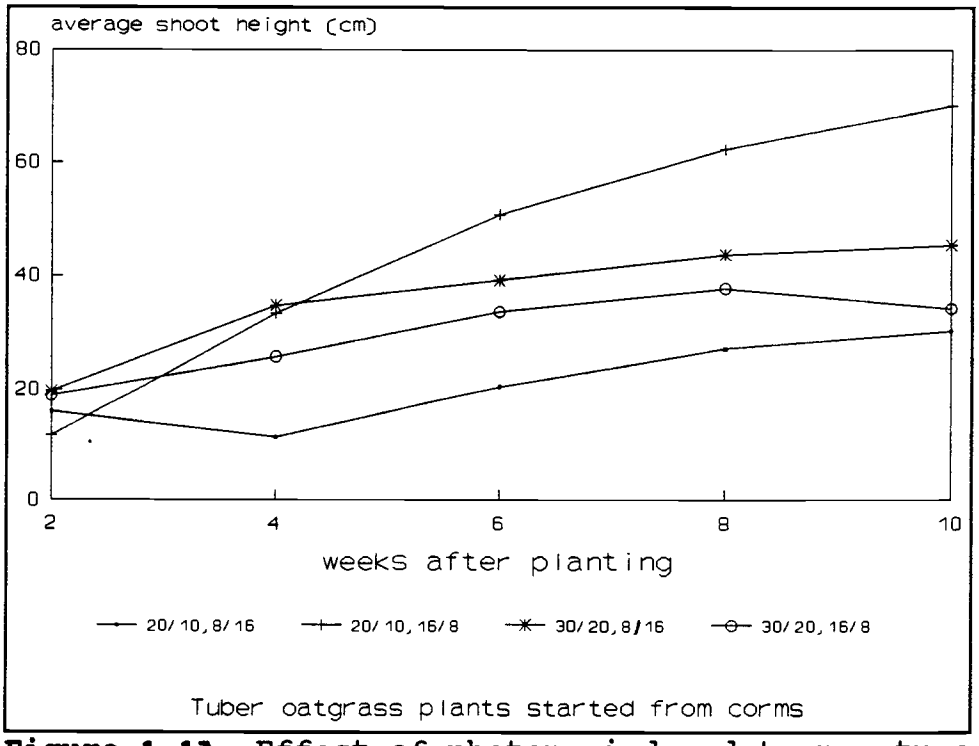


Figure 1.1A Effect of photoperiod and temperature on development of tuber oatgrass plants started from seeds (top) and corms (bottom).

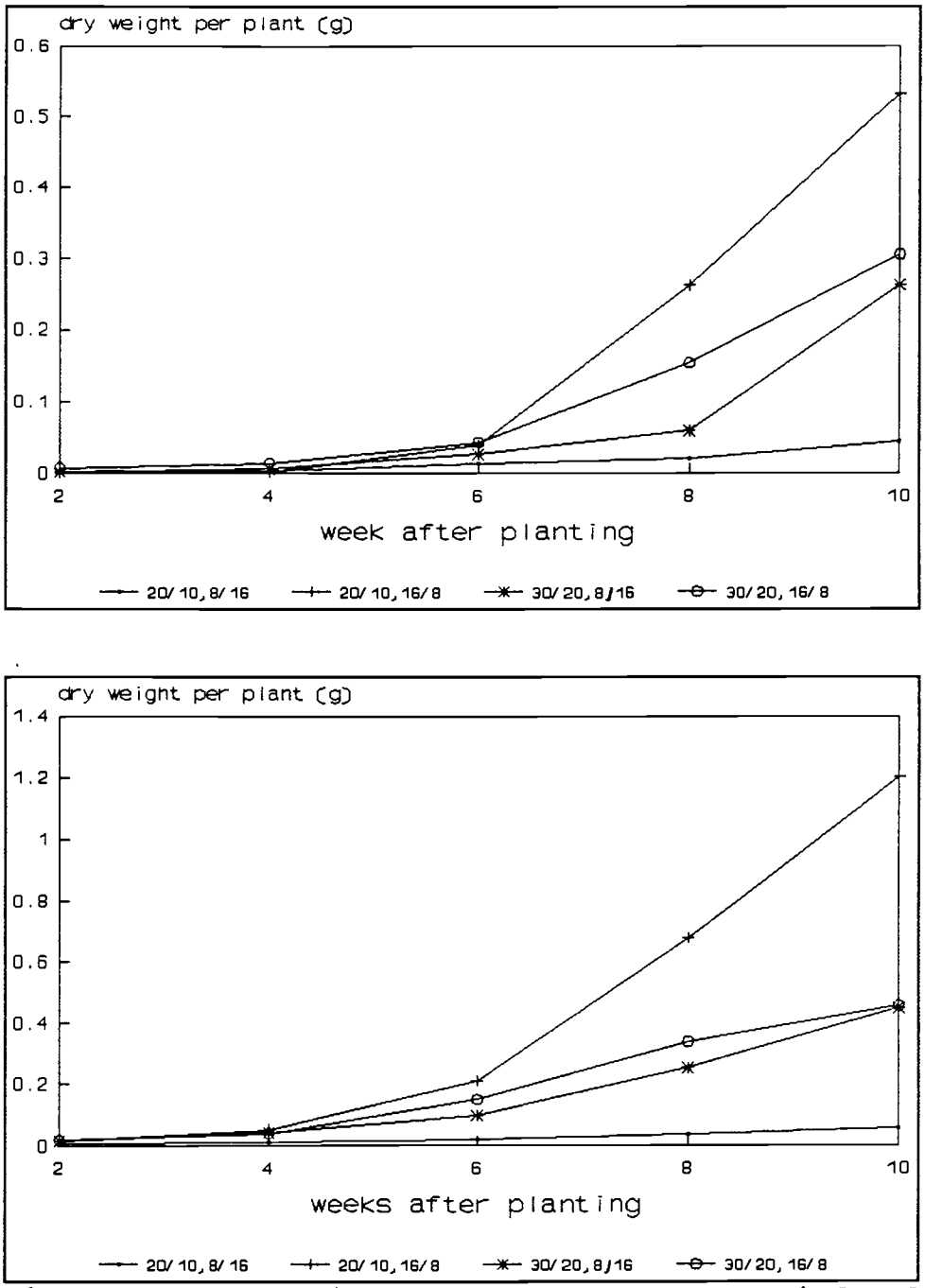


Figure 1.1B. (continued) Effect of photoperiod and temperature on the development of tuber oatgrass plants started from seeds (top) and corms (bottom).

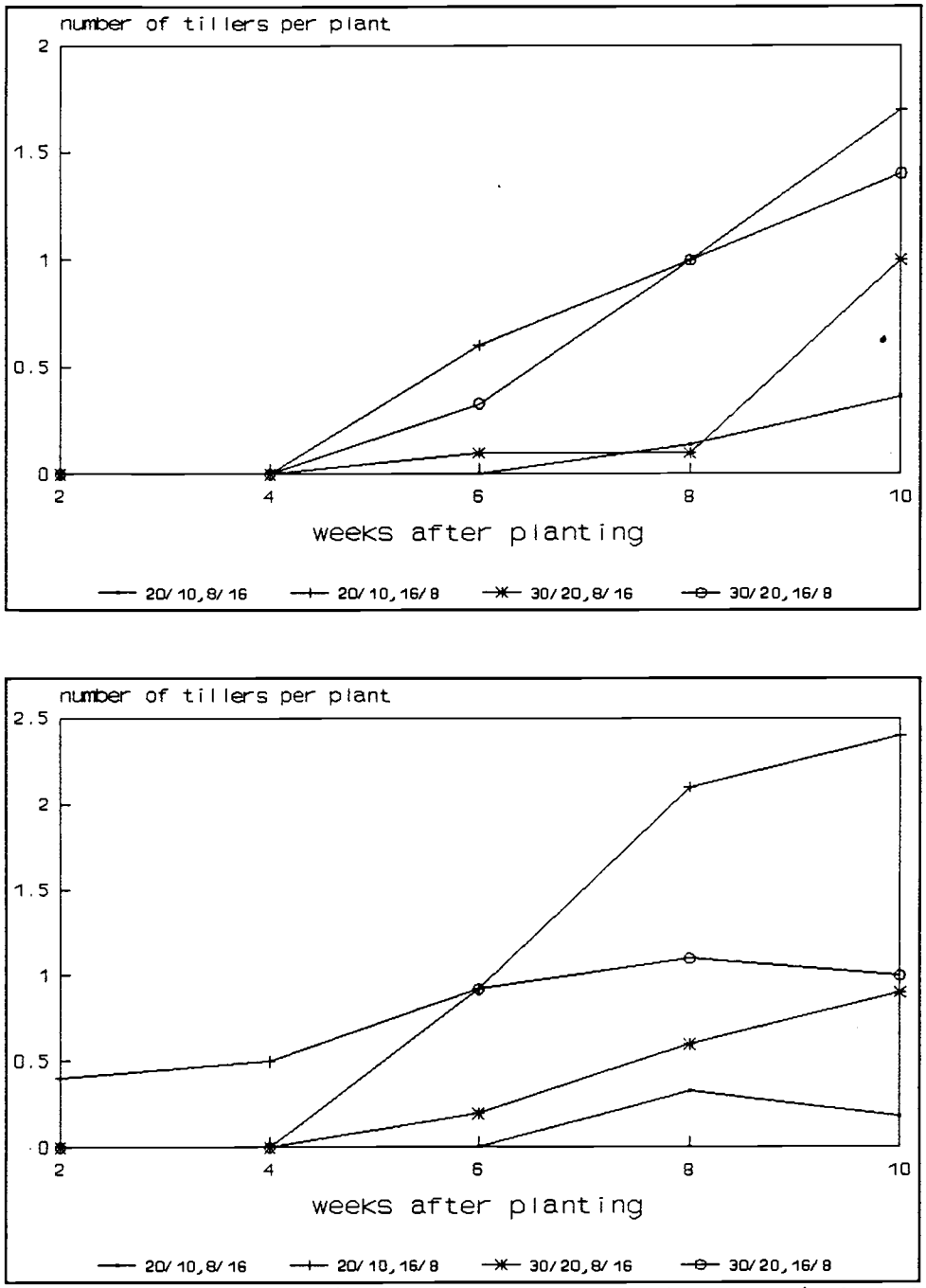


Figure 1.1C. (continued) Effect of photoperiod and temperature on the development of tuber oatgrass plants started from seeds (top) and corms (bottom).

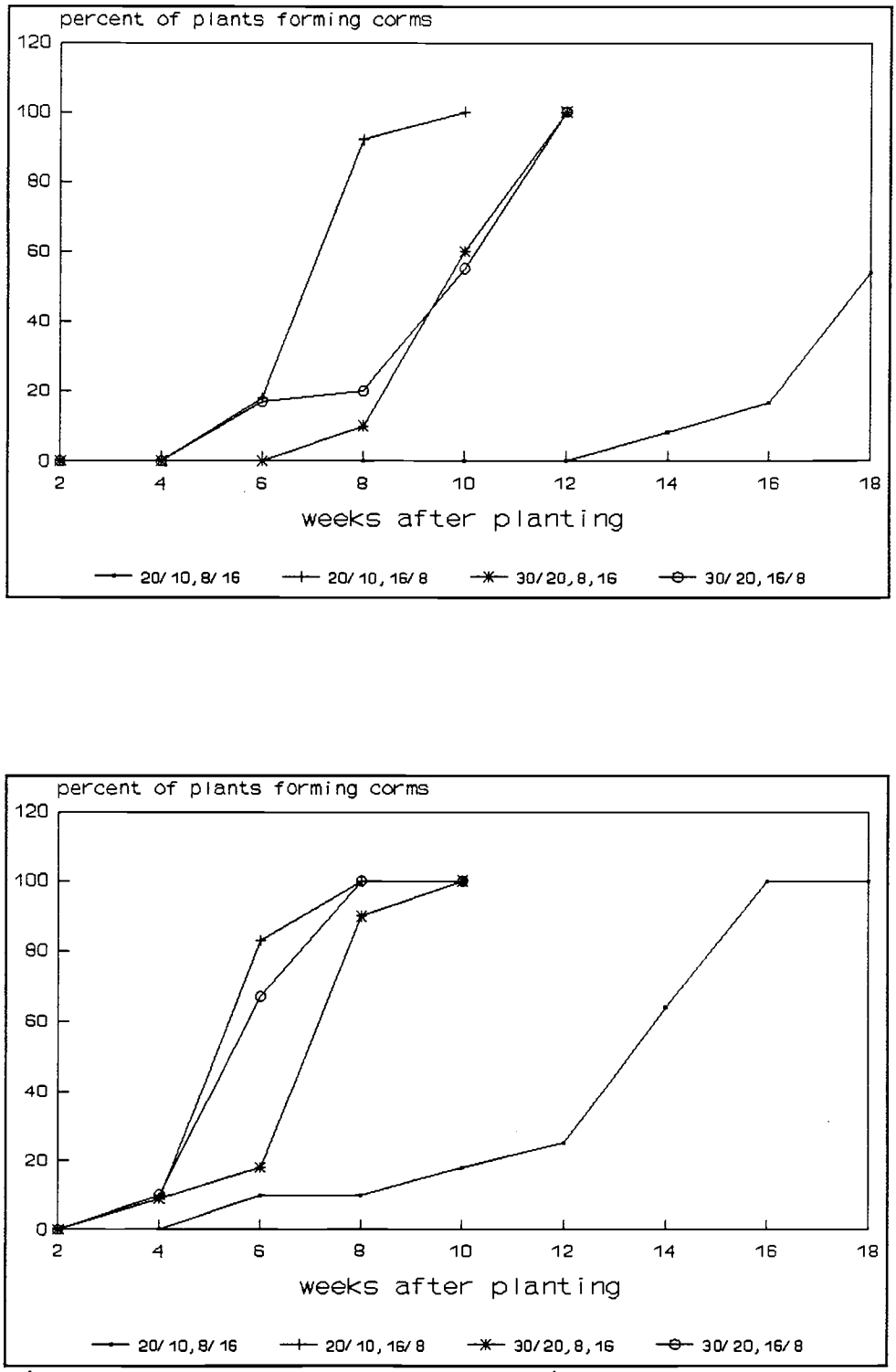


Figure 1.2 Effect of photoperiod and temperature on corm formation in tuber oatgrass plants started from seeds (top) and corms (bottom).

Table 1.1. Effects of photoperiod and temperature on corm formation in tuber oatgrass plants started from corms and seeds.

Treatments	T_{50}[a] (weeks)	
	corm	seed
high temperature, long day	5.4	9.7
high temperature, short day	6.8	9.5
low temperature, long day	5.2	7.0
low temperature, short day	13.3	17.7

[a] T_{50} = time required for 50% of plants to form corms.

high temperature, long day = 30/20C day/night at 16/8h light
high temperature, short day= 30/20C day/night at 8/16h light
low temperature, long day = 20/10C day/night at 16/8h light
low temperature, short day = 20/10C day/night at 8/16h light

Table 1.2. Vernalization of tuber oatgrass plants started from seeds and corms[a].

	Period of vernalization (weeks)				
	0	1	2	3	4
seeds					
Days to flower	58±10	35±10	48±2	57±4	53±8
Panicle numbers	30±20	39±10	38±21	36±10	51±16
corms					
Days to flower	52±6	50±2	46±6	53±6	48±5
Panicle numbers	28±6	38±5	30±13	26±6	24±6

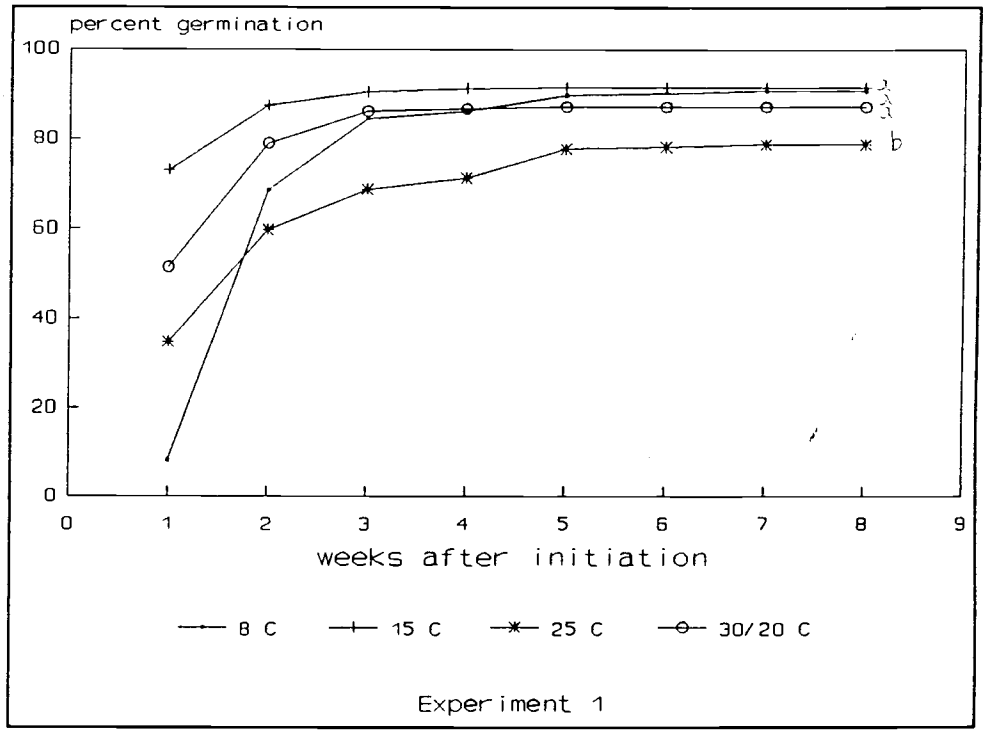
[a] Values following plus and minus signs are standard error.

vernalized and nonvernalized plants produced flowers. Vernalization neither hastened the flowering process nor did it significantly increase panicle formation.

Seed germination study. Light and KNO_3 did not significantly affect tuber oatgrass seed germination. Germination was most rapid at 15C (Figure 1.3). At this temperature, maximum germination was achieved after 4 weeks. Germination was delayed at 25C and total germination after 8 weeks was significantly reduced; the seeds were attacked by fungus. Initial germination delay also was observed at 8C. However, the total germination at this temperature was higher than that at 25C.

Corm sprouting study. Light and temperature did not significantly affect the total number of corm sprouted in one test, however; the total number of corm sprouted was slightly reduced at 25C in the other test (Table 1.3). Most corms sprouted after 3 weeks. The initial sprouting during the first week was delayed at 8C. Most corms that remained unsprouted after 3 weeks were dead. Corms were less sensitive to higher temperature than seeds.

Sprouting of tuber oatgrass corms with different stages of maturity. Corms collected on April 1 were white and had smaller diameters (0.5 to 0.7 cm) than those collected in August (1.0 to 1.2 cm diameters). Corms collected in August were brown. Most corms started sprouting 2 weeks after planting (Figure 1.4). Corms collected on August 1 sprouted



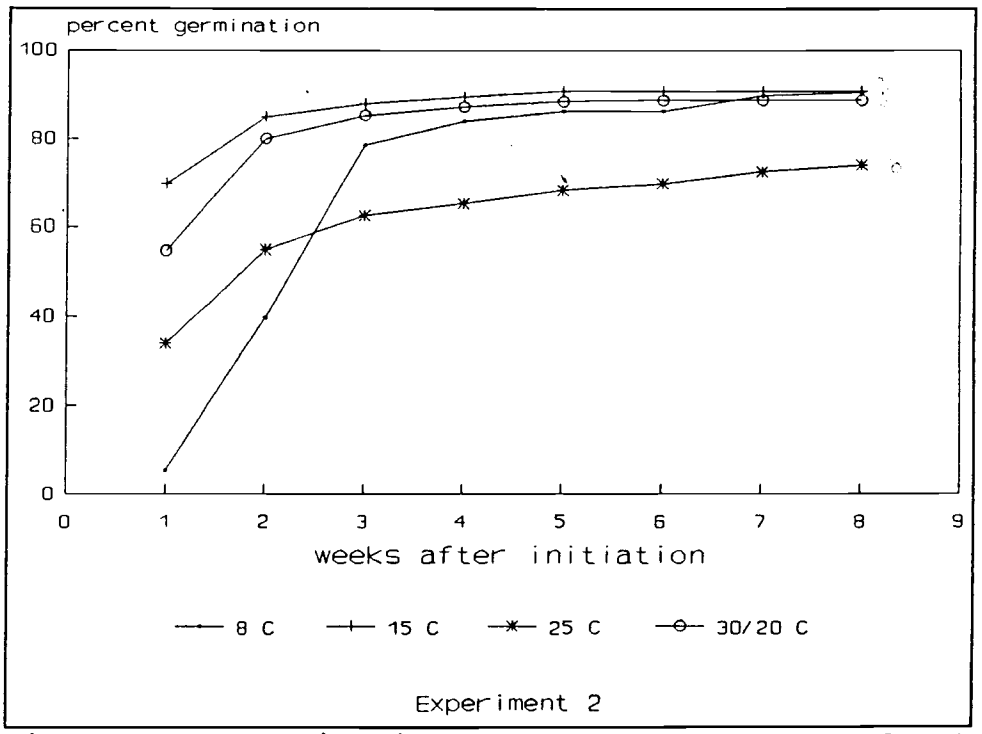


Figure 1.3 Germination of tuber oatgrass seeds at different temperatures, Experiment 1 and 2.

Table 1.3. Percent sprouting of tuber oatgrass corms at different temperatures[a].

Temperature (C)	days after initiation 7	14	21
Experiment 1			
8	41 a	97 a	99 ab
15	98 c	99 a	100 b
25	82 b	93 a	93 a
30/20	97 c	98 a	100 b
Experiment 2			
8	60 a	100 a	100 a
15	97 b	99 a	99 a
25	98 b	98 a	98 a
30/20	94 b	96 a	96 a

[a] Means within a column and within an experiment followed by the same letter are not different (P = 0.05) according to Fisher's Protected LSD Test.

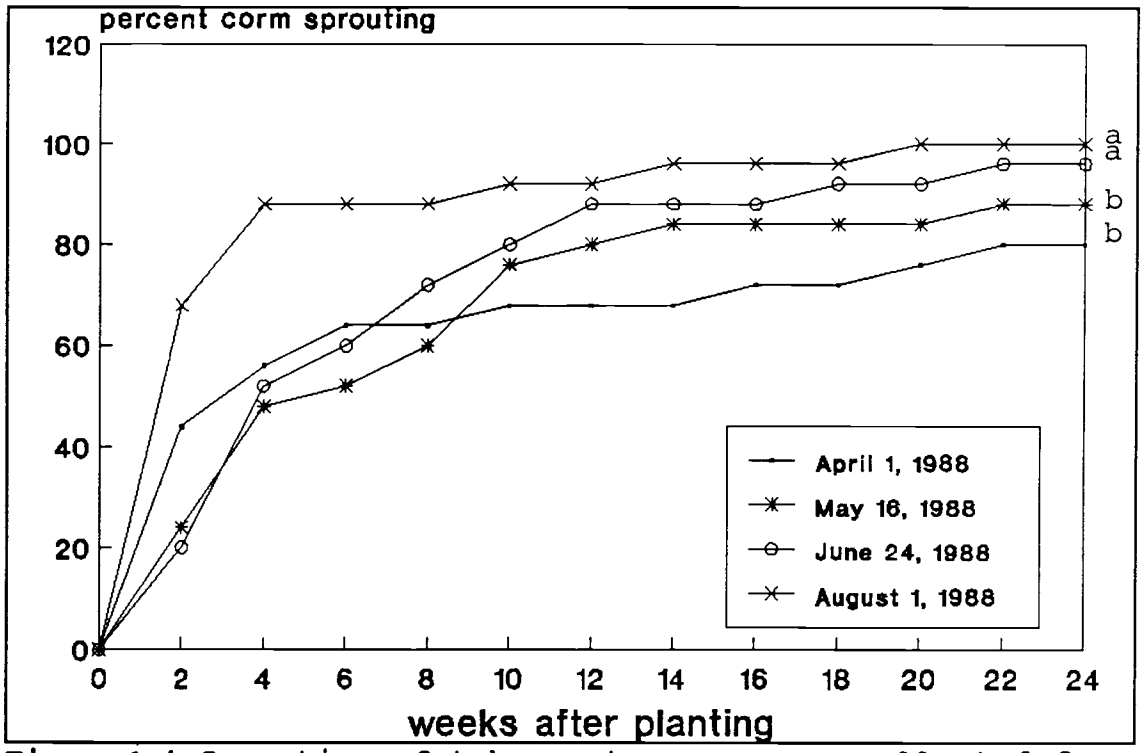


Figure 1.4. Sprouting of tuber oatgrass corms collected from the field at different dates.

more rapidly than those collected earlier; 88% of the corms sprouted after 4 weeks. The number of sprouted corms at 24 weeks was significantly less in the April 1 collection than in the August 1 collection. Corms collected on May 16 and June 24 sprouted less than those collected on August 1, but the differences were not significant. In corms collected on August 1, most of the buds in the superimposed corms sprouted at the same time, while in others, the buds that sprouted first were mostly from those located on the lowest corms. Buds on the upper corms usually did not sprout.

DISCUSSION

Although tuber oatgrass propagates readily by sexual and asexual means, its geographic range is limited. Distribution of this weed could be limited by environmental factors. Our results showed that the plant did not grow well under low temperature and short days or high temperature and long days. Being a C_3-plant, a long period of high temperature (16/8h 30/20C, day/night) would be unfavorable for growth. In Oregon, tuber oatgrass occurs west of the Cascade Mountains where it is sometimes locally abundant (L. JOHNSTON, personal communication). The mild climate of the Willamette Valley could be suitable for tuber oatgrass development. In other areas, the cold winters and hot summers could limit the proliferation of this plant.

Tuber oatgrass seeds were not dormant and had a high germination percentage. High temperature delayed germination and reduced the number of seeds germinated. High temperature may have an indirect effect through the promotion of fungal growth. Corms are less sensitive to high temperature than seeds. Moreover, plants started from corms grow faster than those started from seeds. Since these factors could provide a competitive edge, it is not surprising that propagation by corms is the common reproductive method.

The presence of tuber oatgrass corms with different

stages of maturity in the field could complicate the control of this weed by herbicides. These corms would sprout at different times and escape control from a single herbicide application. Most of the poor control in the field probably is due to dormant corms in the soil that are not connected with an emerged shoot at the time the herbicides are sprayed. Immature corms also produce low shoot per corm ratio, which results in reduced interception of herbicides. The concentration of herbicide reaching the underground system thus would be reduced.

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Chapter 2. Growth and Development of Tuber Oatgrass (*Arrhenatherum elatius* (L.) Presl. var. *bulbosum* (Willd.) Spenn.)

ABSTRACT

Growth and development of tuber oatgrass (*Arrhenatherum elatius* (L.) Presl. var. *bulbosum* (Willd.) Spenn.) was investigated in plants growing in the field and in outdoor pots. Under the mild climate of the Willamette Valley, Oregon, shoot emergence occurred in early fall, followed by vegetative growth during the winter and spring. In the summer, above-ground portions of the plant stopped growing and senesced. The highest absolute growth rate of the plants occurred in early May, shortly before the onset of the reproductive stage. In early May, the growth rate of corms was higher than that of the shoot.

INTRODUCTION

Tall oatgrass (Arrhenatherum elatius (L.) Presl.) is a perennial grass native to Europe. This plant has been introduced into North America as a meadow grass. It can be found from Southwest British Columbia to California as well as in many other locations in the United States (HITCHCOCK and CRONQUIST 1969). Two types exist: non-bulbous and bulbous types (tuber oatgrass, A. elatius var. bulbosum (Willd.) Spenn.). In the bulbous type, the lowest stem internodes swell and form corms which contain regenerative buds. Swelling is due to hypertrophy of both pith and ground tissue in which the vascular bundles lie (ARBER 1925). JENKIN (1931) and PFITZENMEYER (1962) have recommended that these two types not be classified as two separate species.

Several aspects of this plant have been studied by researchers. These include seed/corm biology (LE CLERCH 1977; TANPHIPHAT and APPLEBY 1989), corm anatomy/chemistry (ALFONSINO 1919), and genetics (JENKIN 1931). Corm formation is hereditary and independent of habitat (UNDERWOOD 1911). Soil conditions have no fundamental effect but merely modify the degree of corm development (JENKIN 1931). Inter-crosses between the bulbous and the non-bulbous types result in F1 plants that are definitely bulbous (JENKIN 1931). However, corm development in the hybrids is less

extreme than in the parent bulbous type. The effect of photoperiod on corm formation was studied by LE CLERCH (1971). Plants growing under long-day condition produced corms faster than those growing under short days. TANPHIPHAT and APPLEBY (1989) found that corm formation was influenced by both photoperiod and temperature. Increasing temperature from 20/10C to 30/20C (day/night) hastened corm formation in plants growing under short days (8/16h, day/night) but not in plants growing under long days (16/8h, day/night). The time required for corm formation was longest for plants growing under short days and low temperature, and shortest for plants growing under long days.

In Oregon, tuber oatgrass occurs sporadically west of the Cascade Mountains where it is sometimes locally abundant (L. JOHNSTON, personal communication). It has been reported in six counties, including Benton, Clatsop, Coos, Lane, Multnomah, and Washington Counties.

Information on morphological and phenological development of the plant is limited. The objective of this study was to (a) develop a morphological description of growth and developmental phenomena in Arrhenatherum elatius var. bulbosum (Willd.) Spenn., (b) investigate the quantitative development of plants in normal field conditions, and (c) investigate seasonal changes in biomass accumulation and distribution in potted plants.

MATERIALS AND METHODS

Visual observations of plant development. Morphological characteristics were observed using plants grown naturally in a field west of Monmouth, Oregon. Plant samples were collected from the field at 2-week intervals from October 1986 to April 1987 and at 4-week intervals thereafter to June. Plant samples were excavated from a particular site in the field using a hand shovel. Excavated samples were 30 cm in diameter and 25 cm deep. Three samples were excavated on each sampling date. Plants were washed free of soil, visually observed, and diagrams were drawn.

From the early stage of development until the first corm was formed, supplementary samples of plants were observed using plants grown in 10 by 10-cm plastic pots in the greenhouse. The underground system was evaluated every 3 to 4 days. Plants started from corms placed at different depths, 2.5, 5, 15, and 20 cm from the soil surface, were used to examine crown location and rhizome length. To investigate the order of new corm formation, corms were imbedded in sponge and placed into 100-ml beakers filled with half-strength Hoagland solution. The sponge was placed in contact with the nutrient solution such that the corms were located above the level of the nutrient solution in the beakers. The beakers were wrapped in aluminum foil to exclude light and placed in a growth chamber.

Quantitative description of plant development. Plant samples were collected from the field by using the methods described in the above study. Plants were washed free of soil and the number of new shoots per plant, average shoot height, number of new corms per shoot, percentage of shoots forming new corms, and number of unsprouted corms were recorded. During the final sampling dates when the plants were large, some shoots were broken during washing; thus, the number of new shoots per corm and unsprouted corms could not be obtained. Mean monthly temperatures and precipitation were recorded during the sampling period (Figure 2.1).

Biomass accumulation and distribution in potted plants. Single corms were planted in October 1986 in 3.7-L plastic pots filled with greenhouse soil mix (soil:peat:sand:pumice-1:1:1:2). Pots were buried to the soil line outdoors in a wood frame and fertilized with a slow-release fertilizer, (N:P:K - 18-6-12). Supplementary water was added during the dry period from June to August. Random samples of five plants were taken at 2-week intervals and the soil was removed by washing. Dry weights of shoots, roots, and corms were recorded. The absolute growth rates of shoot and corm were calculated as the change in dry weight per plant per day (REDFORD 1967). Sample collection was terminated in August 1987 when the topgrowth senesced. The experiment was repeated during the same period in 1987-1988.

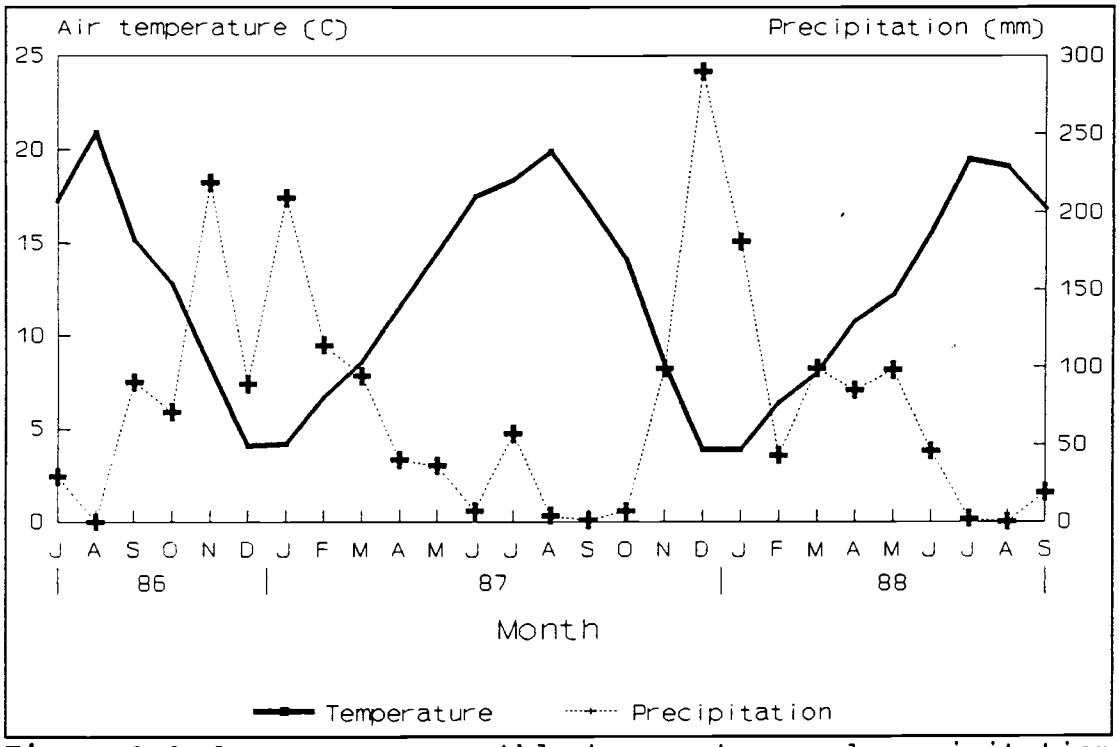

Figure 2.1 Average mean monthly temperature and precipitation recorded at Hyslop Field Laboratory, Oregon, during July 1986 to September 1988.

RESULTS

Visual observations of plant development. Corms normally are the source of the first shoot of the following season. When a bud on a corm sprouts, it produces adventitious roots and a short rhizome, which upon reaching the soil level, becomes an aerial shoot (Figure 2.2A). The crown, which is the region where an underground rhizome and an aerial shoot merge, is formed after the shoot emerges (Figure 2.2B). Adventitious roots also are initiated from the crown. Crowns generally are developed within 15 cm from the soil surface, regardless of the depth of the corms.

Tuber oatgrass rhizomes consist of nodes and internodes. The length of the rhizome depends on where the corm is located in the soil. If the corm is located close to the soil surface, the rhizome will be short and the crown will develop near the corm. If the corm is located deeper, the rhizome internodes will be elongated so that the crown is formed close to the soil surface. A scale leaf is present at each node on the rhizome (Figure 2.2C). Scale leaves vary in length. The longer ones can enclose the internode and the next adjacent node. Secondary shoots are developed from the buds in the axils of the scale leaf. They also can be formed from the buds at the base of the crown.

New corms are formed above the crown. Corms are formed in order, one on the top of another. Newly formed corms are

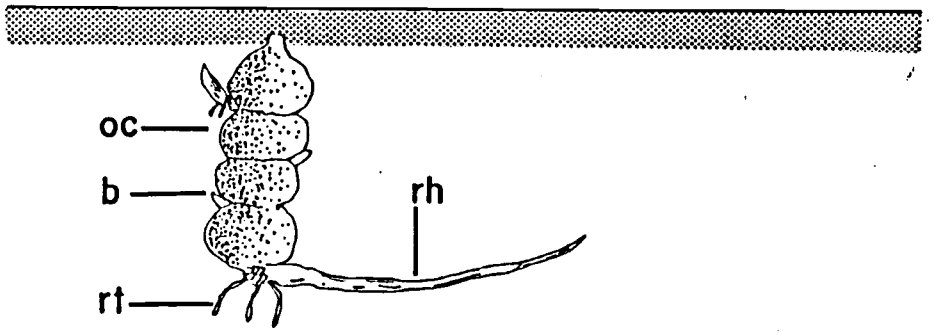

Figure 2.2A. Tuber oatgrass shoots sprouting from corms. Rhizomes (rh) are produced from the buds (b) at the nodes of the original corms (oc). Adventitious roots (rt) are formed at the base of the rhizomes.

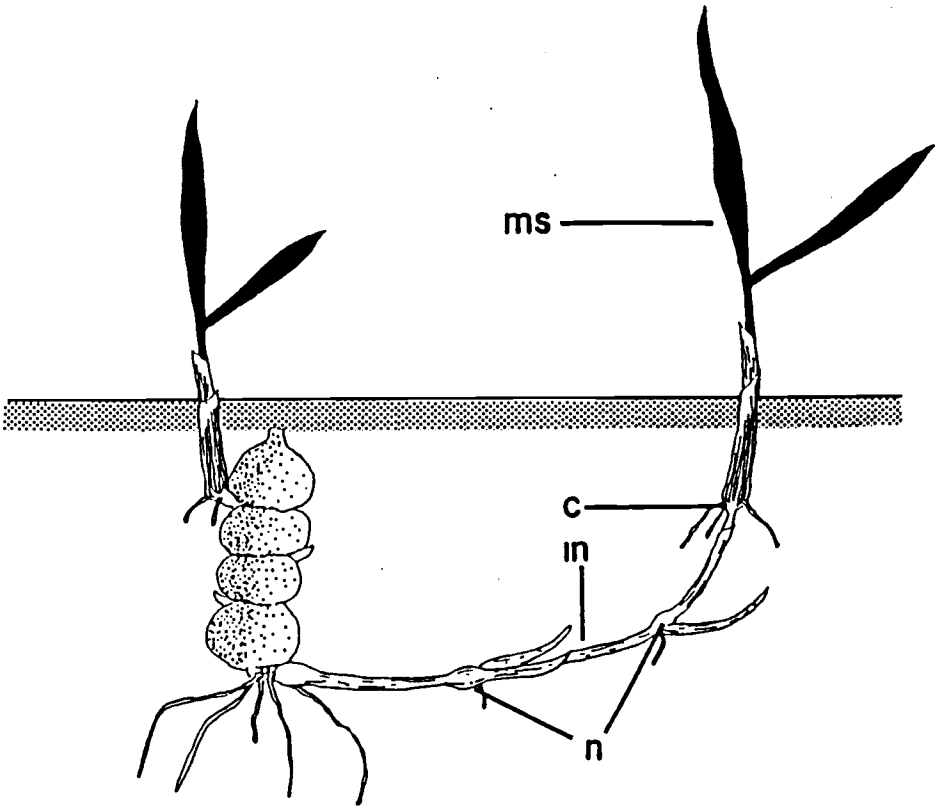

Figure 2.2B. The rhizomes eventually develop into aerial shoots. After a shoot emerges, it forms a crown (c), where an aerial shoot and a rhizome merge. Rhizomes consist of nodes (n) and internodes (in). Main shoots (ms) are the shoots that develop directly from the original corms and their primary rhizomes. Secondary shoots form later from rhizome nodes.

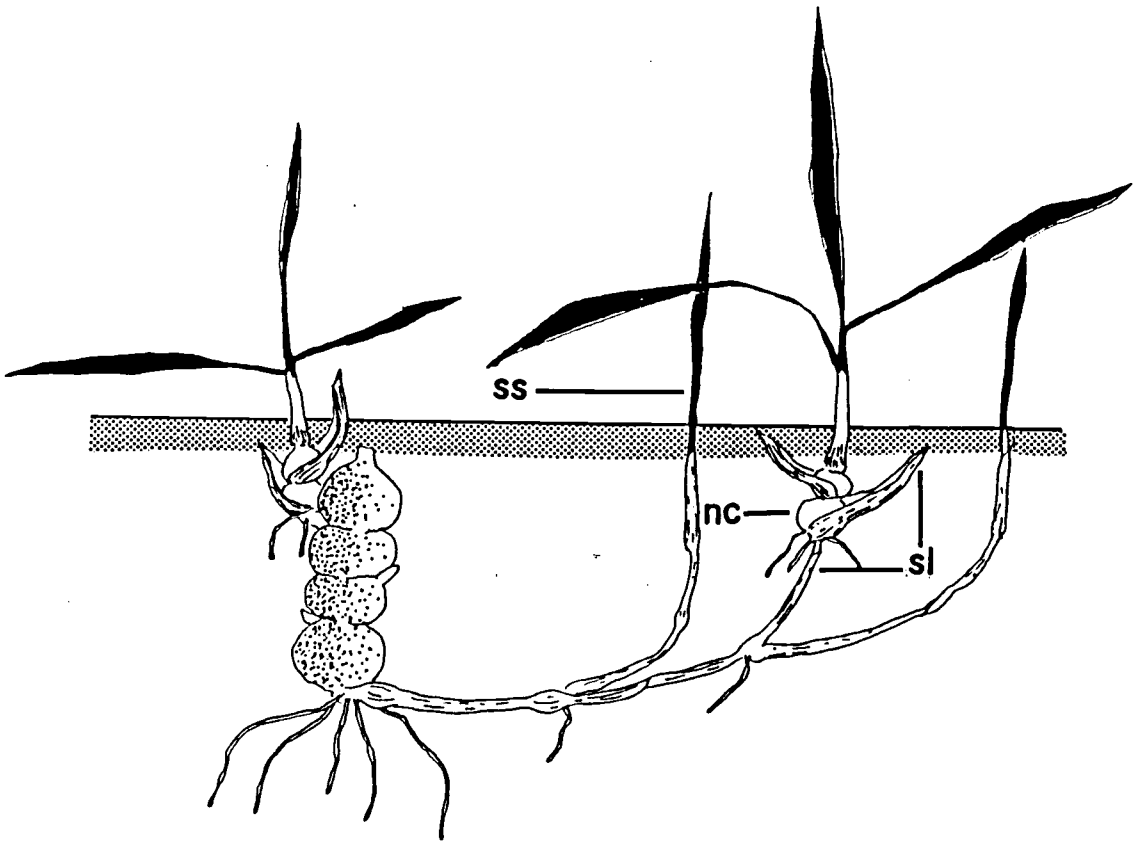

Figure 2.2C. At each node on the rhizome, there is a scale leaf (sl). Secondary shoots (ss) are developed from the buds at the nodes of the rhizomes. New corms (nc) are formed above the crown and are formed in order, one above the other.

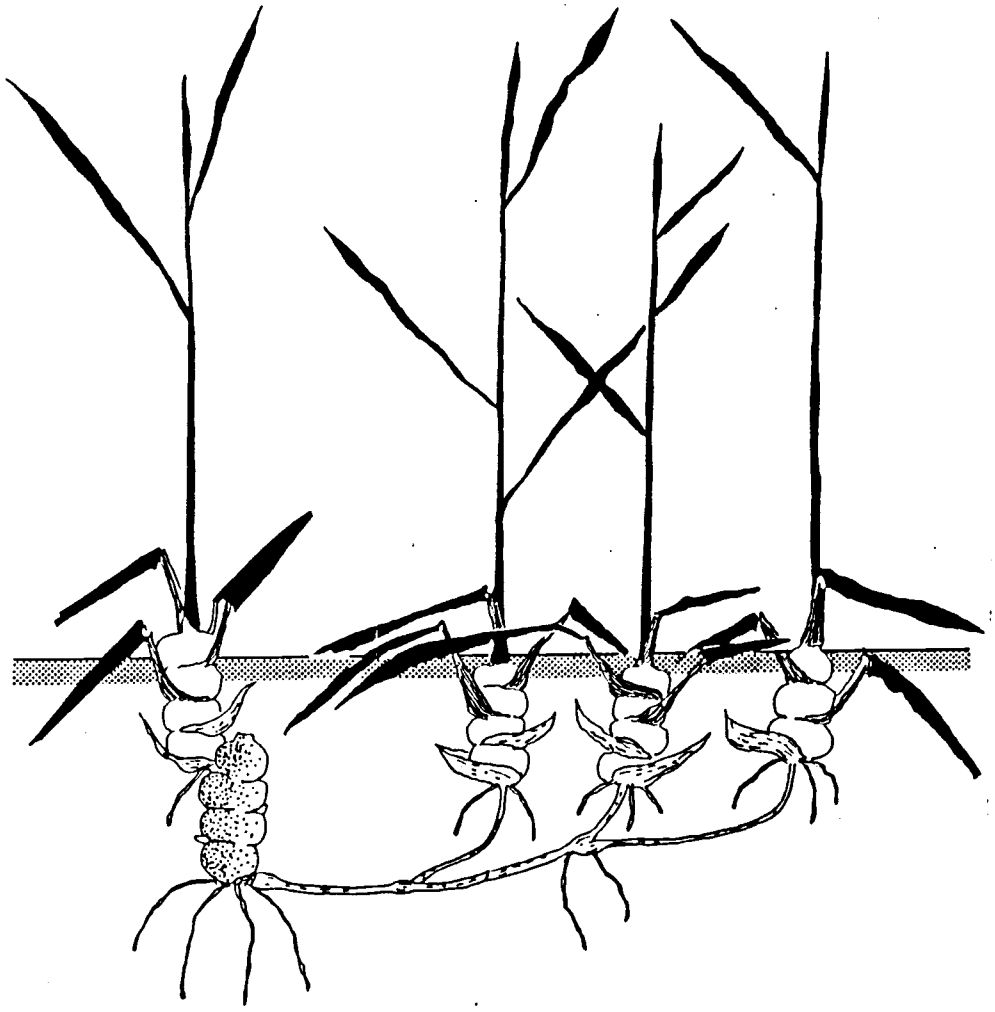

Figure 2.2D. As corm size increases, the leaf-sheaths are split. The top corms can be formed above the soil if the original corms are located close to the soil surface.

small and white. As the season progresses, corms become larger and turn brown when mature. Corms are generally formed first on the main shoot. As corms become bigger, the leaf sheaths enclosing the internodes are split (Figure 2.2D). There are generally three to five superimposed corms per shoot.

The first new corm occasionally can be formed even before its shoot is produced. This was observed on shoots produced from corms grown in a beaker. However, this was observed only once. This finding indicates that photosynthate used to produce new corms does not necessarily come from its own shoot.

Corms are usually formed under the soil surface. However, if the crown is located close to the soil surface, the top corms are formed above the soil. Corms that are formed above ground are green. Buds on new corms usually remain dormant as long as the shoots are alive. Leaves are differentiated from the apical meristem above the crown in the same manner as a typical scale leaf.

Quantitative description of plant development. The aerial shoots of tuber oatgrass emerged in early fall. The first samples in October 1986 were collected shortly after the shoots had emerged. During the fall and winter months (October to February), shoot height increased slowly. The shoots had three to four leaves with an average height of 15 to 20 cm (data not shown). Although there was little

increase in plant height early in the season, the plants were actively growing in the winter, as can be seen from the increase in the number of total shoots per plant (Figure 2.3). The increase in total shoot number was caused by the increase in secondary shoots, which were produced from October to February. After February, new shoot production ceased. The plants apparently were not harmed by exposure to winter frost. Stem elongation began in late March, progressively increased, and peaked in July when the average height reached 109 cm.

Corm formation began in November; by April, each new shoot had produced one or more corms (Figure 2.4). A high rate of corm formation was observed between mid February and early June. After this time, the total number of corms per shoot leveled off at an average of 4 to 5 corms. The plant units, arising from three to four original corms, produced 14 to 18 new corms per plant in one growing season.

By early June, 15% of the shoots had formed panicles. By the end of June, 77% of the shoots had produced flowers. Senescence began in early July; leaves and culms dried and turned brown.

After new corms became mature in late June, they were able to sprout after a short period in the soil. Some new shoots emerged in August after a rainfall. The majority of shoots emerged again in early fall, when soil moisture became abundant. In August 1988, some new shoots had

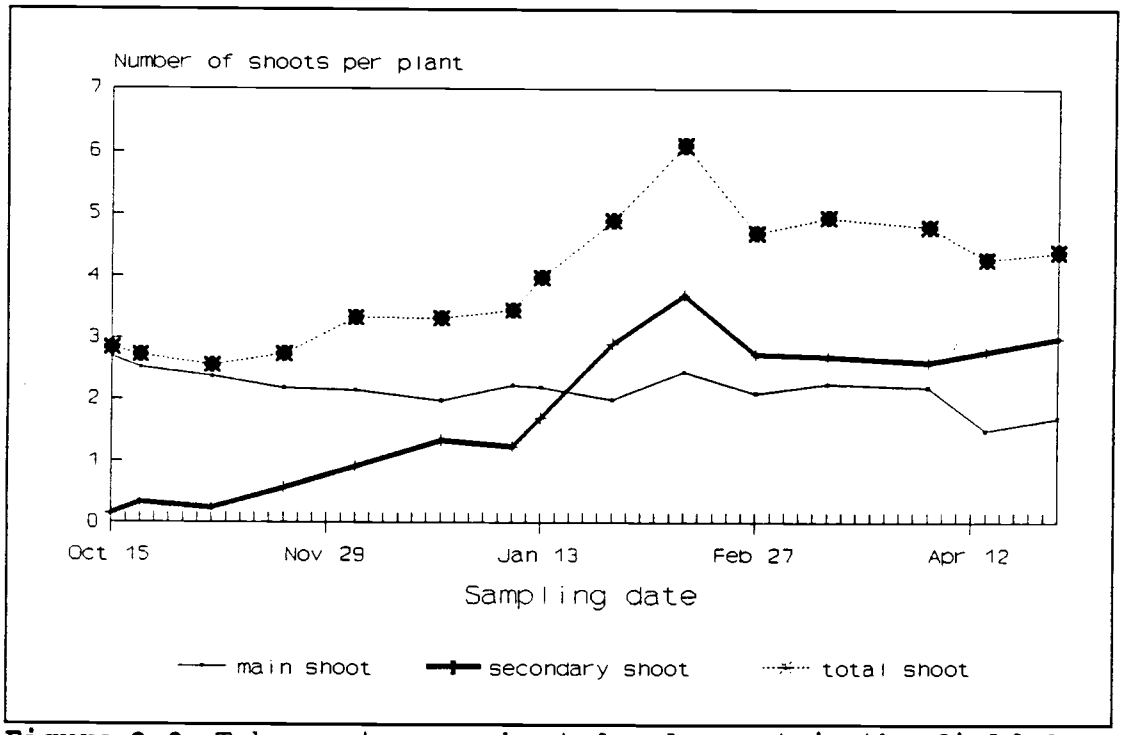

Figure 2.3 Tuber oatgrass shoot development in the field from October 1986 to April 1987. The secondary shoot production was observed from early fall until mid winter. After this point, new shoot production stopped.

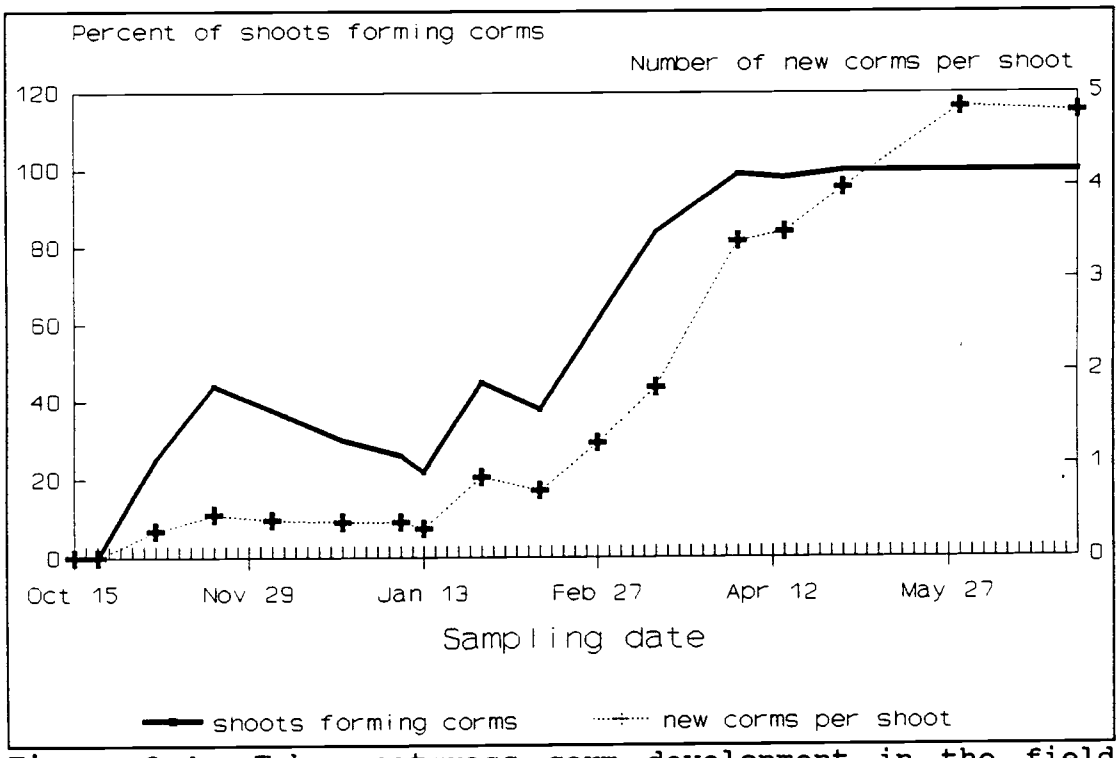

Figure 2.4 Tuber oatgrass corm development in the field during October 1986 to June 1987. Corm formation started in November and continued until April when all the shoots produced corms. A high rate of corm formation was observed in spring.

emerged even though total rainfall since June 1 was less than 5 cm.

Biomass accumulation and distribution in potted plants. Investigation of biomass accumulation and distribution in potted plants provides a simple but meaningful method of characterizing growth and development of plants over time. Only the data from 1987-1988 are presented; data from 1986-1987 were similar. Plants accumulated dry matter slowly during the initial growth phase (October to March) (Figure 2.5). Corm dry weight increased rapidly during late March to May. The trend thereafter was toward dry matter accumulation in shoots. The onset of senescence occurred in late July even though plants were irrigated.

The absolute growth rate of shoots and corms increased rapidly in April and peaked in early May (Figure 2.6). At this point, the growth rate of corms was higher than that of shoots. Thereafter, growth decreased gradually, with shoot growth rate decreasing at a slower rate.

Plants grown in pots formed corms more slowly but had a higher number of corms per plant than those grown in the field. A plant started from a single corm could produce up to 312 new corms in one growing season. Each of these corms is able to regenerate a new plant.

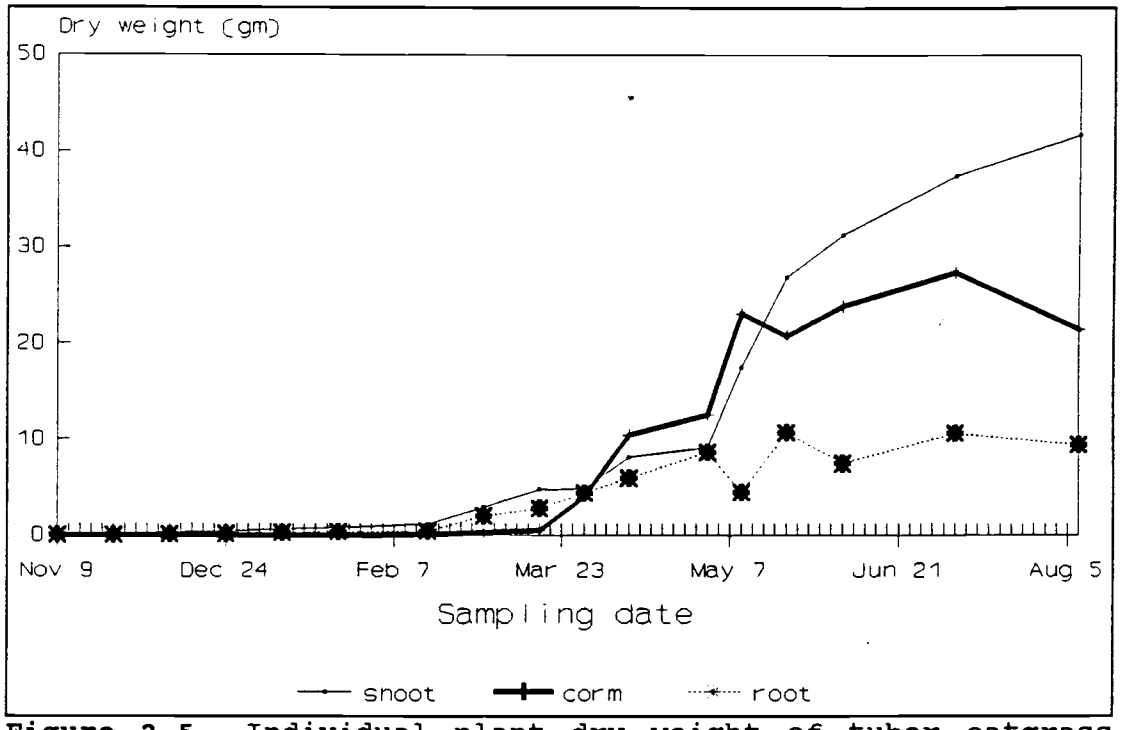

Figure 2.5 Individual plant dry weight of tuber oatgrass grown outdoors from November 1987 to August 1988.

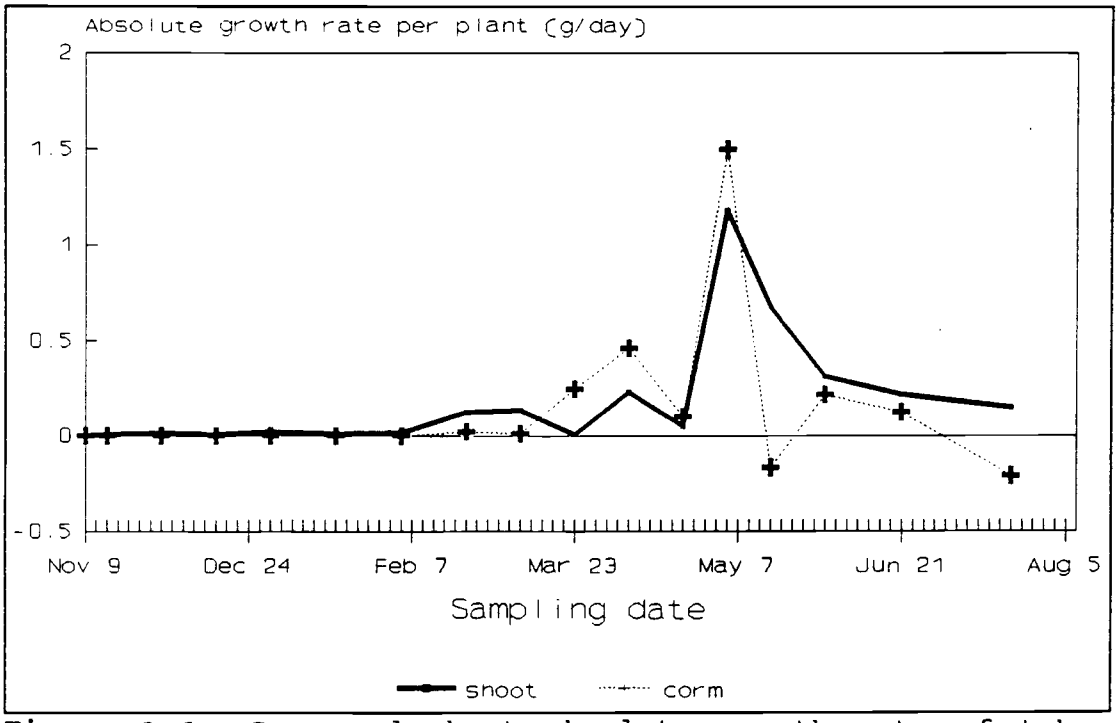

Figure 2.6 Corm and shoot absolute growth rate of tuber oatgrass plants grown outdoors from November 1987 to August 1988.

DISCUSSION

Development of tuber oatgrass in the field and in pots were similar. Under the mild climate of the Willamette Valley, Oregon, oatgrass sprouts in the fall, produces little growth in the winter, grows rapidly in the spring, and senesces in the summer. The seed production of tuber oatgrass could not be estimated because the seeds shattered as soon as they matured. LE CLERCH (1976) found that the seeds were produced in sufficient abundance to ensure reproduction by that means alone. In a separate study, TANPHIPHAT and APPLEBY (1989) found that tuber oatgrass seeds were non-dormant and had a high percentage of germination. They germinated better at 8 and 15 C than at 25 C. At higher temperature (25C), germination was delayed and total germination was significantly reduced, perhaps because seeds were attacked by fungus. LE CLERCH (1976) found that seed longevity varied from year to year but was very short in soil; it may be 2 years when stored in laboratory conditions. In the field where this study was conducted, tuber oatgrass seedlings were not found. All the plants were established from corms. The absence of plants established from seeds might be explained because seeds are more sensitive to higher temperature than corms (TANPHIPHAT and APPLEBY 1989). As seeds were being dropped, senesced leaves were infected with a fungus. We hypothesize that the

seeds could be infected by the same fungus. The surviving seeds may have failed to produce plants because tuber oatgrass plants do not compete well (PFITZENMEYER 1962) under low light intensity common in the Willamette Valley in the fall.

The number of dormant corms in the field ranged from 20% to 59% of the total original corms during the sampling period (data not shown). These corms could be the source of new shoots produced in the next season. Buried corms remain viable for about 2 years (LE CLERCH 1976). Corms that sprouted in a given growing season, however, were unable to function in the following season. In a separate study, we found that corms collected from the field during April to August showed that, under favorable environmental conditions, corm buds could sprout immediately after they matured. In mature corms, most of the buds in the superimposed corms sprouted at the same time, while in the immature corm chains, the buds that sprouted first were mostly from those located on the lowest corms. Buds on the upper corms usually did not sprout. Immature corms began sprouting more slowly and the time required for total sprouting was longer than that of mature corms.

In many perennial grasses, the maximum movement of dry matter to the underground storage organs occurs when plants approach the reproductive stage. A similar pattern of movement was observed in tuber oatgrass. Maximum movement

of photosynthate was observed in May, one month before flowering. During this period, a higher amount of dry matter partitioned to the corms than to the shoots. After this period, the absolute growth rate dropped rapidly and dry matter partitioning was more toward the shoot.

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Chapter 3. Efficacy and Translocation of Glyphosate in Tuber Oatgrass (Arrhenatherum elatius (L.) Presl. var. bulbosum (Willd.) Spenn.)

ABSTRACT

The efficacy of glyphosate on tuber oatgrass was investigated in greenhouse and growth chamber studies. Glyphosate at 1.2 and 2.5 kg ae/ha significantly reduced new corm formation and corm viability. Complete control of tuber oatgrass resulted when glyphosate was applied at the 6- to 7-leaf stage. A 24-h period between glyphosate application and removal of the shoots was sufficient to cause maximum reduction in regrowth. The total amount of ^{14}C translocated out of treated leaves did not differ among different growth stages, but more ^{14}C accumulated in the dormant corms when applied at the 2- to 3-leaf stage than at the 4- to 5- or 6- to 7-leaf stages. Most of the poor control in the field from glyphosate is probably due to dormant corms in the soil that are not connected with an emerged shoot.

INTRODUCTION

Tall oatgrass (Arrhenatherum elatius (L.) Presl.) is a perennial grass native to Europe. It was introduced into North America as a meadow grass. It can be found from Southwestern British Columbia to California, as well as in many other locations in the United States (HITCHCOCK and CRONQUIST 1969). Two types exist: non-bulbous and bulbous (tuber oatgrass, A. elatius var. bulbosum (Willd.) Spenn.). In the bulbous type, the lowest stem internodes swell and form corms which contain regenerative buds. TANPHIPHAT and APPLEBY (1989) found that a plant grown from a single corm could produce up to 312 new corms in one growing season. This variety has become a weed problem in certain areas of Western Oregon.

Glyphosate is a non-selective herbicide used to control perennial weeds because of its rapid translocation and high phytotoxicity. Translocation of glyphosate occurs in the phloem from source leaves to physiologically active sinks, and typically accumulates in shoot and root apices (CLAUS and BEHREN 1976; KELLS and RIECK 1979; SPRANKLE, MEGGITT, and PENNER 1975. Dormant buds, however, may not accumulate lethal dosages of glyphosate, thus allowing shoot regrowth to occur after herbicide is applied.

Although effective control of tuber oatgrass by glyphosate has been reported (AYRES 1981; AYRES 1985; BIRNIE

1983; O'KEEFFE 1981; SAMUEL 1985), researchers and growers in Western Oregon have observed that the weed usually regrows after glyphosate application. The objectives of this study were, therefore, to investigate the efficacy of glyphosate on tuber oatgrass and to determine the translocation of ^{14}C-glyphosate into dormant corms at different growth stages.

MATERIALS AND METHODS

General materials and methods. Tuber oatgrass corms were collected from a field west of Monmouth, Oregon. The plants used in the experiments were grown from single corms and strings of four, superimposed corms. Corms were planted 5 cm deep in 3.7-L plastic pots filled with greenhouse soil mix (soil:peat:sand:pumice-1:1:1:2) with the pH adjusted to 6.5. Tuber oatgrass plants were surface-watered daily and fertilized weekly with a water-soluble fertilizer (N:P:K-20:20:20). Natural light was supplemented with fluorescent lamps that produced 250 $uE.m^{-2}.s^{-1}$ of photosynthetically active radiation and provided a 16-h day. Greenhouse ambient air temperature was 18±3 C. Glyphosate was applied at 1.2 and 2.5 kg ae/ha as the isopropylamine salt plus 0.25% (v/v) a non-ionic surfactant[1] at a spray volume of 230 L/ha delivered by a greenhouse track-mounted sprayer. In most studies, tuber oatgrass plants were sprayed a) shortly after emergence (2- to 3-leaf stage), b) when new corms started forming (4- to 5-leaf stage), and, c) when the plants approached the flowering stage (6- to 7-leaf stage). Experimental design was a randomized complete block design. Means were separated at the 5% level of significance by Fisher's Protected LSD Test. All experiments were conducted

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[1] X-77, a mixture of alkylaryl polyoxyethylene glycols, free fatty acids, and isopropanol.

twice.

Effect of glyphosate on corm formation and corm viability. Tuber oatgrass plants were started from strings of four superimposed corms. Only plant units that contained all sprouted corms were selected and sprayed with glyphosate when the main shoots had two to three, four to five, and six to seven leaves. At each growth stage, plants grown in the same condition were excavated and the underground systems were evaluated; the number of new, forming corms was determined. Seven days after glyphosate application, the treated shoots were clipped at the soil surface and plants were allowed to produce shoot regrowth for 30 days. After 30 days, the fresh weights of regrowing shoots and the number of new, forming corms were recorded. Original corms and new corms were replanted in fresh soil and the percentage of corms sprouting was recorded after an additional 30 days.

Effect of glyphosate on dormant corms. Tuber oatgrass plants were started from strings of four superimposed corms. Only plant units composed of one sprouted bud were selected and sprayed with glyphosate after the main shoots had attained four to five leaves. Fourteen days after spraying, shoot dry weights were measured and the original superimposed corms were sectioned into single corms and replanted in fresh soil. Numbers of regrowing corms were recorded after 2 months.

Effect of glyphosate on well-established tuber oatgrass. Tuber oatgrass plants were started from strings of four superimposed corms. Plants were grown for 4 months to allow extensive development of the underground system. After 4 months, the top growth was clipped at the soil surface and glyphosate was applied to the regrowing shoots when they were at the 2- to 3-, 4- to 5-, and 6- to 7-leaf stages. Treated shoots were clipped off at the soil surface 14 days after treatment. Plants were allowed to regrow for 2 months, before shoot dry weights and dry weights of the underground systems were measured.

Time required for translocation. Tuber oatgrass plants were grown from single corms. Plants were grown for 4 months before the top growth was clipped at the soil surface. Glyphosate at 2.5 kg/ha was applied to the regrowing shoots when they were at the 4- to 5-leaf stage. Treated shoots were clipped at the soil surface 3, 6, 24, 48, 96, and 192 h after spraying. Dry weights of shoot regrowth were determined 1 month after clipping.

Translocation of ^{14}C-glyphosate. Plant units started from four superimposed corms that had only one bud sprouted were selected when they were at the 2- to 3-, 4- to 5-, and 6- to 7-leaf stages. Methyl-^{14}C-glyphosate (sp. act. 1.97 mCi/mM) was mixed with an equimolar amount of isopropylamine

and 0.25% (v/v) of the surfactant MON 0818[2]. A commercial formulation of glyphosate mixed for a field application rate of 230 L/ha at 1 kg ae/ha was added to the ^{14}C-glyphosate to obtain radioactivity of 0.02 uCi/ul. Before the radioactive glyphosate was applied, the plants were pretreated with 1.0 kg/ha of glyphosate. Immediately after spraying, 0.2 uCi of ^{14}C-glyphosate was applied to each plant in 1 ul-droplets using a 5-ul microsyringe. The ^{14}C-glyphosate solution was applied to the adaxial surface of the second or third leaves of each plant.

Treated plants were placed in a growth chamber set at 25/20 C day/night regimes with a 16-h day length at a light intensity of 250 $uE.m^{-2}.s^{-1}$. After 3 days, treated leaves were placed in 20-ml vials and washed twice in 10 ml of distilled water by gently shaking for 1 min to remove any unabsorbed ^{14}C-glyphosate. Leaf washings were combined and assayed for radioactivity by liquid scintillation spectrometry. Plants were removed from the pots, and the underground system was washed free of soil. Plants were divided into treated leaf, remainder of the treated shoot, roots, and corms with their associated buds. Harvested plant material was dried at 75C for 2 days and weighed. Plant material was oxidized in an automatic sample oxidizer and the $^{14}CO_2$ evolved was assayed by scintillation

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[2] A surfactant from Monsanto Co., St. Louis, MO.

spectrometry. Plant parts with large sample size were ground with a mortar and pestle, and subsamples of ground material were taken before oxidizing.

Absorption was determined by comparing the radioactivity recovered in the entire plant, including the treated leaf blade after being washed, to the total radioactivity applied. Translocation was determined by comparing the radioactivity recovered in the entire plant (except the treated leaf blade) to the total radioactivity absorbed. The ^{14}C recovery ranged from 80 to 100%.

Samples of plants used in this study were used to demonstrate the distribution of ^{14}C-glyphosate in the four superimposed corms. All the plants selected had one emerged shoot arising from the lowest corm, which was designated as corm A. The other three corms above corm A were designated as corms B, C, and D, respectively.

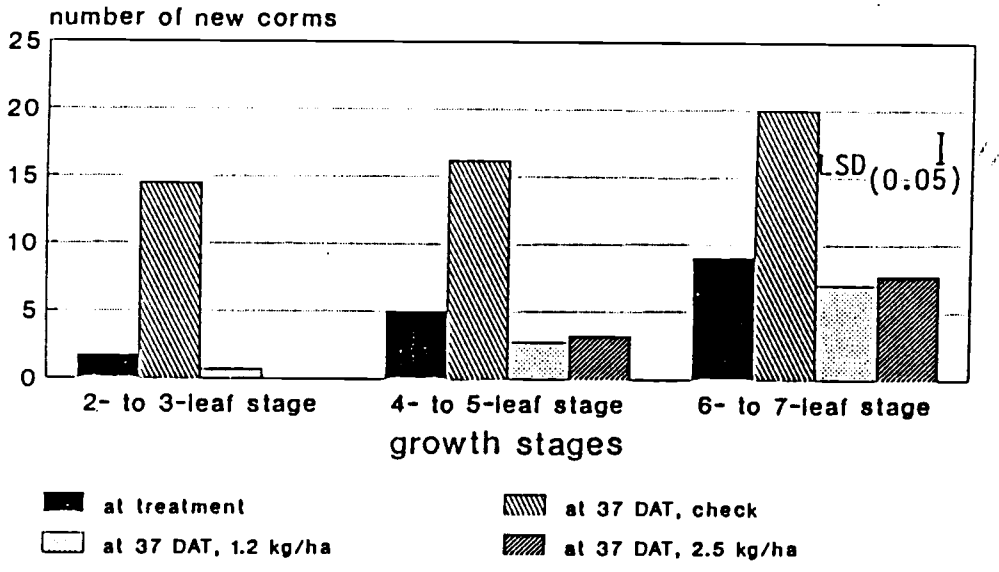
^{14}C-glyphosate translocation studies were also conducted in the well-established tuber oatgrass.

RESULTS

Effects of glyphosate on corm formation and corm viability. Glyphosate at 1.2 and 2.5 kg/ha significantly reduced shoot fresh weights of treated plants 7 days after spraying (data not shown). No shoot regrowth was observed in any of the treated plants after the treated shoots were clipped. New corm formation was significantly reduced after glyphosate application (Figure 3.1). Some new corms from plants treated at the 2- to 3-leaf stage and the 4- to 5-leaf stage were decayed and could not be recovered when they were excavated 30 days after clipping. Glyphosate at 2.5 kg/ha caused more severe symptoms to the newly formed corms than at 1.2 kg/ha at all growth stages. New corms from treated plants did not sprout after 30 days, but 65% of those from untreated plants sprouted.

Effect of glyphosate on dormant corms. Glyphosate at 2.5 kg/ha killed all dormant corms on the superimposed corm-string (Table 3.1). Only 5 to 10 percent of the dormant corms sprouted after treatments of glyphosate at 1.2 kg/ha, whereas untreated plants retained 75 to 85% viability. Shoots arising from the few surviving dormant corms formed a "witch's broom", indicating the presence of glyphosate in the corms.

Effects of glyphosate on well-established tuber oatgrass. Glyphosate significantly reduced shoot regrowth



DAT • DAYS AFTER TREATMENT

Figure 3.1 Effects of glyphosate on new corm formation. The number of new corms were determined at 37 days after Spraying with glyphosate at 1.2 and 2.5 kg/ha.

Table 3.1. Effect of glyphosate on dormant corms[a].

Rate	Experiment 1		Experiment 2	
	Dry weight of treated shoots	Percent viable corms	Dry weight of treated shoots	Percent viable corms
(kg/ha)	(g)	(%)	(g)	(%)
0	0.29	85	0.41	75
1.2	0.08	10	0.11	5
2.5	0.11	0	0.15	0
$LSD_{(0.05)}$	0.07	19	0.18	16

[a] Data are averages of five replications.

Table 3.2. Dry weights of shoot regrowth of tuber oatgrass 2 months after sprayed with glyphosate at different growth stages.

Rates (kg/ha)	Dry weight		
	2 to 3 leaf	4 to 5 leaf	6 to 7 leaf
Experiment 1	----------(% of untreated)----------		
0	100	100	100
1.2	37	0	0
2.5	35	0	0
$LSD_{(0.05)}$ growth stage = 17			
$LSD_{(0.05)}$ rate = 17			
Experiment 2			
0	100	100	100
1.2	52	4	0
2.5	58	0	0
$LSD_{(0.05)}$ growth stage = 14			
$LSD_{(0.05)}$ rate = 14			

of tuber oatgrass (Table 3.2). This effect was influenced by growth stage at the time of treatment. Significant shoot regrowth was observed in plants treated with both glyphosate rates when sprayed at the 2-to 3-leaf stage but not at the 4- to 5-leaf stage. Plants treated at the 6- to 7-leaf stage were completely killed.

Time required for translocation. Shoot regrowth was significantly reduced when the treated shoots were clipped 3h or more after treatment (Table 3.3). No significant differences in regrowth dry weight occurred between clipping at 3 and 6h. Twenty-four hours before clipping was sufficient to cause maximum reduction in regrowth.

Translocation of ^{14}C-glyphosate. Growth stage did not affect the total amount of glyphosate absorption and translocation out of the treated leaf (Table 3.4). An average of 30 to 60% of absorbed glyphosate translocated out of the treated leaf. Glyphosate was distributed extensively in the treated plants (Table 3.5); distribution in most parts of the plants was independent of the growth stage, except in the original corms and their associated buds. More glyphosate accumulated in these parts when applied at the 2- to 3-leaf stage.

The distribution of ^{14}C-glyphosate in the string of superimposed corms showed that the deepest corm which was attached to the exposed leaf (corm A), accounted for 67% of the total amount of ^{14}C translocated into the four corms

Table 3.3. Time required for translocation[a].

Time between application and clipping	Dry weight of shoot regrowth at 30 days after treatment	
	Experiment 1	Experiment 2
(h)	-----(% of untreated)-----	
untreated	100	100
3	46	75
6	57	55
24	2	14
48	1	7
96	19	3
192	7	9
$LSD_{(0.05)}$	35	27

[a] Each data point is the mean of four replications.

Table 3.4. Absorption and translocation of ^{14}C-glyphosate in tuber oatgrass at different growth stages.

Growth stage	Experiment 1	Experiment 2
	----------(%)----------	
Absorption[a]		
2- to 3-leaf stage	51	50
4- to 5-leaf stage	34	48
6- to 7-leaf stage	47	54
$LSD_{(0.05)}$	NS	NS
Translocation[a]		
2- to 3-leaf stage	61	48
4- to 5-leaf stage	36	49
6- to 7-leaf stage	32	34
$LSD_{(0.05)}$	NS	NS

[a] Absorption is expressed as percentage of total amount ^{14}C applied and translocation is expressed as percentage of total amount absorbed.

Table 3.5. Distribution of ^{14}C-glyphosate in tuber oatgrass at different growth stages.

Plant parts	^{14}C-glyphosate accumulation	
	Experiment 1	Experiment 2
Treated leaf	---------(% of absorbed)---------	
2- to 3-leaf stage	39	52
4- to 5-leaf stage	64	51
6- to 7-leaf stage	68	66
$LSD_{(0.05)}$	NS	NS
Remainder of treated shoot (aboveground)		
2- to 3-leaf stage	19	15
4- to 5-leaf stage	13	18
6- to 7-leaf stage	9	7
$LSD_{(0.05)}$	NS	NS
Treated shoot (underground)		
2- to 3-leaf stage	27	11
4- to 5-leaf stage	16	21
6- to 7-leaf stage	14	15
$LSD_{(0.05)}$	NS	NS
Original corms with associated buds		
2- to 3-leaf stage	1.6	3.9
4- to 5-leaf stage	0.3	1.2
6- to 7-leaf stage	0.3	0.5
$LSD_{(0.05)}$	0.5	1.7
Roots		
2- to 3-leaf stage	14	19
4- to 5-leaf stage	6	9
6- to 7-leaf stage	8	12
$LSD_{(0.05)}$	NS	NS

Table 3.6. Typical distribution pattern of ^{14}C-glyphosate in tuber oatgrass superimposed corms. The corm subtending the treated shoot is designated as corm A. Corm B, C, and D are above corm A, respectively[a].

Corm location	Total ^{14}C in corms		
	(% of total ^{14}C in corms)	(% of absorbed)	(dpm/g)
D	5.3 ± 4.0	0.008 ± 0.005	210 ± 180
C	6.3 ± 1.2	0.021 ± 0.025	410 ± 520
B	20.7 ± 18.7	0.110 ± 0.170	1550 ± 2220
A	67.0 ± 16.4	0.160 ± 0.170	3700 ± 2850

[a] The values are the means of three plants.

(Table 3.6). Reduced accumulation of ^{14}C occurred in corms B, C, and D, respectively. The amount of ^{14}C-glyphosate in each corm ranged from 0.008 to 0.16% of the total amount absorbed into the plant.

In the well-established tuber oatgrass, the total translocation of ^{14}C-glyphosate out of the treated leaf was significantly higher at the 2- to 3-leaf stage than at the 4- to 5- and 6- to 7-leaf stages in Experiment 1 (data not shown), but this difference could not be detected in Experiment 2. Translocation of ^{14}C-glyphosate to newly formed corms and dormant corms was not significantly different among different growth stages (data not shown), however; there was a trend toward higher accumulation of ^{14}C in dormant corms at 2- to 3-leaf stage in Experiment 1.

Discussion

Glyphosate was highly effective in killing tuber oatgrass when one or more shoots had emerged. These results agreed with those reported earlier by other researchers (AYRES 1981; AYRES 1985; BIRNIE 1983; O'KEEFFE 1981; SAMUEL 1985). Newly formed corms were killed by glyphosate and are not the source of regrowing shoots. Glyphosate rates recommended for perennial weed control in the field range from 1.0 to 4.0 kg/ha. Quite often, farmers tend to use the lower rates. Our results showed that a small amount of shoot regrowth occurred after glyphosate at 1.2 kg/ha was applied to tuber oatgrass plants that contain dormant corms. Reduced control in the field from these lower rates (less than 1.2 kg/ha) would not be surprising, considering that plants grown in the field are less susceptible to herbicides than plants grown in the greenhouse.

Growth stage influenced the effectiveness of glyphosate on the well-established tuber oatgrass. This result differs from that reported by BIRNIE (1983), who suggested that glyphosate application appeared to be influenced more by time of application than by tuber oatgrass growth stage.

It is well established for perennial grasses that a minimum amount of foliage is required for satisfactory control with glyphosate. Well-established tuber oatgrass plants have large numbers of dormant corms. The dense mass

of corms and few aerial shoots present in plants at the 2- to 3-leaf stage may greatly reduce the concentration of glyphosate reaching the dormant buds. Poor control in the field could result if glyphosate is sprayed when the majority of shoots have 2 to 3 leaves.

The ^{14}C-glyphosate study showed no significant differences in the total amount of glyphosate translocated out of the treated leaves at different growth stages, although there was a consistent trend toward more translocation at the 2- to 3-leaf stage. The poor control from a spray application at the 2- to 3-leaf stage could result from the small, upright leaves of the plants intercepting less herbicide, which might result in less glyphosate reaching the dormant corms. Greater runoff from smaller plants would not occur in these experiments.

In quackgrass, researchers observed more ^{14}C-glyphosate translocated into rhizomes when applied at early growth stages (1- to 2- or 2- to 3-leaf stages) than at later growth stages (4- to 5- or 6- to 7-leaf stages) (SPRANKLE, MEGGITT, and PENNER 1975; HARKER and DEKKER 1988). This phenomenon was not consistent with field and greenhouse studies in which glyphosate was more effective when sprayed at later growth stages (BAIRD and BEGEMAN 1972; RIOUX, BANDEEN, and ANDERSON 1974).

The accumulation of ^{14}C in dormant corms in the same string gradually decreased as distance increased from the

corm subtending the treated shoot. Shoots arising from dormant corms after spraying with glyphosate at 1.2 kg/ha could result from those corms that are located at a distance from corms subtending the treated shoot. Although only a small amount of glyphosate translocated to the corms, as indicated by the ^{14}C study, the concentration was sufficient to kill most corms. Also, a great number of corms presumably are not attached to an above-ground shoot and could be expected to survive a glyphosate treatment.

Twenty-four hours was sufficient for enough glyphosate to translocate to the corms to significantly reduce corm regrowth. Mechanical damage occurring to the plants in this period could result in poor control.

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GENERAL DISCUSSION

Although tuber oatgrass seems to be a potential weed, its distribution is not extensive in the United States. Distribution of this weed could be limited by the environmental conditions. The plants may not be well adapted to severe winters and long, hot summers. The mild climate of the Willamette Valley could be favorable for the development of this plant.

For perennial grasses, a minimum amount of foliage is required for satisfactory control with glyphosate. The dense mass of corms and few aerial shoots present in tuber oatgrass plants could greatly reduce glyphosate efficacy. Tuber oatgrass growing under normal field conditions does not produce the maximum shoot number per plant until late February. Application of glyphosate after this time should provide good control of the weed. However, under winter crop production practices, this is not feasible because glyphosate is nonselective to crops. Selective herbicides need to be investigated for potential uses under these production practices.

The pattern of winter crop production practices in Western Oregon allows a limited time interval between harvest and planting for tuber oatgrass control with glyphosate. This interval is too short to allow sufficient sprouting of dormant corms. Post-harvest application of

glyphosate could result in poor control because of the presence of dormant corms in the soil that are not connected with an emerged shoot. Moreover, the majority of emerged shoots are in the 2- to 3-leaf stage, which was shown in this work not to be optimum for control of this weed by glyphosate.

Delaying the planting date of winter crops allows more dormant corms to sprout. Subsequently, glyphosate can be sprayed before the crops are planted, but caution is advised because under some circumstances the herbicide may have soil activity.

Rotation from winter cropping to spring cropping increases the interval between harvest and planting. SAMUEL (1985) observed a large reduction in tuber oatgrass population from changing from winter to spring cropping combined with winter plowing and use of glyphosate.

Although the effectiveness of glyphosate against tuber oatgrass was demonstrated in the greenhouse, performance of the herbicide in the field needs to be investigated. More information on herbicide rate, application timing, and effects of tillage operations on tuber oatgrass would be necessary for effective and economical control of this weed.

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APPENDIX

Appendix Table 1. Development of tuber oatgrass at different temperature and photoperiod

Weeks after planting	Shoot height (cm)	No. of leaf	Shoot dry weight (g)	Plants forming corms (%)	Tillers per plant
20/10C, 8/16h light					
Seed					
2	11.3	1.1	0.002	0	0.0
4	15.4	2.0	0.005	0	0.0
6	22.4	3.5	0.015	0	0.0
8	25.7	3.8	0.022	0	0.1
10	27.3	4.7	0.045	0	0.4
Corm					
2	8.7	1.1	0.008	0	0.0
4	15.9	1.8	0.015	0	0.0
6	20.5	2.8	0.020	10	0.0
8	27.2	3.2	0.036	10	0.3
10	30.4	3.8	0.058	18	0.2
20/10C, 16/8h light					
Seed					
2	9.2	1.0	0.001	0	0.0
4	19.6	3.0	0.003	0	0.0
6	33.2	4.0	0.040	18	0.6
8	52.8	5.8	0.262	92	1.0
10	61.0	8.0	0.532	100	1.7
Corm					
2	11.7	1.4	0.018	0	0.4
4	33.4	2.9	0.055	9	0.5
6	50.8	4.7	0.214	83	0.9
8	62.4	6.2	0.681	100	2.1
10	70.3	8.0	1.205	100	2.4

Appendix Table 1. (continued)

Weeks after planting	Shoot height (cm)	No. of leaf	Shoot dry weight (g)	No. of new corms	Tillers per plant
30/20C, 8/16h light					
Seed					
2	13.0	1.7	0.002	0	0.0
4	21.5	3.1	0.007	0	0.0
6	27.5	4.5	0.027	0	0.1
8	33.6	6.1	0.060	10	0.1
10	39.3	8.7	0.263	60	1.0
Corm					
2	19.7	2.0	0.019	0	0.0
4	34.8	3.5	0.046	9	0.0
6	39.2	5.1	0.101	18	0.2
8	43.8	7.3	0.256	90	0.6
10	45.5	9.2	0.452	100	0.9
30/20C, 16/8h light					
Seed					
2	17.3	2.7	0.008	0	0.0
4	20.0	3.0	0.015	0	0.0
6	23.7	4.8	0.044	17	0.3
8	25.7	6.1	0.154	20	1.0
10	31.5	7.0	0.306	55	1.4
Corm					
2	18.9	1.9	0.020	0	0.0
4	25.8	3.2	0.043	10	0.0
6	33.7	5.1	0.153	67	0.9
8	37.8	6.1	0.341	100	1.1
10	34.3	6.8	0.459	100	1.0

Appendix Table 2. Vernalization of tuber oatgrass plants started from seeds and corms.

Vernalization period (days)	RI	RII	RIII	RIV	RV	RVI
Seeds			Days to flower			
0	46	62	72	64	52	52
7	28	27	48	28	29	48
14	46	49	49	47	46	51
21	56	55	59	56	64	52
28	57	63	43	52	57	43
Corms						
0	45	51	59	59	52	45
7	49	52	51	49	48	52
14	43	42	45	43	57	44
21	56	50	63	48	47	53
28	49	51	41	54	52	42
Seeds			Panicle numbers			
0	65	17	20	24	22	32
7	27	33	42	33	49	51
14	73	41	35	40	27	9
21	28	26	35	53	37	35
28						
Corms						
0	26	31	32	18	34	24
7	36	45	41	33	37	34
14	52	26	32	14	25	29
21	28	17	21	30	25	35
28	23	18	18	30	21	32

Appendix Table 3. Germination of tuber oatgrass seeds at different temperatures, light conditions, and germinating solution (Experiment 1). There were twenty-five seeds per treatment.

Temperature (C)		Numbers of seeds germinated Weeks after initiation							
		1	2	3	4	5	6	7	8
					Replication I				
Light									
8	water	0	20	22	22	24	24	24	24
	KNO3	0	19	19	19	23	23	23	23
15	water	14	21	21	21	21	21	21	21
	KNO3	15	19	22	24	24	24	24	24
25	water	2	7	13	14	16	16	16	16
	KNO3	5	12	15	17	21	21	21	21
30/20	water	21	25	25	25	25	25	25	25
	KNO3	7	19	20	20	21	21	21	21
Dark									
8	water	0	16	24	24	24	24	24	24
	KNO3	0	18	20	20	20	20	20	20
15	water	18	22	22	22	22	22	22	22
	KNO3	15	19	20	20	21	21	21	21
25	water	12	21	22	22	22	22	22	22
	KNO3	7	9	9	10	17	17	17	17
30/20	water	13	19	19	19	19	19	19	19
	KNO3	0	16	24	24	24	24	24	24
					Replication II				
Light									
8	water	0	21	24	24	24	24	24	24
	KNO3	0	14	17	17	22	23	23	23
15	water	18	24	24	24	24	24	24	24
	KNO3	19	21	22	22	22	22	22	22
25	water	5	17	18	19	21	21	21	21
	KNO3	4	12	17	18	22	22	22	22
30/20	water	6	19	19	19	20	20	20	20
	KNO3	13	21	21	21	21	21	21	21
Dark									
8	water	20	20	22	22	22	22	22	22
	KNO3	13	13	20	20	21	21	22	22
15	water	22	22	23	23	23	23	23	23
	KNO3	24	24	24	24	24	24	24	24
25	water	15	15	15	15	16	17	17	17
	KNO3	17	17	17	17	17	17	17	17
30/20	water	22	22	24	24	24	24	24	24
	KNO3	18	18	23	23	23	23	23	23

Appendix Table 3. (continued)

Temperature		Numbers of seeds germinated, Weeks after initiation							
		1	2	3	4	5	6	7	8
					Replication III				
Light									
8	water	0	19	21	21	21	21	21	21
	KNO3	0	16	21	22	23	23	23	23
15	water	22	24	24	24	24	24	24	24
	KNO3	19	23	23	23	23	23	23	23
25	water	6	16	20	20	20	20	21	21
	KNO3	6	16	19	20	21	21	21	21
30/20	water	17	22	23	23	23	23	23	23
	KNO3	8	21	22	23	22	22	22	22
Dark									
8	water	0	15	22	23	23	23	23	23
	KNO3	0	14	22	23	23	23	23	23
15	water	14	20	22	23	23	23	23	23
	KNO3	20	23	23	23	23	23	23	23
25	water	9	14	14	14	14	14	14	14
	KNO3	11	14	18	19	21	21	21	21
30/20	water	19	22	23	23	23	23	23	23
	KNO3	11	15	17	18	19	19	19	19
					Replication IV				
Light									
8	water	0	15	20	23	23	23	23	23
	KNO3	0	15	19	19	19	20	21	21
15	water	19	24	24	24	24	24	24	24
	KNO3	19	21	22	22	22	22	22	22
25	water	5	12	17	18	18	19	19	19
	KNO3	4	17	20	20	22	22	23	23
30/20	water	14	24	24	24	24	24	24	24
	KNO3	17	21	23	23	23	23	23	23
Dark									
8	water	0	20	23	23	23	23	23	23
	KNO3	0	19	22	23	24	24	24	24
15	water	21	23	23	23	23	23	23	23
	KNO3	13	20	23	23	23	23	23	23
25	water	14	19	19	19	19	19	19	19
	KNO3	17	21	22	23	24	24	24	24
30/20	water	15	18	19	19	19	19	19	19
	KNO3	5	14	19	19	19	19	19	19

Appendix Table 4. Germination of tuber oatgrass seeds at different temperatures, light conditions, and germinating solution (Experiment 2). There were twenty-five seeds per treatment.

Temperature (C)		Numbers of seeds germinated, Weeks after initiation							
		1	2	3	4	5	6	7	8
					Replication I				
Light									
8	water	1	15	20	20	20	20	21	21
	KNO3	0	7	24	24	24	24	24	24
15	water	19	22	24	24	24	24	24	24
	KNO3	19	20	22	22	22	22	22	22
25	water	4	6	9	9	9	9	10	10
	KNO3	4	14	21	21	22	23	24	24
30/20	water	16	23	23	24	24	24	24	24
	KNO3	8	17	19	20	21	21	21	21
Dark									
8	water	2	11	20	22	25	25	25	25
	KNO3	0	11	19	20	20	20	20	21
15	water	18	23	25	25	25	25	25	25
	KNO3	14	22	22	22	22	22	22	22
25	water	9	15	15	15	16	16	17	17
	KNO3	9	15	16	16	16	17	17	17
30/20	water	17	19	21	21	21	21	21	21
	KNO3	2	11	20	22	25	25	25	25
					Replication II				
Light									
8	water	0	5	13	18	20	20	20	20
	KNO3	2	8	17	17	17	17	21	21
15	water	22	24	24	24	24	24	24	24
	KNO3	18	24	24	25	25	25	25	25
25	water	4	9	13	14	14	14	14	15
	KNO3	5	11	15	15	17	19	19	21
30/20	water	17	20	20	21	21	21	21	21
	KNO3	19	23	23	23	23	23	23	23
Dark									
8	water	3	13	19	21	21	21	22	22
	KNO3	3	10	20	21	22	22	22	22
15	water	15	18	20	20	20	20	20	20
	KNO3	16	19	21	21	22	22	22	22
25	water	16	20	20	20	20	20	20	20
	KNO3	13	18	20	21	21	21	21	21
30/20	water	11	16	16	16	16	17	17	17
	KNO3	14	23	23	24	24	24	24	24

Appendix Table 4. (continued)

Temperature		Numbers of seeds germinated Weeks after initiation							
		1	2	3	4	5	6	7	8
Light									
8	water	0	7	18	20	21	21	22	22
	KNO3	1	9	19	22	22	22	23	23
15	water	18	22	22	22	22	22	22	22
	KNO3	17	21	22	22	24	24	24	24
25	water	8	14	14	14	14	14	15	15
	KNO3	6	11	15	16	21	22	23	24
30/20	water	21	25	25	25	25	25	25	25
	KNO3	15	24	24	24	24	24	24	24
Dark									
8	water	1	8	19	23	24	24	25	25
	KNO3	2	13	20	20	20	20	21	21
15	water	18	22	22	22	22	22	22	22
	KNO3	16	21	22	23	24	24	24	24
25	water	13	18	18	18	18	18	18	18
	KNO3	9	19	19	19	20	20	20	20
30/20	water	13	21	21	21	21	21	21	21
	KNO3	11	17	21	22	23	23	23	23
					Replication IV				
Light									
8	water	0	6	20	21	21	21	21	22
	KNO3	2	9	22	22	23	23	25	25
15	water	15	18	18	22	22	22	22	22
	KNO3	19	22	22	22	23	23	23	23
25	water	6	10	13	16	17	18	19	19
	KNO3	6	10	10	15	16	16	21	22
30/20	water	16	22	22	22	22	22	22	22
	KNO3	14	22	23	23	23	23	23	23
Dark									
8	water	1	13	24	24	24	24	24	24
	KNO3	4	14	20	21	21	21	23	24
15	water	15	19	19	19	19	19	19	19
	KNO3	20	23	23	23	23	23	23	23
25	water	10	11	12	12	12	12	12	12
	KNO3	14	19	20	20	20	20	20	21
30/20	water	9	16	17	17	17	17	17	17
	KNO3	16	21	23	24	24	24	24	24

Appendix Table 5. Sprouting of tuber oatgrass corms at different temperatures (Experiment 1). There were ten corms per treatment.

Temperature (C)	Replication I	II	III	IV
7 days after initiation				
Light				
8	3	3	5	3
15	10	9	10	8
25	9	7	8	8
20/30	10	7	8	10
Dark				
8	5	6	5	3
15	10	8	10	10
25	8	6	8	10
20/30	8	10	10	10
14 days after initiation				
Light				
8	10	10	9	10
15	10	9	10	9
25	9	10	8	8
20/30	10	7	10	10
Dark				
8	9	9	10	7
15	10	9	10	10
25	9	9	9	10
20/30	8	10	10	10
21 days after initiation				
Light				
8	10	10	9	10
15	10	9	10	10
25	9	10	9	8
20/30	10	10	10	10
Dark				
8	10	10	10	7
15	10	10	10	10
25	9	9	9	10
20/30	10	10	10	10

Appendix Table 6. Sprouting of tuber oatgrass corms at different temperatures (Experiment 2). There were eight corms per treatment.

Temperature (C)	Replication I	II	III	IV
7 days after initiation				
Light				
8	4	4	3	3
15	8	8	7	8
25	8	7	7	7
20/30	7	8	6	8
Dark				
8	5	8	3	6
15	6	8	8	6
25	8	8	8	8
20/30	8	7	7	7
14 days after initiation				
Light				
8	8	8	7	7
15	8	8	7	8
25	8	7	7	7
20/30	8	8	6	8
Dark				
8	8	8	8	8
15	8	8	8	6
25	8	8	8	8
20/30	8	7	7	7
21 days after initiation				
Light				
8	8	8	7	7
15	8	8	7	8
25	8	7	7	7
20/30	8	8	6	8
Dark				
8	8	8	8	8
15	8	8	8	6
25	8	8	8	8
20/30	8	7	7	7

Appendix Table 7. Sprouting of tuber oatgrass corms collected from the field at different dates. Twenty-five corms were planted in each replication.

Weeks after planting	Replications			
	I	II	III	IV
April 1, 1988.				
2	12	10	16	7
4	16	10	19	12
6	17	11	19	16
8	17	11	19	16
10	18	11	20	18
12	19	11	20	19
14	19	11	20	19
16	19	12	21	19
18	20	12	22	19
20	20	13	22	20
22	20	15	22	21
24	20	15	22	21
May 16, 1988.				
2	6	9	7	3
4	11	14	13	8
6	13	16	14	10
8	15	17	16	11
10	20	19	19	16
12	22	19	21	17
14	22	19	22	19
16	22	19	22	19
18	22	19	22	19
20	22	20	22	20
22	22	22	22	21
24	22	22	23	21
June 24, 1988.				
2	6	5	6	3
4	14	12	15	12
6	16	15	16	14
8	18	19	18	18
10	21	20	20	20
12	25	21	20	21
14	25	22	20	21
16	25	22	20	22
18	25	24	20	22
20	25	24	21	23
22	25	25	21	24
24	25	25	21	25

Appendix Table 7. (Continued)

Weeks after planting	Replications			
	I	II	III	IV
April 1, 1988.				
2	12	17	19	20
4	19	23	23	22
6	20	24	23	22
8	20	24	23	22
10	21	24	23	22
12	22	24	24	23
14	22	24	24	24
16	23	25	24	24
18	23	25	24	25
20	25	25	24	25
22	25	25	24	25
24	25	25	24	25

Appendix Table 8. Development of tuber oatgrass in the field from October, 15, 1986 to August, 8, 1987. Numbers in parenthesis represent standard error of the mean.

Date	Number of plants evaluated	Number of shoots per plant			Original corms per plant	Average shoot height (cm)	Dormant corms (%)	Shoots shorter than 5 cm (%)	Number of new corm per plant	Shoots forming corms(%)	Number of new corms per shoot	Shoots with flower (%)
		main	tiller	total								
Oct/15	52	2.7(1.0)	0.2(0.5)	2.8(1.2)	3.6(0.7)	16.0(8.8)	20	25.00	-	-	-	-
Oct/22	67	2.5(1.0)	0.3(0.9)	2.7(1.2)	3.9(2.2)	20.6(8.1)	23	7.50	-	-	-	-
Nov/5	66	2.3(0.9)	0.2(0.5)	2.6(1.0)	3.7(0.6)	20.2(6.5)	31	5.10	0.7(0.8)	25	0.3	-
Nov/19	65	2.2(0.8)	0.6(0.1)	2.7(1.4)	4.0(0.8)	20.4(6.8)	42	5.10	1.3(1.2)	44	0.5	-
Dec/4	54	2.4(1.0)	0.9(0.4)	3.3(1.3)	3.8(0.7)	19.0(6.0)	50	4.10	1.2(1.0)	37	0.4	-
Dec/24	56	2.0(0.8)	1.3(1.5)	3.3(1.8)	4.0(0.8)	16.8(5.7)	49	4.80	1.3(1.2)	30	0.4	-
Jan/6	47	2.2(0.7)	1.2(2.1)	3.5(2.3)	3.5(0.8)	17.5(5.9)	36	6.80	1.2(1.1)	26	0.4	-
Jan/14	52	2.2(0.7)	1.7(1.6)	4.0(1.9)	3.8(0.6)	16.0(7.1)	41	-	1.2(1.3)	22	0.3	-
Jan/28	22	2.0(0.8)	2.9(1.7)	4.9(2.0)	4.1(0.7)	18.6(4.9)	52	1.60	4.1(3.4)	45	0.9	-
Feb/13	20	2.5(1.1)	3.7(3.1)	6.1(3.7)	4.1(0.9)	19.4(5.6)	40	-	4.4(3.4)	38	0.7	-
Feb/28	20	2.1(0.5)	2.7(1.6)	4.7(1.9)	3.3(0.9)	26.0(6.0)	30	-	5.9(3.6)	61	1.2	-
Mar/12	20	2.3(0.6)	2.7(1.7)	5.0(1.8)	3.7(1.1)	22.6(5.9)	37	1.50	14.8(7.0)	84	1.8	-
Apr/3	21	2.2(0.6)	2.6(1.9)	4.8(2.0)	3.5(0.8)	34.4(7.2)	38	-	15.0(6.4)	99	3.4	-
Apr/15	14	1.5(0.7)	2.8(0.9)	4.3(1.1)	3.6(0.8)	31.3(6.5)	59	-	14.9(4.5)	98	3.5	-
Apr/30	10	1.7(0.7)	3.0(1.4)	4.4(1.6)	3.2(1.0)	51.1(9.3)	47	-	17.5(8.0)	100	4.0	-
May/30	10	-	-	-	-	52.0(14.4)	-	-	12.6(11.0)	100	4.9	15
Jun/30	8	-	-	-	-	109.0(31.3)	-	-	13.3(6.5)	100	4.8	77
Aug/8	20	2.0(0.8)	-	2.0(0.8)	3.2(0.7)	13.6(6.3)	41	-	-	-	-	-

Appendix Table 9. Development of tuber oatgrass in the outdoors pots from November 8, 1986 to June 19, 1987.

Dates	Shoot height (cm)	Leaf area (cm^2)	Shoot weight (g)	Tillers per plant	Shoot forming corms (%)	Corm per shoot	Corm dry weight (g)
Nov/8	15.3	1.94	0.017	0.0	0	0.0	0.000
Nov/16	10.1	2.79	0.028	1.0	0	0.0	0.000
Nov/30	9.3	16.77	0.120	4.5	0	0.0	0.000
Dec/24	11.2	17.95	0.159	3.0	0	0.0	0.000
Jan/6	13.3	26.90	0.260	5.5	0	0.0	0.000
Jan/13	12.9	42.78	0.365	6.0	0	0.0	0.000
Jan/28	12.1	29.17	0.296	5.0	0	0.0	0.000
Feb/14	13.7	86.71	0.906	7.0	0	0.0	0.000
Feb/28	19.1	269.67	2.534	22.0	0	0.0	0.000
Mar/14	25.4	393.70	4.200	24.0	46	0.6	2.180
Apr/3	22.9	584.34	5.000	33.0	83	1.2	2.580
Apr/17	26.0	639.11	6.060	34.5	77	1.4	5.760
May/2	34.0	1211.00	9.670	38.0	100	2.4	14.400
May/21	41.1	965.00	15.800	41.0	100	2.3	20.100
Jun/19	66.6	683.00	24.900	30.5	100	2.1	18.350

Appendix Table 10. Development of tuber oatgrass in the outdoors pots from November, 9, 1987 to August, 8, 1988. Numbers in parenthesis represent standard error of the mean.

Sampling Date	Shoot height (cm)		Tillers per plant	Corms per shoot	corms per plant	Dry weight (gm)			Flowering shoot (%)
	main	tiller				shoot	root	corm	
Nov/9	19.5(2.3)	3.5(1.4)	1(1)	-	-	0.06(0.01)	0.01(0.01)	-	-
Nov/23	19.3(1.8)	6.2(5.5)	5(3)	-	-	0.15(0.05)	0.04(0.02)	-	-
Dec/10	20.7(4.5)	9.4(6.3)	5(2)	-	-	0.32(0.12)	0.10(0.04)	-	-
Dec/23	21.2(4.6)	11.9(4.5)	8(5)	-	-	0.41(0.17)	0.13(0.05)	-	-
Jan/9	20.1(1.6)	11.8(5.5)	10(3)	-	-	0.68(0.18)	0.26(0.09)	-	-
Jan/24	18.8(4.9)	12.5(5.2)	18(7)	-	-	0.81(0.42)	0.37(0.19)	-	-
Feb/15	23.0(4.2)	14.4(6.2)	20(3)	0.1(0.1)	1(1)	1.15(0.30)	0.43(0.08)	0.01(0.02)	-
Mar/1	25.2(2.5)	15.5(7.0)	30(8)	0.2(0.1)	5(6)	2.92(0.50)	2.02(0.54)	0.31(0.31)	-
Mar/17	27.1(3.6)	16.4(7.7)	32(9)	0.2(0.1)	6(5)	4.80(1.36)	2.80(1.02)	0.48(0.35)	-
Mar/30	33.5(3.5)	22.7(9.4)	26(5)	1.5(0.9)	35(19)	4.90(1.00)	4.40(2.10)	3.93(2.01)	-
Apr/11	39.3(9.2)	29.2(10.2)	31(8)	2.3(0.3)	73(19)	8.10(3.65)	5.92(1.79)	10.41(3.26)	-
May/2	45.3(8.5)	35.6(8.5)	19(10)	3.4(0.3)	71(36)	9.14(3.79)	8.61(2.99)	12.54(6.65)	-
May/9	63.0(8.0)	50.5(9.8)	42(12)	3.9(1.3)	158(16)	17.43(7.96)	4.45(1.09)	23.04(6.43)	-
May/23	72.8(13.1)	62.7(15.9)	25(5)	4.0(1.0)	101(14)	26.87(9.03)	10.65(3.10)	20.72(4.32)	-
Jun/6	93.6(19.5)	72.3(20.1)	26(11)	4.0(1.0)	104(28)	31.28(7.60)	7.44(4.03)	23.79(2.87)	50
Jul/7	125.4(13.8)	99.5(31.4)	24(5)	3.5(0.5)	88(16)	37.42(7.60)	10.59(4.63)	27.31(9.02)	74
Aug/8	126.3(9.5)	103.2(26.4)	31(7)	3.5(0.8)	143(97)	41.67(8.15)	9.36(2.85)	21.45(5.88)	78

Appendix Table 11. Effect of glyphosate on corm formation and viability (Experiment 1).

Rates (kg/ha)	Fresh weight at 7 DAT (g)			Fresh weight of regrowth (g)			Number of new forming corms[a]		
	I	II	III	I	II	III	I	II	III
2- to 3-leaf stage									
0	1.98	1.82	2.73	2.22	2.09	2.58	15(73)	20(95)	10(100)
1.2	0.95	1.63	1.07	0.00	0.00	0.00	2 (0)	2 (0)	0 (0)
2.5	1.01	1.30	0.86	0.00	0.00	0.00	0 (0)	0 (0)	0 (0)
4- to 5-leaf stage									
0	1.58	4.87	3.66	2.73	6.01	2.59	13(62)	21(67)	14(100)
1.2	1.84	2.06	3.27	0.00	0.00	0.00	4 (0)	3 (0)	0 (0)
2.5	2.46	1.76	2.88	0.00	0.00	0.00	8 (0)	4 (0)	0 (0)
6- to 7-leaf stage									
0	9.85	8.07	8.85	5.67	1.15	3.29	25(68)	15(53)	19(100)
1.2	3.71	6.25	3.79	0.00	0.00	0.00	8 (0)	10 (0)	7 (0)
2.5	2.76	4.37	2.91	0.00	0.00	0.00	10 (0)	10 (0)	10 (0)

[a] Numbers in parenthesis represent percentage of corms sprouted.

Appendix Table 12. Effect of glyphosate on corm formation and viability (Experiment 2).

Rates (kg/ha)	Fresh weight at 7 DAT (g)			Fresh weight of regrowth (g)			Number of new forming corms[a]		
	I	II	III	I	II	III	I	II	III
2- to 3-leaf stage									
0	1.21	1.68	0.98	2.19	5.20	3.90	15(53)	16(56)	11(18)
1.2	0.71	0.52	0.45	0.00	0.00	0.00	0 (0)	0 (0)	0 (0)
2.5	0.52	0.27	0.57	0.00	0.00	0.00	0 (0)	0 (0)	0 (0)
4- to 5-leaf stage									
0	4.53	2.42	2.96	1.93	2.93	3.60	15(60)	8(88)	23(13)
1.2	2.00	2.18	1.09	0.00	0.00	0.00	0 (0)	3 (0)	0 (0)
2.5	1.40	1.56	1.27	0.00	0.00	0.00	0 (0)	0 (0)	0 (0)
6- to 7-leaf stage									
0	5.04	7.93	7.75	2.98	1.66	2.63	29(57)	14(57)	18(94)
1.2	2.11	2.80	2.32	0.00	0.00	0.00	8 (0)	3 (0)	6 (0)
2.5	2.93	1.75	1.76	0.00	0.00	0.00	7 (0)	6 (0)	3 (0)

[a] Numbers in parenthesis represent percentage of corms sprouted.

Appendix Table 13. Effect of glyphosate on dormant corms (Experiment 1).

Rate	Replication				
	I	II	III	IV	V
	----------Dry weight (g)----------				
0	0.29	0.40	0.22	0.36	0.18
1.2	0.09	0.10	0.08	0.08	0.07
2.5	0.15	0.15	0.11	0.08	0.04
	---------- % dormant corms sprouting----------				
0	75	75	75	100	100
1.2	0	0	0	50	0
2.5	0	0	0	0	0

Appendix Table 14. Effect of glyphosate on dormant corms (Experiment 2).

Rate	Replication				
	I	II	III	IV	V
	----------Dry weight (g)----------				
0	0.13	0.52	0.35	0.33	0.72
1.2	0.08	0.19	0.10	0.11	0.06
2.5	0.07	0.12	0.15	0.17	0.22
	---------- % dormant corms sprouting----------				
0	100	75	67	60	75
1.2	0	0	0	0	25
2.5	0	0	0	0	0

Appendix Table 15. Effect of glyphosate on well-established tuber oatgrass (Experiment 1).

Rates (kg/ha)	Dry weight (g) I	II	III	IV
2- to 3-leaf stage				
0	4.43	8.68	4.47	4.02
1.2	4.00	3.81	0.14	0.00
2.5	2.32	7.36	0.00	0.00
4- to 5-leaf stage				
0	10.31	10.40	7.32	13.20
1.2	0.00	0.00	0.00	0.00
2.5	0.00	0.00	0.00	0.00
6- to 7-leaf stage				
0	4.00	11.40	5.27	5.30
1.2	0.00	0.00	0.00	0.00
2.5	0.00	0.00	0.00	0.00

Appendix Table 16. Effect of glyphosate on well-established tuber oatgrass (Experiment 2).

Rates (kg/ha)	Dry weight (g) I	II	III
2- to 3-leaf stage			
0	1.60	1.83	1.85
1.2	1.45	0.48	0.73
2.5	0.69	1.46	0.95
4- to 5-leaf stage			
0	0.72	2.02	1.35
1.2	0.09	0.00	0.00
2.5	0.00	0.00	0.00
6- to 7-leaf stage			
0	1.91	1.91	0.23
1.2	0.00	0.00	0.00
2.5	0.00	0.00	0.00

Appendix Table 17. Time required for translocation (Experiment 1).

Time between application and clipping (h)	Dry weight (g) I	II	III	IV
Untreated	3.72	3.37	4.26	4.21
3	1.50	0.55	3.47	1.71
6	2.65	2.81	0.62	2.76
24	0.04	0.05	0.15	0.08
48	0.02	0.03	0.05	0.00
96	0.01	2.95	0.02	0.00
192	0.03	0.13	0.24	0.75

Appendix Table 18. Time required for translocation (Experiment 2).

Time between application and clipping (h)	Dry weight (g) I	II	III	IV
Untreated	3.78	3.53	3.22	3.06
3	2.02	1.82	3.15	3.24
6	1.63	1.27	3.61	0.93
24	1.04	0.02	0.30	0.59
48	0.02	0.23	0.62	0.12
96	0.32	0.00	0.08	0.00
192	0.01	0.83	0.01	0.40

Appendix Table 19. Translocation of 14C-glyphosate to dormant corms (Experiment 1).

Plant parts	Dry weight (g)	DPM
	Replication I	
2- to 3-leaf stage		
treated leaf	0.0240	80017
remainder of treated shoot (above)	0.0391	54322
treated shoot (underground)	0.0168	27162
corms and their associated buds	0.2784	3619
roots	0.0130	30806
4- to 5-leaf stage		
treated leaf	0.0156	103056
remainder of treated shoot (above)	0.0606	38123
treated shoot (underground)	0.0457	74208
corms and their associated buds	0.3585	717
roots	0.0193	21691
6- to 7-leaf stage		
treated leaf	0.0627	232050
remainder of treated shoot (above)	1.1037	17853
treated shoot (underground)	0.3520	28637
corms and their associated buds	0.5150	103
roots	0.0994	12376

Appendix Table 19. (continued)

Plant parts	Dry weight (g)	DPM
	Replication III	
2- to 3-leaf stage		
treated leaf	0.0142	67979
remainder of treated shoot (above)	0.0354	24020
treated shoot (underground)	0.0190	45222
corms and their associated buds	0.3664	2748
roots	0.0221	23386
4- to 5-leaf stage		
treated leaf	0.0113	108036
remainder of treated shoot (above)	0.0463	12589
treated shoot (underground)	0.0207	11996
corms and their associated buds	0.3893	548
roots	0.0180	5345
6- to 7-leaf stage		
treated leaf	0.0425	104410
remainder of treated shoot (above)	1.1761	46283
treated shoot (underground)	0.4717	40492
corms and their associated buds	0.4889	1711
roots	0.1772	45307

Appendix Table 19. (continued)

Plant parts	Dry weight (g)	DPM
	Replication II	
2- to 3-leaf stage		
treated leaf	0.0105	77464
remainder of treated shoot (above)	0.0300	35130
treated shoot (underground)	0.0200	92647
corms and their associated buds	0.2591	3368
roots	0.0202	25127
4- to 5-leaf stage		
treated leaf	0.0184	113799
remainder of treated shoot (above)	0.0551	22817
treated shoot (underground)	0.0276	14828
corms and their associated buds	0.1373	206
roots	0.0153	5524
6- to 7-leaf stage		
treated leaf	0.0644	220642
remainder of treated shoot (above)	0.6750	6456
treated shoot (underground)	0.3729	39497
corms and their associated buds	0.5700	456
roots	0.0848	6300

Appendix Table 20. Translocation of 14C-glyphosate to dormant corms (Experiment 2).

Plant parts	Dry weight (g)	DPM
Replication I		
2- to 3-leaf stage		
treated leaf	0.0101	137212
remainder of treated shoot (above)	0.0358	17229
treated shoot (underground)	0.0163	16235
corms and their associated buds	0.6473	10660
roots	0.0076	25945
4- to 5-leaf stage		
treated leaf	0.0151	103812
remainder of treated shoot (above)	0.0832	22456
treated shoot (underground)	0.0165	4807
corms and their associated buds	0.2562	1557
roots	0.0213	9665
6- to 7-leaf stage		
treated leaf	0.0378	74916
remainder of treated shoot (above)	1.2060	8593
treated shoot (underground)	0.5778	22222
corms and their associated buds	0.1238	136
roots	0.2121	16935

Appendix Table 20. (continued)

Plant parts	Dry weight (g)	DPM
	Replication II	
2- to 3-leaf stage		
treated leaf	0.0172	107346
remainder of treated shoot (above)	0.0296	22684
treated shoot (underground)	0.0142	20651
corms and their associated buds	0.0514	5634
roots	0.0091	24420
4- to 5-leaf stage		
treated leaf	0.0207	91420
remainder of treated shoot (above)	0.0789	68621
treated shoot (underground)	0.0300	64051
corms and their associated buds	0.3569	3481
roots	0.0265	43280
6- to 7-leaf stage		
treated leaf	0.0305	178519
remainder of treated shoot (above)	0.6962	19056
treated shoot (underground)	0.3522	33055
corms and their associated buds	0.2528	1183
roots	0.0948	31843

Appendix Table 20. (continued)

Plant parts	Dry weight (g)	DPM
	Replication III	
2- to 3-leaf stage		
treated leaf	0.0156	72743
remainder of treated shoot (above)	0.0352	56629
treated shoot (underground)	0.0174	31013
corms and their associated buds	0.5287	8781
roots	0.0134	74840
4- to 5-leaf stage		
treated leaf	0.0325	87918
remainder of treated shoot (above)	0.1080	22804
treated shoot (underground)	0.0824	69776
corms and their associated buds	0.4077	2305
roots	0.0489	9654
6- to 7-leaf stage		
treated leaf	0.0585	204515
remainder of treated shoot (above)	1.4758	19564
treated shoot (underground)	0.5905	41233
corms and their associated buds	0.4884	2926
roots	0.1782	28883

Appendix Table 21. Absorption and translocation of ^{14}C-glyphosate in well-established tuber oatgrass at different growth stages.

Plant parts	^{14}C-glyphosate accumulation	
	Experiment 1	Experiment 2
Absorption	------(% of applied)------	
2- to 3-leaf stage	42	42
4- to 5-leaf stage	33	36
6- to 7-leaf stage	44	46
$LSD_{(0.05)}$	NS	NS
Translocation	------(% of absorbed)------	
2- to 3-leaf stage	29	24
4- to 5-leaf stage	18	13
6- to 7-leaf stage	12	27
$LSD_{(0.05)}$	12	NS

Appendix Table 22. Translocation of ^{14}C-glyphosate to corms of well-established tuber oatgrass at different growth stages.

Plant parts	^{14}C-accumulation	
	Experiment 1	Experiment 2
	---------(% of absorbed)----------	
Corms on treated shoot		
2- to 3-leaf stage	12.3	18.6
4- to 5-leaf stage	7.5	21.5
6- to 7-leaf stage	12.9	23.7
$LSD_{(0.05)}$	NS	NS
Dormant corms		
2- to 3-leaf stage	7.1	5.8
4- to 5-leaf stage	4.6	5.7
6- to 7-leaf stage	1.6	6.0
$LSD_{(0.05)}$	NS	NS

Appendix Table 23. Distribution of ^{14}C-glyphosate in well-established tuber oatgrass at different growth stages.

Plant parts	^{14}C-glyphosate accumulation	
	Experiment 1	Experiment 2
Treated leaf	---------(% of absorbed)---------	
2- to 3-leaf stage	46	47
4- to 5-leaf stage	72	60
6- to 7-leaf stage	71	43
$LSD_{(0.05)}$	21	NS
Remainder of treated shoot		
2- to 3-leaf stage	71	76
4- to 5-leaf stage	82	87
6- to 7-leaf stage	88	73
$LSD_{(0.05)}$	12	NS
Untreated shoots		
2- to 3-leaf stage	5	5
4- to 5-leaf stage	2	1
6- to 7-leaf stage	1	4
$LSD_{(0.05)}$	NS	NS
Roots		
2- to 3-leaf stage	17	13
4- to 5-leaf stage	10	7
6- to 7-leaf stage	11	17
$LSD_{(0.05)}$	NS	NS

Appendix Table 24. Translocation of glyphosate in well-established tuber oatgrass at different growth stages (Experiment 1).

Plant parts	Dry weight (g)	DPM	DPM/MG	Trans
	Replication I			
2- to 3-leaf stage				
treated leaf	0.0210	79715	3796	
remainder of treated shoot	0.0835	12690	152	14.6
corms on treated shoot	0.0653	11487	176	13.2
buds on corms on treated shoot	0.0047	1595	339	1.8
underground parts	5.9427	9976	2	11.5
buds on underground part	0.0373	415	11	0.5
untreated shoots	1.0661	16587	16	19.1
roots	6.1175	33885	6	39.1
original corm	0.0438	100	2	0.1
leaf wash		264160		
4- to 5-leaf stage				
treated leaf	0.0290	125352	4322	
remainder of treated shoot	0.2186	545	2	1.2
corms on treated shoot	0.3744	4313	12	9.7
buds on corms on treated shoot	0.0087	2064	237	4.6
underground parts	7.5339	8676	1	19.4
buds on underground part	0.0526	682	13	1.5
untreated shoots	1.0269	5364	5	12.0
roots	5.3290	22763	4	51.0
original corm	0.1913	213	1	0.5
leaf wash		246160		
6- to 7-leaf stage				
treated leaf	0.0722	126139	1747	
remainder of treated shoot	0.6912	7280	11	14.1
corms on treated shoot	0.8217	16925	21	32.8
buds on corms on treated shoot	0.0039	465	119	0.9
underground parts	4.4237	1265	0	2.4
buds on underground part	0.0204	402	20	0.8
untreated shoots	1.6238	1364	1	2.6
roots	5.5181	23929	4	46.3
original corm	0.0488	10	0	0.0
leaf wash		208960		

Appendix Table 24. (continued)

Plant parts	Dry weight (g)	DPM	DPM/MG	Trans
		Replication II		
2- to 3-leaf stage				
treated leaf	0.0145	140591	9696	
remainder of treated shoot	0.0661	37456	567	40.4
corms on treated shoot	0.0442	12127	274	13.1
buds on corms on treated shoot	0.0032	2786	871	3.0
underground parts	3.1809	5397	2	5.8
buds on underground part	0.0186	970	52	1.0
untreated shoots	0.0531	4874	92	5.3
roots	1.4036	29005	21	31.3
original corm	0.0640	66	1	0.1
leaf wash		209200		
4- to 5-leaf stage				
treated leaf	0.0361	105561	2924	
remainder of treated shoot	0.2814	5738	20	11.8
corms on treated shoot	0.4580	14373	31	29.6
buds on corms on treated shoot	0.0058	1644	283	3.4
underground parts	7.2594	5875	1	12.1
buds on underground part	0.0206	165	8	0.3
untreated shoots	0.7022	2623	4	5.4
roots	4.3415	18194	4	37.4
original corm	0.0395	0	0	0.0
leaf wash		297200		
6- to 7-leaf stage				
treated leaf	0.0583	177479	3044	
remainder of treated shoot	0.4146	3496	8	5.6
corms on treated shoot	1.0000	48533	49	77.7
buds on corms on treated shoot	0.0081	1384	171	2.2
underground parts	4.4015	3800	1	6.1
buds on underground part	0.0400	211	5	0.3
untreated shoots	0.2523	120	0	0.2
roots	2.0225	4886	2	7.8
original corm	0.0407	0	0	0.0
leaf wash		187680		

Appendix Table 24. (continued)

Plant parts	Dry weight (g)	DPM	DPM/MG	Trans
		Replication III		
2- to 3-leaf stage				
treated leaf	0.0233	34048	1461	
remainder of treated shoot	0.0644	14869	231	19.2
corms on treated shoot	0.0670	22791	340	29.5
buds on corms on treated shoot	0.0022	1528	695	2.0
underground parts	4.3227	11653	3	15.1
buds on underground part	0.0613	2153	35	2.8
untreated shoots	0.3283	1806	6	2.3
roots	4.2278	22440	5	29.0
original corm	0.0523	94	2	0.1
leaf wash		210400		
4- to 5-leaf stage				
treated leaf	0.0310	85164	2747	
remainder of treated shoot	0.1447	932	6	3.3
corms on treated shoot	0.3852	8228	21	29.3
buds on corms on treated shoot	0.0068	1178	173	4.2
underground parts	10.4652	4070	0	14.5
buds on underground part	0.0750	913	12	3.2
untreated shoots	1.1693	2969	3	10.6
roots	3.3781	9791	3	34.8
original corm	0.0347	24	1	0.1
leaf wash		346560		
6- to 7-leaf stage				
treated leaf	0.0520	86161	1657	
remainder of treated shoot	0.6509	8597	13	21.0
corms on treated shoot	0.5074	9409	19	23.0
buds on corms on treated shoot	0.0066	919	139	2.2
underground parts	6.4444	2478	0	6.1
buds on underground part	0.0546	60	1	0.1
untreated shoots	3.6461	847	0	2.1
roots	4.0266	18577	5	45.4
original corm	0.0000	0	0	0.0
leaf wash		303920		

Appendix Table 25. Translocation of ^{14}C-glyphosate in well-established tuber oatgrass at different growth stages (Experiment 2).

Plant parts	Dry weight (g)	DPM	DPM/MG	Trans
	Replication I			
2- to 3-leaf stage				
treated leaf	0.0290	55621	1918	
remainder of treated shoot	0.0908	46570	513	24.3
corms on treated shoot	0.0296	21684	733	11.3
buds on corms on treated shoot	0.0018	3677	2043	1.9
underground parts	2.2717	23677	10	12.3
buds on underground part	0.0113	1206	107	0.6
untreated shoots	1.0316	17644	17	9.2
roots	1.3263	77274	58	40.3
original corm	0.0278	60	2	0.0
leaf wash		126720		
4- to 5-leaf stage				
treated leaf	0.0648	97193	1500	
remainder of treated shoot	0.3646	9907	27	15.7
corms on treated shoot	0.2479	32731	132	51.9
buds on corms on treated shoot	0.0045	1408	313	2.2
underground parts	8.5348	7371	1	11.7
buds on underground part	0.0331	562	17	0.9
untreated shoots	0.5410	807	1	1.3
roots	5.6261	10219	2	16.2
original corm	0.0493	22	0	0.0
leaf wash		278080		
6- to 7-leaf stage				
treated leaf	0.0308	43374	1408	
remainder of treated shoot	0.2458	5604	23	7.9
corms on treated shoot	0.0876	28694	328	40.7
buds on corms on treated shoot	0.0015	1852	1235	2.6
underground parts	1.0768	2122	2	3.0
buds on underground part	0.0111	19	2	0.0
untreated shoots	1.7761	1398	1	2.0
roots	0.6317	30752	49	43.6
original corm	0.0133	83	6	0.1
leaf wash		261840		

Appendix Table 25. (continued)

Plant parts	Dry weight (g)	DPM	DPM/MG	Trans
		Replication II		
2- to 3-leaf stage				
treated leaf	0.0265	73124	2759	
remainder of treated shoot	0.0393	0	0	0.0
corms on treated shoot	0.0130	41394	3184	77.0
buds on corms on treated shoot	0.0002	2821	14105	5.2
underground parts	4.9672	5378	1	10.0
buds on underground part	0.0303	971	32	1.8
untreated shoots	0.4058	566	1	1.1
roots	5.1310	2651	1	4.9
original corm	0.0091	0	0	0.0
leaf wash		215920		
4- to 5-leaf stage				
treated leaf	0.0270	75962	2813	
remainder of treated shoot	0.0983	0	0	0.0
corms on treated shoot	0.1184	20107	170	60.1
buds on corms on treated shoot	0.0024	1542	643	4.6
underground parts	3.3241	4858	1	14.5
buds on underground part	0.0342	591	17	1.8
untreated shoots	0.6243	403	1	1.2
roots	0.9465	5863	6	17.5
original corm	0.0304	67	2	0.2
leaf wash		315200		
6- to 7-leaf stage				
treated leaf	0.0427	98597	2309	
remainder of treated shoot	0.3977	0	0	0.0
corms on treated shoot	0.1177	45323	385	39.4
buds on corms on treated shoot	0.0013	923	710	0.8
underground parts	0.4567	24555	54	21.3
buds on underground part	0.0100	495	50	0.4
untreated shoots	0.9074	16727	18	14.5
roots	0.2585	26991	104	23.5
original corm	0.0368	17	0	0.0
leaf wash		173600		

Appendix Table 25. (continued)

Plant parts	Dry weight (g)	DPM	DPM/MG	Trans
		Replication III		
2- to 3-leaf stage				
treated leaf	0.0200	57160	2858	
remainder of treated shoot	0.0567	13867	241	36.0
corms on treated shoot	0.0305	9978	327	25.9
buds on corms on treated shoot	0.0002	216	1080	0.6
underground parts	4.8678	2100	0	5.5
buds on underground part	0.0534	104	2	0.3
untreated shoots	0.7865	7502	10	19.5
roots	2.0524	4728	2	12.3
original corm	0.0388	13	0	0.0
leaf wash		328880		
4- to 5-leaf stage				
treated leaf	0.0300	96116	3204	
remainder of treated shoot	0.1757	22135	126	22.2
corms on treated shoot	0.1327	43266	326	43.4
buds on corms on treated shoot	0.0039	2253	578	2.3
underground parts	1.9531	13058	7	13.1
buds on underground part	0.0198	1324	67	1.3
untreated shoots	0.2511	1125	4	1.1
roots	1.1435	16479	14	16.5
original corm	0.0272	1	0	0.0
leaf wash		227360		
6- to 7-leaf stage				
treated leaf	0.0221	85907	3887	
remainder of treated shoot	0.2142	22163	103	21.6
corms on treated shoot	0.1315	39455	300	38.5
buds on corms on treated shoot	0.0034	3196	940	3.1
underground parts	1.9784	7787	4	8.0
buds on underground part	0.0368	588	16	0.6
untreated shoots	2.0688	5867	3	5.7
roots	0.6758	23492	35	22.9
original corm	0.0000	0	0	0.0
leaf wash		236480		