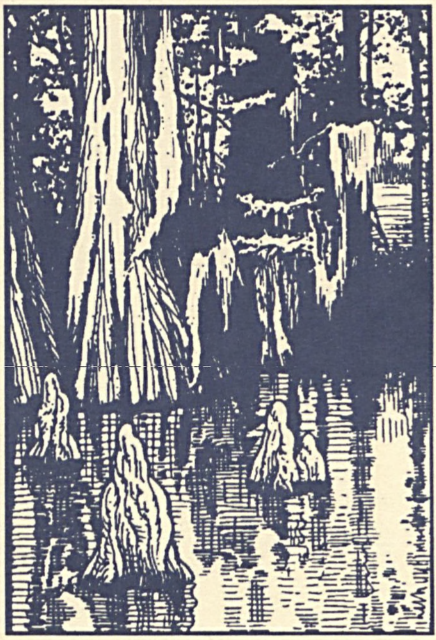
US Army Corps
of Engineers
Waterways Experiment
Station

Wetlands Research Program Technical Report WRP-SM-8

Management of Shallow Impoundments to Provide Emergent and Submergent Vegetation for Waterfowl

by Len G. Polasek, Milton W. Weller, K. C. Jensen



October 1995 – Final Report

Wetlands Research Program

Technical Report WRP-SM-8
October 1995

Management of Shallow Impoundments to Provide Emergent and Submergent Vegetation for Waterfowl

by Len G. Polasek, Milton W. Weller

Department of Wildlife and Fisheries Sciences
Texas A&M University
College Station, TX 77843-2258

K. C. Jensen

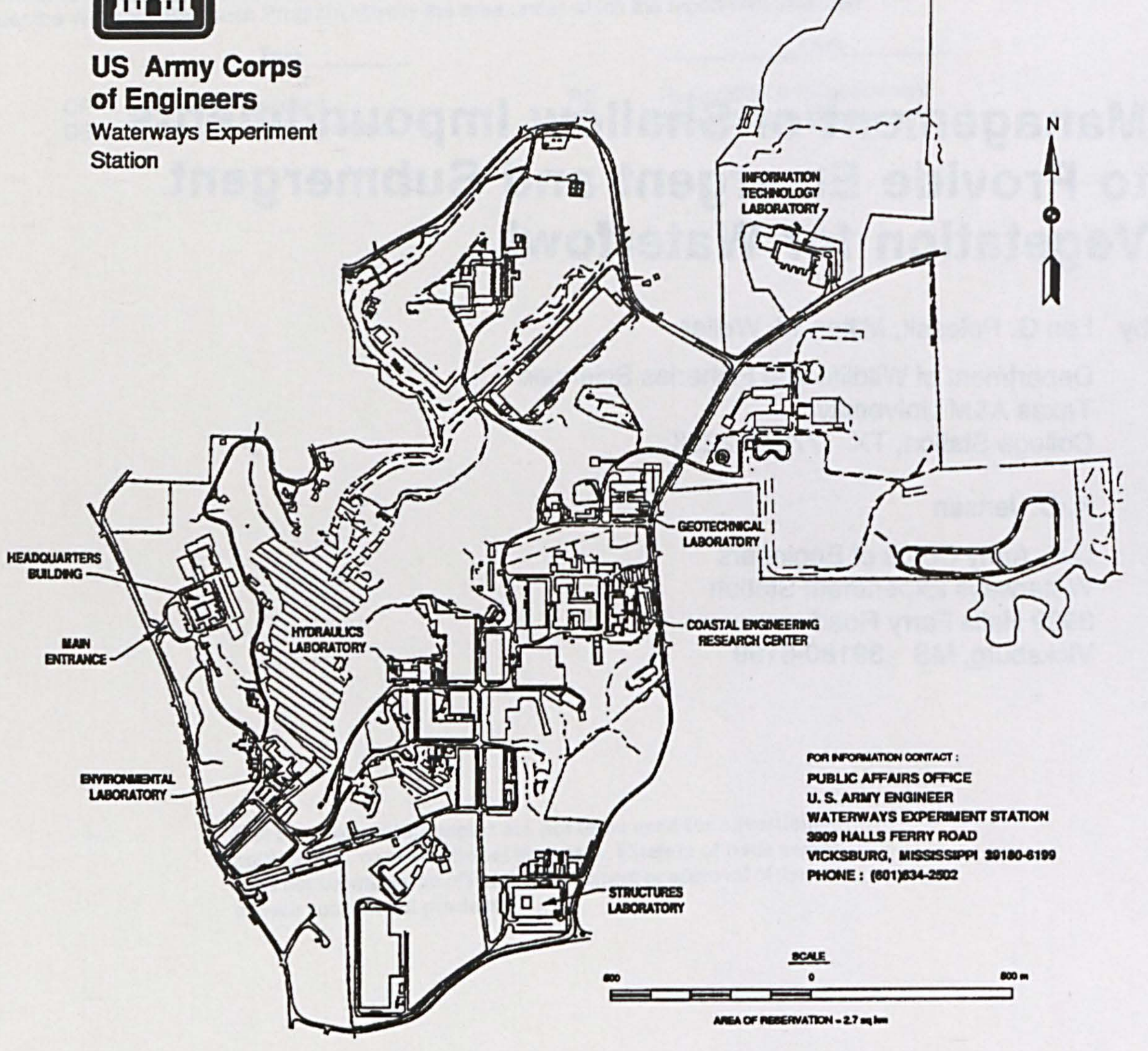
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

US Army Corps of Engineers
Waterways Experiment Station



Waterways Experiment Station Cataloging-in-Publication Data

Polasek, Len G.

Management of shallow impoundments to provide emergent and submergent vegetation for waterfowl / by Len G. Polasek, Milton, W. Weller, K.C. Jensen ; prepared for U.S. Army Corps of Engineers.

82 p. : ill. ; 28 cm. -- (Technical report ; WRP-SM-8) (Wetlands Research Program technical report ; WRP-SM-8)

Includes bibliographic references.

1. Waterfowl management. 2. Effect of reservoir drawdown on reservoir plants. 3. Waterfowl -- Habitat -- Management. 4. Aquatic plants. I. Weller, Milton Webster. II. Jensen, K. C. III. United States. Army. Corps of Engineers. IV. U.S. Army Engineer Waterways Experiment Station. V. Wetlands Research Program (U.S.) VI. Title. VII. Series: Wetlands Research Program technical report ; WRP-SM-8. VIII. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; WRP-SM-8.

TA7 W34 no.WRP-SM-8

Wetland Management for Waterfowl

Management of Shallow Impoundments to Provide Emergent and Submergent Vegetation for Waterfowl (WRP-SM-8)

ISSUE:

Moist-soil management is a strategy of food production involving dewatering lowlands during the germination and growing season, followed by winter reflooding to allow waterfowl access to food produced in the area. Most moist-soil research has been conducted in the Upper Midwest, and little is known or published about the effectiveness of this technique in the southcentral United States where the growing season is long, the climate is warmer, and southern plant assemblages are involved.

RESEARCH:

Research was conducted at the U.S. Army Engineer Waterways Experiment Station, Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, TX, to determine (a) the seed bank response to three water regimes created by a partial drawdown on ponds, (b) the effect of soil disturbance (disking and tilling) on emergent and submergent plants, and (c) the effect of season of drawdown on emergent and submergent plant growth. Four experimental ponds at LAERF were used (three treatment and one control). Tilled strips were established within each experimental pond, and drawdown experiments were conducted using the precise water level control capabilities of LAERF. Ponds were under drawdown conditions during two late-summer/early-fall seasons (24 August to 17 December 1992 and 23 August to 15 November 1993) and one spring season (5 April to 20 August 1993).

SUMMARY:

Species composition, percent cover (PC), and aboveground biomass (AGB) revealed that partial drawdowns on LAERF ponds produce a typical zonation of wetland plants. Taxon richness of emergent plants was highest in the dewarered zones. Soil disturbance with rototilling created diversity in ponds by increasing taxon richness of emergent plants, encouraging annuals, and discouraging perennial plant growth. Most submergent macrophytes were unaffected by tilling. Drawdown season did not affect taxon richness of emergent plants within dewatered zones, but forb and sedge PC and AGB and grass AGB were highest during spring drawdown.

AVAILABILITY OF REPORT:

This report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, telephone (601) 634-2355.

To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4650. For help in identifying a title for sale, call (703) 487-4780. NTIS report numbers may also be requested from the WES librarians.

About the Authors:

Mr. Len G. Polasek was a Master of Science candidate at Texas A&M University and is now employed at Fort Campbell, KY. Dr. Milton W. Weller holds the Ceasar Kleberg Chair of Wildlife Ecology in the Department of Wildlife and Fisheries Sciences, Texas A&M University. Dr. K. C. Jensen is a wildlife ecologist from the WES Environmental Laboratory. Point of contact is Dr. Jensen at (601)634-3047.

Contents

List of Figures

List of Tables

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Critical Processes Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32766, "Stewardship and Management Demonstration Studies," for which Mr. Chester O. Martin was Technical Manager. Ms. Denise White (CECW-ON) was the WRP Technical Monitor for this work.

Mr. Dave Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitors' Representative; Dr. Russell F. Theriot, U.S. Army Engineer Waterways Experiment Station (WES), was the Wetlands Program Manager. Mr. Chester O. Martin, WES, was the Task Area Manager.

This report was prepared by Mr. Len G. Polasek, Dr. Milton W. Weller, Department of Wildlife and Fisheries Sciences, Texas A&M University (TAMU), and Dr. K. C. Jensen, Stewardship Branch (SB), Natural Resources Division (NRD), Environmental Laboratory (EL), WES, under the general supervision of Mr. Hollis H. Allen, Acting Chief, SB, EL, and Dr. Robert M. Engler, Chief, NRD, EL. Dr. Edwin A. Theriot was the Assistant Director, EL, and Dr. John W. Keeley was Director, EL.

Numerous individuals contributed to this study. Field assistance was provided by Drs. R. Michael Smart, John D. Madsen, and Gary O. Dick of the U.S. Army Engineer Waterways Experiment Station, Lewisville Aquatic Ecosystem Research Facility (LAERF). Mr. Mike Crouch, Mr. Chris Houtchens, Mr. Stephen Wood, Mr. Joe Snow, Mr. Mathew Haynes, Mr. Marty Sewell, Ms. Kimberly Hodson, LAERF, and Mr. James Thomas, TAMU, also provided much needed and appreciated field assistance. Drs. Nova J. Silvy and Murray H. Milford, TAMU, offered thoughtful reviews of the manuscript, and Drs. Omer C. Jenkins and Michael T. Longnecker, TAMU, provided advice and assistance with statistical analyses. Drs. James S. Wakeley and Richard A. Fischer and Mr. Chester O. Martin reviewed and improved the manuscript.

At the time of publication of this report, the Director of WES was Dr. Robert W. Whalin. The Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

Polasek, L. G., Weller, M. W., and Jensen, K. C. (1995). "Management of shallow impoundments to provide emergent and submergent vegetation for waterfowl," Technical Report WRP-SM-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

1 Introduction and Objectives

Research on habitat requirements of wintering waterfowl has increased in the last three decades because of concern over loss of habitat (White and James 1978; Chabreck 1979; Fredrickson and Drobney 1979; Heitmeyer and Vohs 1984; Smith, Pederson, and Kaminski 1989). Texas alone lost 52 percent of its natural wetlands between 1780 and 1980 (Dahl 1990). Although not of equal quality to natural wetlands, man-made reservoirs, flood prevention lakes, and farm ponds in north-central Texas are used by significant numbers of wintering waterfowl (Hobaugh and Teer 1981; Texas Parks and Wildlife Department 1982). In addition, many waterfowl managers throughout the United States construct moist-soil units to provide supplemental food sources for waterfowl.

Moist-soil management is a strategy of food production involving dewatering lowlands during the germination and growing season, followed by winter reflooding to allow waterfowl access to food produced in the area (Givens and Atkenson 1957; Bellrose and Low 1978; Fredrickson and Taylor 1982). Traditional moist-soil units consist of shallow basins with gradual slopes (Fredrickson and Taylor 1982). Typically, these units are dewatered to mud flat conditions to induce the germination of annual emergent plants. Plants commonly found in moist-soil units include several species of barnyard grass (*Echinochloa* spp.), smartweed (*Polygonum* spp.), and panic grass (*Panicum* spp.) (Fredrickson and Taylor 1982). Seeds of these plants are important food sources for waterfowl (Martin, Zim, and Nelson 1951). If available, exploitation of the native seed bank can be cheaper than artificial planting and can produce plants that are adapted to the local climate (van der Valk and Pederson 1989; Weller 1990).

Much of the research and experimentation with moist-soil management and drawdowns, whether natural or artificial, has been done in the Upper Midwest (Kadlec 1962; Harris and Marshall 1963; Burgess 1969; Meeks 1969; Weller and Fredrickson 1974). However, little is known and published about the effectiveness of moist-soil management in the south-central United States where the growing season is long, the climate is warmer, and southern plant assemblages are involved. Haukus and Smith (1993) reported that moist-soil management was an effective tool in increasing the seed production and aboveground standing crop of selected waterfowl food plants within playa lakes in the panhandle of Texas.

Previous studies on migrant and wintering waterfowl revealed partitioning of feeding locations among water depths and emergent and submergent plant communities (White and James 1978; Chabreck 1979; Paulus 1982; DeRoia 1993). Although traditional moist-soil management solely encourages annual emergent plant production, previous research also showed that a partial drawdown on a lake produced emergents in dewatered zones while maintaining submergent plants in flooded regions (Kadlec 1962; Harris and Marshall 1963). Consideration must be given to impoundment design and drawdown extent to provide a mixture of water depths and emergent and submergent vegetation to satisfy a greater number of waterfowl species.

Soil disturbance is a common technique used to alter the composition and distribution of plants in natural wetlands and moist-soil units. Disking and tilling eliminate unwanted woody plants such as willow (*Salix* spp.) and cottonwood (*Populus* spp.), set back succession to annual emergents (Fredrickson and Taylor 1982; Reid et al. 1989), and decrease potential plant competition (Brumsted and Hewitt 1952). In addition, soil disturbance can be used to maintain heterogeneity of plant species and proper cover-to-water ratios within a wetland (Fredrickson and Reid 1988b; Kirkman and Sharitz 1994).

The following objectives and corresponding null hypotheses were formulated to achieve a better understanding of moist-soil management strategies in north-central Texas.

a. Determine seed bank response to three water regimes created by a partial drawdown.

H_o: Taxon richness, percent cover, seed production, and aboveground biomass (AGB) of emergents will not differ among three water regimes within a pond during partial drawdown.

b. Compare the response of disturbed and undisturbed seed banks.

H_o: Taxon richness, percent cover, seed production, and AGB of emergents and submergents will not differ between disturbed and undisturbed plots.

c. Compare spring versus late-summer/early-fall drawdowns in stimulating food production for migrant and wintering waterfowl.

H_o: Taxon richness, percent cover, seed production, and AGB of emergents and submergents will not differ between spring drawdown and late-summer/early-fall drawdowns.

d. Determine patterns of resource partitioning by waterfowl.

H_o: Waterfowl species and numbers will not differ between water depths and emergent and submergent plant communities.

2 Study Area and Pond Design

Research was conducted at the U.S. Army Engineer Waterways Experiment Station, Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, TX. The facility is located along the boundary of the cross timbers and prairies and the blackland-prairies vegetational regions of Denton County in north-central Texas (Gould 1975a). Owenby and Ezell (1992) list the normal and median annual precipitations for Denton County as 94.67 and 89.87 cm, respectively, with highest monthly precipitation in May. The growing season is a 226-day, freeze-free period from approximately 27 March to 8 November (Ford and Pauls 1980).

The Texas Parks and Wildlife Department operated the facility as a fish hatchery between 1956 and 1985.[1] The U.S. Army Engineer District, Fort Worth, maintained the facility from 1985 to 1988, but the ponds were dry except for precipitation. In 1989, an agreement was reached between the Fort Worth District and the U.S. Army Engineer Waterways Experiment Station to operate the facility for aquatic plant research.

The LAERF maintains 53 experimental ponds ranging from 0.20 to 0.79 ha. Each pond is equipped with a gravitational water-flow system that receives water from adjacent Lewisville Lake. A cast-iron inflow valve is used to control the amount of water entering any one pond. Water is maintained at a constant level in a pond by placing a 10.16-cm- (4-in.-) diam polyvinyl chloride (PVC) stand pipe even with the desired water level in a pond (Figure 1).

Four of the fifty-three ponds on the facility were used for experimentation from July 1992 to March 1994. Soils within the ponds were comprised of a sandy clay-loam texture (Appendix A). The four ponds went through various periods of flooding and drawdown (1989-1992) with the last inundation for 71 days during the winter of 1991. Prior to project initiation, the ponds were dry and periodically mowed to control weeds. These conditions provided terrestrial or moist-soil conditions that predominantly supported grasses,

---

[1] Personal Communication, November 1993, Gary O. Dick, Ecologist, LAERF, Lewisville, TX.

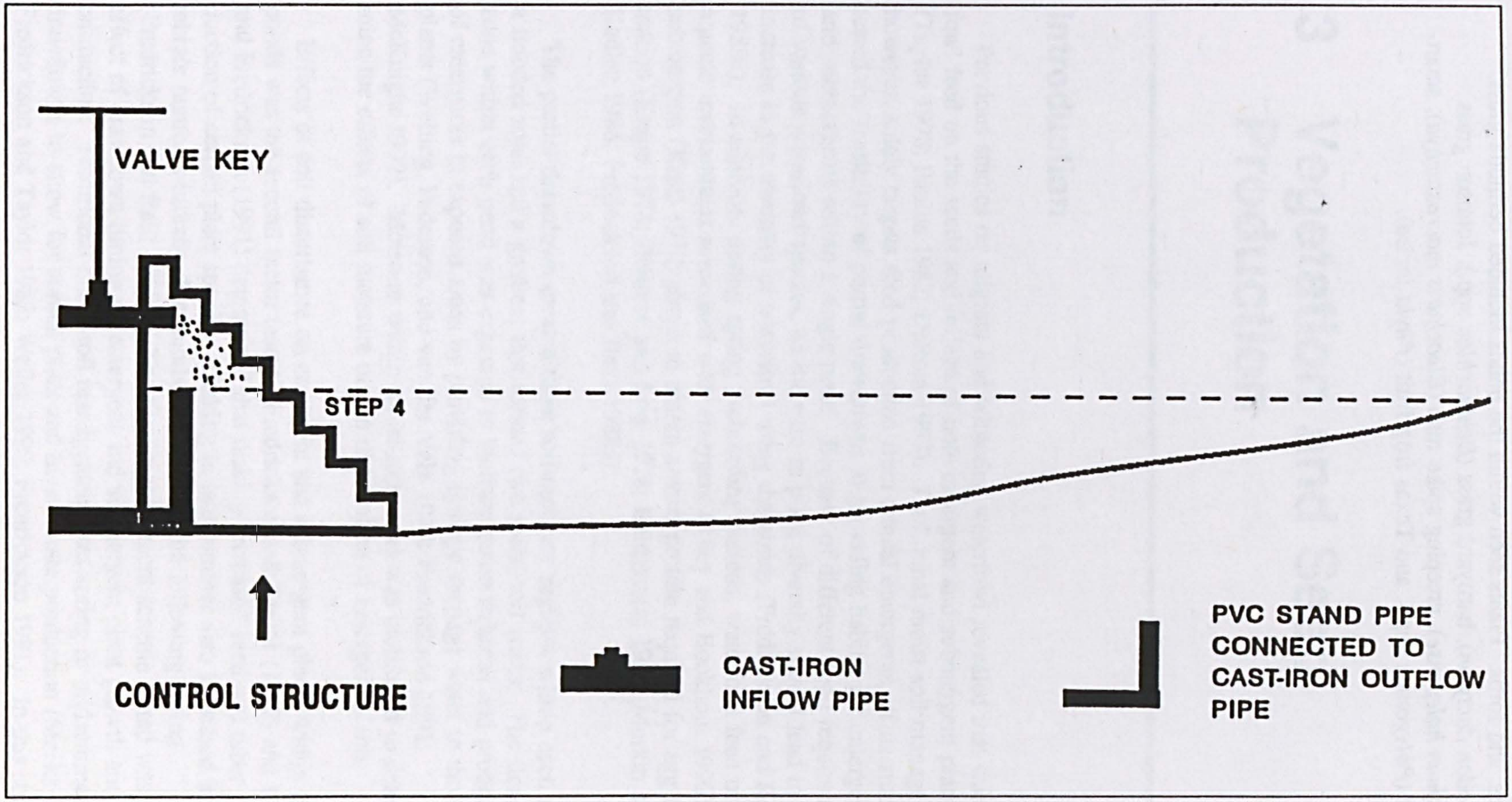


Figure 1. Cross-sectional view of water-control structure used in 1992 and 1993 studies on shallow-pond management in Lewisville, TX

sedges, and forbs. Plants seen within the ponds included bermuda grass (*Cynodon dactylon*), barnyard grass (*Echinochloa* spp.), Johnson grass (*Sorghum halepense*), creeping spike rush (*Eleocharis macrostachya*), smartweed (*Polygonum* spp.), and Texas frog fruit (*Phyla incisa*).

3 Vegetation and Seed Production

Introduction

Previous studies on migrant and wintering waterfowl revealed that waterfowl feed on the seeds and foliage of both emergent and submergent plants (Taylor 1978; Paulus 1982; DeRoia 1993). Traditional moist-soil management, however, solely targets seed production from annual emergents. This study tested the feasibility of partial drawdowns in providing habitat for emergents and submergents within a single pond. Because of different food requirements of various waterfowl species, an increase in plant diversity should lead to an increase in the diversity of waterfowl using the ponds (Fredrickson and Reid 1988c). In addition, during spring prebreeding periods, waterfowl feed on aquatic invertebrates associated with emergent (Riley and Bookhout 1990) and submergent (Krull 1970) plants to obtain animal protein required for egg formation (Krapu 1974; Bellrose and Low 1978; Baldassarre 1980; Murkin and Kadlec 1986; Fredrickson and Reid 1988a).

The partial drawdown created three soil-moisture regimes within each pond: a flooded zone and a gradient that formed two moist-soil zones. The flooded zone within each pond was expected to increase taxon richness and production of emergents in exposed areas by providing upslope seepage water to those plants (Welling, Pederson, and van der Valk 1988; Fredrickson 1991; McKnight 1992). Moisture within moist-soil zones was monitored to determine the effects of soil moisture on the distribution of emergent plants.

Effects of soil disturbance on emergent and submergent plants within the ponds was the second factor tested. Fredrickson and Taylor (1982) and Kelley and Fredrickson (1991) determined that disking increased seed and tuber production of certain plant species. Disking in late summer also increased invertebrate numbers initially, but numbers decreased the following spring (Fredrickson and Reid 1988a). The final management scheme tested was the effect of drawdown timing on emergent and submergent plant growth and seed production. Traditional moist-soil management uses spring or midsummer drawdowns to allow for annual plant and invertebrate production (Meeks 1969; Fredrickson and Taylor 1982; Weller 1990; Fredrickson 1991). In this study, plant production was compared between two late-summer/early-fall (LSEF) drawdowns and a single spring (SPG) drawdown. The long growing season in Texas allowed for the germination and production of emergent and submergent plants during LSEF drawdowns. LSEF drawdowns allowed plants in the ponds to drop their seeds just prior to the time of reflooding for waterfowl use.

Methods

Pond morphology

Four 0.28-ha ponds were used for experimentation: one randomly selected control and three replicate treatments. All four ponds received the same pre-flood treatment. A transit and rod were used to approximate the location of the water's edge when levels were raised to a predetermined level on the control structure. Step 6 of the control structure was the highest water level used in the experiment and marked the uppermost boundary for the experimentation of moist-soil management for emergents. Step 6 was located by numbering the steps from the bottom to the top of the control structure. Distance was measured from the end of the concrete control structure to the step 6 water level opposite the dam (Figure 2a). The distance was permanently marked to serve as a midline for each pond. Ponds were divided into three equal areas based upon the length of the midline (Figure 2b). Midlines of the ponds were used to divide the two more uniform areas near the dam into halves, creating four study blocks within each pond (Figure 2c).

Experimental design

Statistical design and analyses. A split-split plot experimental design was applied to the ponds to meet the three vegetation objectives. Whole plots were soil-moisture regimes, split plots were tillage treatments, and split-split plots were drawdown timings. Individual ponds served as replicates.

Data were tested for statistical normality with the Shapiro-Wilk statistic and box plots (SAS Institute, Inc. 1987); nonnormal data were transformed by $\log_{10}(x + 1)$. Analysis of variance (PROC GLM, SAS Institute, Inc. 1987) was then used to test for differences ($\alpha = 0.05$) in response variables because of soil-moisture regime, tillage application, drawdown timing, and their 2-way interactions. Tukey's test (SAS Institute, Inc. 1987) and the least significant difference (LSD) test (Gomez and Gomez 1984:204-207) were used for mean separation ($\alpha = 0.05$) in response variables within main effects and interactions, respectively.

Drawdown application. The highest water level used in the ponds during the experiment was at step 6 on the control structure. At step 6 level, ponds averaged 91.3 cm at their deepest locations near the control structures. Under

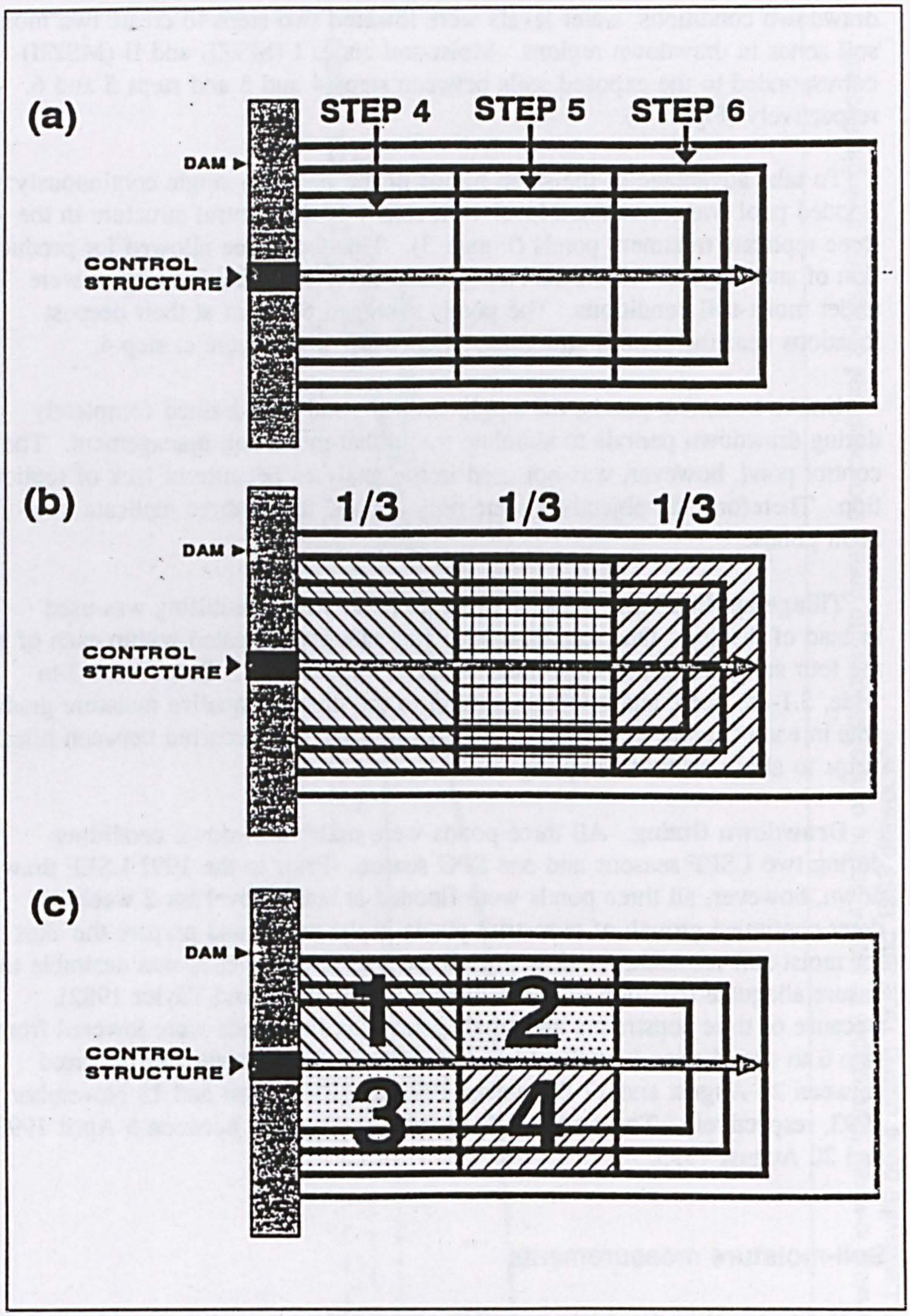


Figure 2. Lewisville ponds were divided at three levels based on morphology: (a) midline creation between control structure and step 6 water line, (b) division of water area into three equal regions based upon midline length, and (c) division of the two more uniform areas within each pond into four equal study blocks

drawdown conditions, water levels were lowered two steps to create two moist-soil zones in drawdown regions. Moist-soil zones I (MSZI) and II (MSZII) corresponded to the exposed soils between steps 4 and 5 and steps 5 and 6, respectively (Figure 3).

To take advantage of the steep basins of the ponds, a single continuously flooded pool was maintained level with step 4 of the control structure in the three replicate treatment ponds (Figure 3). This technique allowed for production of submergents within the step 4 water level while basin margins were under moist-soil conditions. The ponds averaged 61.3 cm at their deepest locations near the control structures when water levels were at step 4.

Unlike treatment ponds, the single control pond was drained completely during drawdown periods to simulate traditional moist-soil management. The control pond, however, was not used in the analyses because of lack of replication. Therefore, the objectives were only applied to the three replicate treatment ponds.

Tillage application. Because of small pond sizes, rototilling was used instead of disking. One rototilled strip was randomly located within each of the four study blocks of each pond in early August 1992. Strips were 3-m wide, 5.1-cm deep, and oriented parallel to the dam to equalize moisture gradients in each (Figure 4). A buffer zone of at least 1 m occurred between tilled strips to allow walk-in sampling.

Drawdown timing. All three ponds were under drawdown conditions during two LSEF seasons and one SPG season. Prior to the 1992 LSEF drawdown, however, all three ponds were flooded at step 6 level for 2 weeks to deter continued growth of terrestrial plants in the ponds and prepare the sites for moist-soil research. A slow drawdown over 2 to 3 weeks was desirable to ensure adequate retention of soil moisture (Fredrickson and Taylor 1982). Because of time constraints and small pond size, the ponds were lowered from step 6 to step 4 over 1 week. First and second LSEF drawdowns occurred between 24 August and 17 December 1992 and 23 August and 15 November 1993, respectively. The single SPG drawdown occurred between 5 April 1993 and 20 August 1993.

Soil-moisture measurements

Field capacity. Fredrickson and Taylor (1982) reported that viable seeds germinate when soil moisture is at or slightly below field capacity. Therefore, attempts were made to maintain soil-moisture near this level. The percentage of water remaining in the soil 3 hr after saturation and free drainage was used as an estimate of field capacity. Measurements were conducted on 18 September 1992 and 27 May 1993. During September 1992, four samples were collected randomly from MSZII in each pond; two from tilled (T) and two from nontilled (NT) plots. During May 1993 sampling, however, six samples were

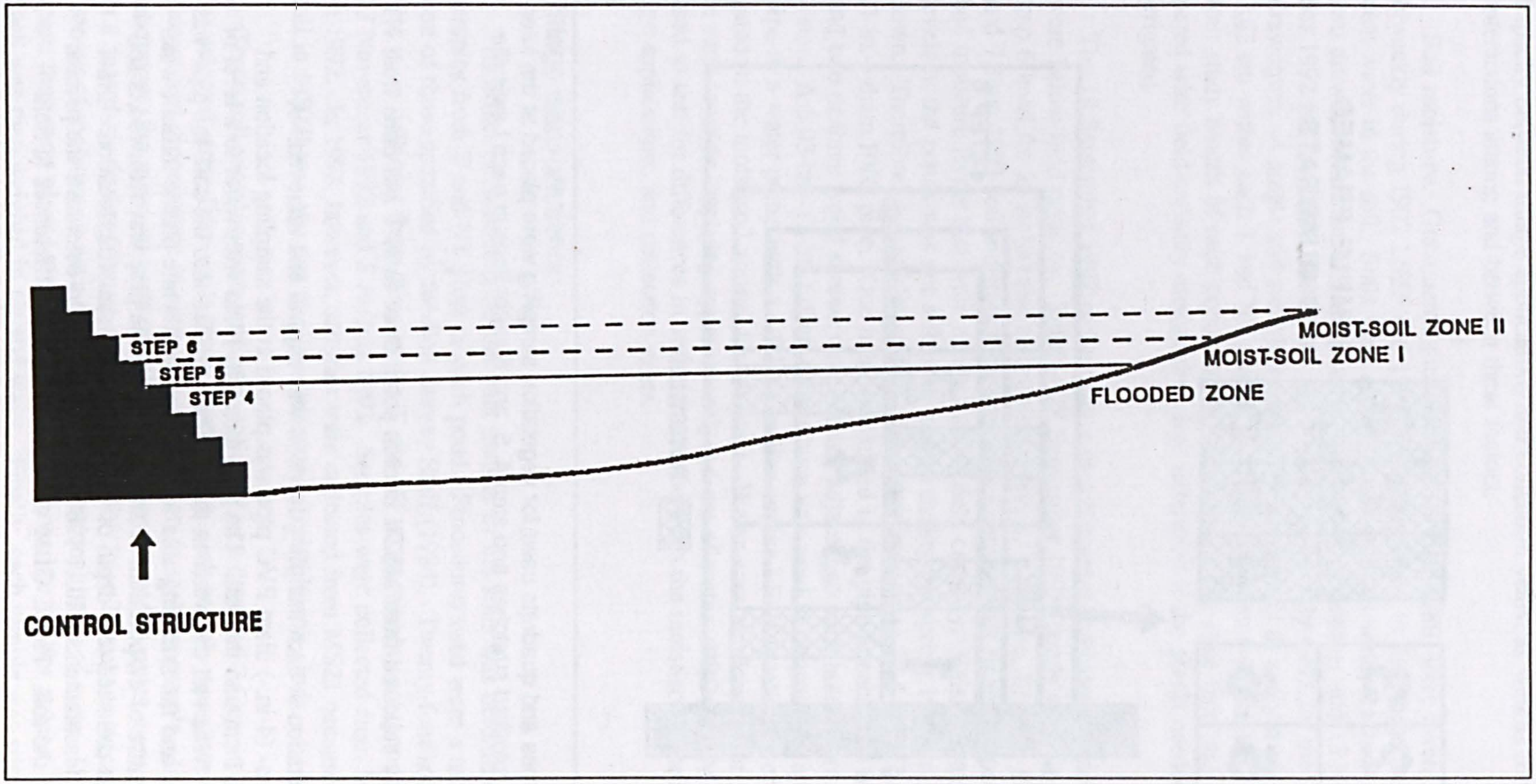


Figure 3. Water levels were lowered from step 6 to step 4 on the control structure to create two moist-soil zones and a single flooded zone in each Lewisville pond during 1992 and 1993 drawdowns

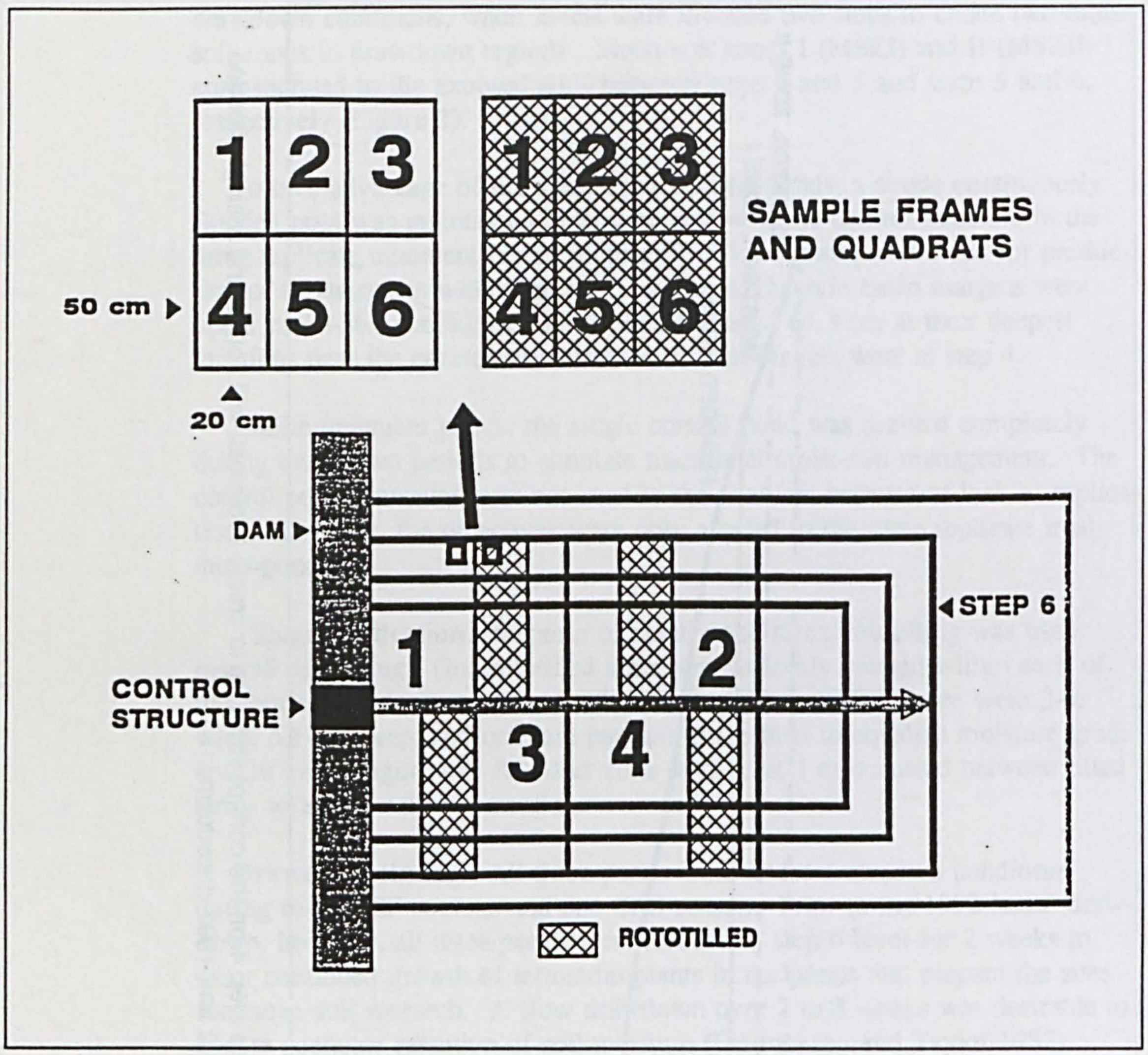


Figure 4. Sample frames and quadrats used for vegetation sampling were placed at the intersections of rototilled stretches and step 4, 5, and 6 water lines in each Lewisville pond

randomly collected from MSZII in each pond; three from T and three from NT plots.

Vegetation at each sampling location was clipped and removed. A 10.16-cm- (4-in.-) diam PVC pipe was placed at the sampling location and inserted 1 cm into the soil. The pipe then was filled with water to a level of 5.1 cm. When all the water in the pipe had drained into the soil, the pipe was removed and the sampling area was covered with white plastic to limit water loss because of evaporation. Three hours after the pipe was removed, a soil plug was collected to a depth of 7.62 cm at each sampling location. Gravimetric measurements (Hillel 1980) then were used to determine the percent water in the soil. PROC GLM was used to test for differences in field capacity between tillage applications and collection years, as well as for interactions among and between these factors.

Soil moisture. Gravimetric measurements (Hillel 1980) were taken biweekly during 1992 LSEF and 1993 SPG drawdowns to determine the percent water in the soil. Soils were sampled on five dates within each of the two drawdowns. Sampling dates were between 18 September and 13 November 1992 for the LSEF drawdown and 11 May and 6 July 1993 for the SPG drawdown. A single soil sample was collected randomly to a depth of 7.62 cm within each T and NT plot of each moist-soil zone within the four study blocks of each pond. Mean soil moisture per zone then was compared with field-capacity measurements to determine if the ponds needed to be irrigated.

The 18 September 1992 soil-moisture measurements indicated the ponds were below field capacity. Starting 28 September 1993, ponds were flooded to step 6 level for 24 hr to raise soil-moisture levels. Likewise, 27 May 1993 and 7 June 1993 soil-moisture measurements indicated that treatment ponds had moisture levels that were nearly half of field capacity. Raising water levels in the ponds was not a feasible option during the spring 1993 drawdown. Therefore, a sprinkler system was constructed from 24.4 m of 2.54-cm- (1-in.-) diam PVC pipe. One hole was drilled in the pipe at each 3-m interval and two or three wood screws were affixed adjacent to each hole to broadcast water. A 5.08-cm- (2-in.-) diam rubber hose was used to connect the sprinkler pipe to a water pump with a 5.0-hp gasoline engine. Five locations were irrigated in the moist-soil zones of each pond. Water was broadcasted for 30 min in each location, applying approximately 2.5 cm of water. PROC GLM was used to test for differences in soil moisture between the moist-soil zones, tillage applications, and collection years.

Tillage measurements

The effect of rototilling on the bulk density of the soils was determined for samples from T and NT plots of each pond. Procedures used were a modification of those specified by the Soil Survey Staff (1984). Twenty-four soil samples were collected from three of the T and NT strips within each pond on 13 November 1992 and 2 August 1993. Samples were collected from MSZII in 1992. In 1993, however, samples were collected from MSZI because the soil in MSZII was too dry to allow retrieval of suitable soil clods.

Three soil samples were randomly collected at a depth of 7.6 cm in each of the selected strips from each pond. In the field, each sample was placed in a hairnet and dipped once in saran-solvent solution to seal the sample. In the laboratory, the saran on each sample was punctured, and samples were placed in a forced-air drying oven at approximately 32 °C for 2 weeks to equalize the amount of moisture in each sample. Three additional coats of saran, 15 min apart, then were placed on each sample and allowed to dry for at least 24 hr. Each was then weighed in air and water. Finally, each sample was sliced open, and the contents were washed through a 2-mm sieve to collect coarse fragments. The fragments from each sample then were dried in an oven at 105 °C and weighed. Volume for coarse fragments was calculated by dividing fragment weights by 2.65 (specific gravity of quartz).

Equations used to determine bulk density of the clods followed those specified by the Soil Survey Staff (1984) for oven-dried bulk density measurements. However, only a relative bulk density could be calculated because of lack of weight and volume measurements for the saran. A mean was calculated for the three bulk-density measurements in each chosen strip, pond, and year. PROC GLM was used to test for differences in bulk density between tillage applications and collection years, as well as interactions among and between these factors.

Vegetation sampling

Moist-soil zone. Vegetation sampling was conducted during 4-6 December 1992, 11-14 July 1993, and 5 November 1993 for the first LSEF, SPG, and second LSEF drawdowns, respectively. Plant species lists, percent cover (PC) estimates, and AGB were collected to determine the effects of soil moisture, tillage, and drawdown timing on emergent plant composition and production. Samples were taken in MSZI, MSZII, and just inside the flooded zone to compare emergent vegetation production along a soil-moisture gradient from flooded to dry.

Two permanent 60- by 100-cm sampling frames were placed at the intersections of the tilled strip and the step 4, 5, and 6 water lines within each study block (i.e., one in the T and one in the NT) of the three treatment ponds (Figure 4). The two sampling frames could be located on either side of the T strip. The first random drawing was to determine which side of the T strip the sampling frames would be placed (dam side or opposite-dam side). Each sampling frame was located 50 cm from the respective edge of the T strip. This placement provided a path for data collection at the quadrats and ensured that soil displaced by tilling was not shifted onto NT strips. Each 60- by 100-cm sampling-frame location was marked by placing a single PVC pipe at opposite corners of the frame. Sampling frames then were removed and replaced around the two corner pipes each time data were collected. Each 60- by 100-cm sampling frame was divided into six (20- by 50-cm) individual quadrats (Figure 4). Two of the six quadrats were randomly selected for the collection of vegetation data during each of the three drawdowns. This sampling technique created 16 quadrats within MSZI, MSZII, and the flooded zone of each pond. Equal numbers of samples were taken within T and NT plots.

Plant lists were recorded for each of the sampled quadrats, and a list was determined for individual frames by recording each taxon that occurred in either of the two sampled quadrats. Identification of individual plant taxon followed keys from Correll and Correll (1975) and Gould (1975b). Lists from individual sampling frames were used to determine frequency of occurrence for individual plant taxon within soil-moisture, tillage, and season treatments. Finally, lists from each frame were used with PROC GLM to test for differences in plant taxon richness within each soil-moisture, tillage, and season treatment, as well as interactions between and among these factors.

The Bailey and Poulton (1968) rating scale (Appendix B) was used to estimate the PC for herbaceous vegetation as well as black willow (*Salix nigra*) within the collection quadrats of the three drawdowns. Grasses, sedges, and forbs were not classified to finer levels because measurements were taken after frost when most plants had dropped their seeds. The midpoint of each PC interval was substituted for its corresponding rank. A mean then was calculated for the midpoints of each of the three vegetational categories, cattail (*Typha* sp.), and black willow occurring within the two sampled quadrats from each sampling frame. PROC GLM was used to test for significant differences in the PC of grass, sedge, and forb categories between the three soil-moisture regimes, tillage applications, and drawdown timings, as well as interactions between and among these factors. Cattail and black willow were not analyzed because of low frequencies of occurrence.

In addition to PC, AGB was collected for the grass, sedge, and forb categories, cattail, and black willow during the first LSEF and SPG drawdowns. The four quadrats used for PC estimates in the LSEF and SPG drawdowns were used for AGB collection as well. Vegetation rooted within the 20- by 50-cm quadrats was clipped, placed in labeled paper bags, and dried at 60 °C for 48 hr. Vegetation then was removed from the bags and weighed to the nearest 0.01 g. Mean weights were calculated and converted to grams per square meter for the three vegetational categories, cattail, and black willow occurring within the two sampled quadrats from each sampling frame. Data from each frame were analyzed with PROC GLM for significant differences in AGB within each soil-moisture regime, tillage application, and drawdown timing, as well as interactions between and among these factors. Cattail and black willow, however, were again not analyzed because of low frequencies of occurrence.

Flooded zone. Sampling was conducted on 16 and 17 December 1992, 20 July 1993, and 6 November 1993 for first LSEF, SPG, and second LSEF drawdowns, respectively. Plant lists and PC estimates were collected per taxon to determine the effects of tillage and drawdown timing on emergent and submergent plant composition and production. Twenty-four 20- by 50-cm quadrats were used to estimate PC of plants within the continuously flooded pool of each treatment pond. Three quadrats were used within the four T and four NT strips of each pond. A species list was recorded for each of the three quadrats within a strip, and an overall list was determined for each strip by recording individual plant taxon that occurred in any one of the three sampled quadrats. Lists from individual strips then were used to determine the frequency of occurrence for individual plant taxon within tillage and drawdown timing. Finally, plant lists from each strip were analyzed with PROC GLM for differences in plant taxon richness within tillage applications and drawdown timings, as well as interactions between and among these factors.

PC of each plant taxon was determined within a quadrat using the Bailey and Poulton (1968) rating scale. For statistical analyses, the midpoint of each PC interval was substituted for its corresponding rank. A mean then was calculated for the midpoints of individual plant taxon occurring within the three quadrats of a single stretch. Only individual plant taxon with frequencies above 0.25 for a sampling period were tested. Plant taxa with a majority of frequencies below 0.50 for NT and T plots within a drawdown were $\log_{10}(x + 1)$ transformed to reduce heterogeneity in treatment variances. PROC GLM was used to test for differences in the PC of individual plant taxon within tillage applications and drawdown timings, as well as interactions between and among these factors. If an individual plant taxon did not occur within a drawdown, soil moisture and tillage effects were analyzed in the drawdowns in which it did occur. The effects of drawdown timing were not tested for taxa that occurred only during one drawdown.

Water depths were recorded at three locations within each of the quadrats used for vegetation sampling within the flooded zone. Mean-water depth then was determined at each quadrat location. Spearman's rank correlation (SAS Institute, Inc. 1987) was used to determine potential correlations between the PC of individual plant taxon and mean-water depth within tillage applications and drawdown timings. Only individual plant taxon with frequencies above 0.25 for a sampling period were tested.

Seed collection

Trap construction and placement. Measuring the number of seeds produced by plants is difficult because seed maturation and release from the plant can take place over variable lengths of time (Hutchings 1986). Previous studies used "Tanglefoot" and adhesives to trap seeds (Werner 1975; Huenneke and Graham 1987). Both techniques allowed a count of seeds but not weight since adhesive substances were added to seeds. Johnson and West (1987) tested five seed-trap designs and found that seed traps that mimic soil depressions, (i.e., funnel traps) caught and retained significantly more seeds than four other trap designs. Therefore, standard No. 2 vegetable cans were used for seed traps to allow for a comparison of seed numbers and biomass produced per unit area. Seed traps were attached to wood lathes and covered with hardware cloth to prevent birds and mice from eating the seeds.

Three individual seed traps were randomly placed within the boundaries of each quadrat that was selected for vegetation collection during 1992 LSEF and 1993 SPG drawdowns. Seed traps in the moist-soil and flooded zones stood 2 cm above the soil and water surfaces, respectively, to minimize rusting of the cans. A total of 576 seed traps was used during each of the drawdowns.

Trap collection. Seed traps were collected when most of the plants in each quadrat had dropped their seeds. Collection dates were 25 November 1992 and 7 July 1993 during the first LSEF and SPG drawdowns, respectively. Contents from individual seed traps were washed into coffee filters. Filters and their contents then were placed in labeled whirl-paks and frozen until time of seed identification.

Seed identification. For seed identification, coffee filters and seeds were removed from their whirl-paks and air dried. Seeds were identified to the finest taxonomic level possible based on Martin and Barkley (1961), Delorit (1970), and plant specimens collected on the site. Seed lists were recorded for each trap, and an overall list was determined for the 0.2-m^2 area covered by the two sampled quadrats by recording each taxon that occurred in any one of the six seed traps. Frequency of occurrence was determined within the 0.2-m^2 area for individual taxon within each soil-moisture, tillage, and drawdown timing treatment.

Seed numbers (SN). SN per taxon were counted for each trap, and a mean number was calculated for the six seed traps within each sampling frame. Surface area of seed-trap openings was used to calculate the mean number of seeds/m^2 for each taxon.

Seed biomass. Seeds from each taxon were stored separately by season (first LSEF and SPG). The seeds from each season then were oven-dried to constant weight at 60 °C and weighed to 0.001 g (Appendix C). Mean seed biomass was determined by taking the cumulative weight of a taxon and dividing it by the number of seeds collected for that taxon each season. Individual seed weights for each taxon then were multiplied by the mean number of seeds produced per square meter; thus giving the mean grams per square meter produced for each taxon with frequencies greater than 0.23 for one drawdown timing (Appendix D).

Seed data analysis. SN for identified taxa with frequencies greater than 0.23 for one of the drawdown timings were $\log_{10}(x + 1)$ transformed to reduce heterogeneity in treatment variances. SN data were then analyzed with PROC GLM for differences between soil-moisture, tillage, and drawdown timing treatments, as well as interactions between and among these factors. If seeds from an individual taxon were not trapped during a drawdown or had frequencies below 0.10 for a drawdown, soil moisture and tillage effects were analyzed in the drawdown in which they had been trapped at frequencies above 0.10. The effects of drawdown timing were not tested for taxa that occurred at frequencies below 0.10 during a drawdown.

4 Results

Soil-Moisture and Tillage Measurements

Field capacity did not differ between T and NT plots ($P = 0.78$). However, data from September 1992 did show higher field capacity than did measurements from May 1993 ($\bar{x} = 26.6$ percent, SE = 1.1, $n = 12$ versus $\bar{x} = 22.0$ percent, SE = 1.5, $n = 18$, respectively, $P = 0.01$). The interaction between tillage treatment and sampling date was not significant ($P = 0.93$).

Biweekly measurements were higher ($P = 0.03$) in MSZI ($\bar{x} = 29.7$ percent, SE = 0.6, $n = 120$) than in MSZII ($\bar{x} = 18.9$ percent, SE = 0.6, $n = 120$). T versus NT plots did not show a difference ($P = 0.52$). LSEF 1992 measurements were, however, higher than SPG 1993 measurements ($\bar{x} = 28.8$ percent, SE = 0.6, $n = 120$ versus $\bar{x} = 19.8$ percent, SE = 0.7, $n = 120$, respectively, $P = 0.0009$). In addition, there were no two-way interactions ($0.43 \leq P \leq 0.85$) between or among moist-soil zones, tillage treatments, or collection seasons.

T and NT plots did not show a difference in relative bulk density ($\bar{x} = 1.30$ g/cm^3, SE = 0.03, $n = 18$ versus $\bar{x} = 1.29$ g/cm^3, SE = 0.02, $n = 18$, respectively, $P = 0.65$). Likewise, a significant difference was not detected between the November 1992 and August 1993 samples ($\bar{x} = 1.32$ g/cm^3, SE = 0.03, $n = 18$ versus $\bar{x} = 1.27$ g/cm^3, SE = 0.02, $n = 18$, respectively, $P = 0.25$). Finally, the two-way interaction between tillage treatment and collection date was not significant ($P = 0.40$).

Moist-Soil Zone Vegetation

Plant frequencies

Eleven grass taxa were recorded during the study; two taxa occurred most frequently in the flooded zone, three in MSZI, and six in MSZII (Table 1). Three taxa occurred most frequently in NT plots, seven in T plots, and one taxon had equal frequencies for NT and T plots. During the three drawdown

Table 1
Frequency of Occurrence of Emergent Plant Taxa Within Three Lewisville Ponds During 1992 and 1993 Studies

Common Name	Scientific Name	Soil-Moisture Regime			Tillage Treatment		Drawdown Timing		
		Flooded Zone (n = 72)	MSZI (n = 72)	MSZII (n = 72)	Nontilled (n = 108)	Tilled (n = 108)	1st LSEF (n = 72)	SPG (n = 72)	2nd LSEF (n = 72)
Grasses									
Barnyard grasses	*Echinochloa* spp.[1]	0.46	0.43	0.28	0.36	0.42	0.21	0.39	0.57
Knot-root bristle grass	*Setaria geniculata*	0.07	0.56	0.64	0.39	0.45	0.43	0.17	0.67
Fall panicum	*Panicum dichotomiflorum*	0.18	0.28	0.26	0.23	0.25	0.19	0.01	0.51
Hairy crabgrass	*Digitaria sanguinalis*	0.13	0.40	0.57	0.38	0.35	0.24	0.56	0.31
Bermuda grass	*Cynodon dactylon*	0.53	0.79	0.75	0.67	0.71	0.74	0.67	0.67
Dallis grass	*Paspalum dilatatum*	0.00	0.15	0.56	0.23	0.24	0.08	0.36	0.26
Knotgrass	*Paspalum distichum* var. *distichum*	0.08	0.04	0.06	0.05	0.07	0.00	0.14	0.04
Johnson grass	*Sorghum halepense*	0.01	0.06	0.22	0.10	0.09	0.13	0.08	0.08
Prairie cup grass	*Eriochloa contracta*	0.08	0.15	0.18	0.13	0.15	0.08	0.25	0.08
Carolina canary grass	*Phalaris caroliniana*	0.00	0.00	0.03	0.01	0.01	0.00	0.03	0.00
Bluestem	*Andropogon* sp.	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01

(Sheet 1 of 3)

Note: Plants are categorized by grass, sedge, forb, cattail, and willow. Frequencies of occurrence are presented for the flooded zone, moist-soil zones I (MSZI) and II (MSZII), two tillage treatments, and three drawdown timings. Data for the first late-summer/early-fall (LSEF), spring (SPG), and second LSEF drawdowns were collected in November 1992, July 1993, and November 1993, respectively.

[1] Barnyard grasses included *Echinochloa crusgalli* var. *crusgalli* and *Echinochloa crus-pavonis* var. *crus-pavonis*.

Table 1 (Continued)

Common Name	Scientific Name	Soil-Moisture Regime			Tillage Treatment		Drawdown Timing		
		Flooded Zone (n = 72)	MSZI (n = 72)	MSZII (n = 72)	Nontilled (n = 108)	Tilled (n = 108)	1st LSEF (n = 72)	SPG (n = 72)	2nd LSEF (n = 72)
Sedges									
Britton's sedge	*Carex brittoniana*	0.22	0.47	0.54	0.45	0.37	0.00	0.58	0.65
Flatsedge	*Cyperus acuminatus*	0.08	0.03	0.07	0.03	0.09	0.01	0.14	0.03
Creeping spike rush	*Eleocharis macrostachya*	0.78	0.50	0.38	0.53	0.57	0.50	0.58	0.57
Dwarf spike rush	*Eleocharis parvula*	0.04	0.00	0.00	0.00	0.03	0.03	0.01	0.00
Unknown sedge		0.13	0.15	0.26	0.21	0.15	0.49	0.06	0.00
Forbs									
Pigweed	*Amaranthus palmeri*	0.00	0.29	0.24	0.12	0.23	0.46	0.01	0.06
Smartweeds	*Polygonum* spp.[2]	0.18	0.21	0.10	0.13	0.19	0.10	0.22	0.17
Curly dock	*Rumex crispus*	0.06	0.24	0.24	0.16	0.19	0.07	0.28	0.18
Arrowhead	*Sagittaria platyphylla*	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00
Tooth-cup	*Ammannia coccinea*	0.36	0.06	0.03	0.05	0.25	0.18	0.17	0.10
Aster	*Aster subulatus*	0.13	0.26	0.19	0.19	0.20	0.06	0.00	0.53
Texas frog fruit	*Phyla incisa*	0.57	0.82	0.89	0.74	0.78	0.67	0.85	0.76
Ground cherry	*Physalis pubescens* var. *integrifolia*	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01

(Sheet 2 of 3)

[2] Smartweeds included *Polygonum persicaria* and *Polygonum hydropiperoides* var. *hydropiperoides*.

Table 1 (Concluded)

Common Name	Scientific Name	Soil-Moisture Regime			Tilage Treatment		Drawdown Timing		
		Flooded Zone (*n* = 72)	MSZI (*n* = 72)	MSZII (*n* = 72)	Nontilled (*n* = 108)	Tilled (*n* = 108)	1st LSEF (*n* = 72)	SPG (*n* = 72)	2nd LSEF (*n* = 72)
Forbs (Continued)									
Mustang grape	*Vitis mustangensis*[3]	0.00	0.01	0.03	0.01	0.02	0.00	0.04	0.00
Spurge	*Euphorbia* sp.	0.00	0.11	0.06	0.07	0.04	0.01	0.15	0.00
Thistle	*Cirsium* sp.	0.00	0.13	0.11	0.07	0.08	0.24	0.00	0.00
Unknown forbs[4]		0.39	0.78	0.81	0.61	0.70	0.69	0.68	0.60
Cattail									
Cattail	*Typha* sp.	0.35	0.01	0.00	0.06	0.18	0.03	0.11	0.22
Willow									
Black willow	*Salix nigra*	0.06	0.04	0.01	0.00	0.07	0.01	0.06	0.04

(Sheet 3 of 3)

[3] Correll and Johnston (1970).
[4] Unknown forbs accounted for one or more forb taxa.

timings, three taxa occurred most frequently during the first LSEF drawdown, five during the SPG drawdown, and four during the second LSEF drawdown.

Five sedge taxa were recorded during the study (Table 1). Three taxa occurred most frequently within the flooded zone and T plots. Two taxa occurred most frequently in MSZII and NT plots. Two taxa had highest frequencies of occurrence during the first LSEF drawdown, two during the SPG drawdown, and one during the second LSEF drawdown.

Twelve forb taxa were recorded during the study (Table 1). Within the three soil-moisture regimes, one taxon occurred most frequently within the flooded zone, six within MSZI, and four within MSZII. One taxon had equal frequencies of occurrence within MSZI and MSZII; one taxon occurred most frequently in NT plots, while 11 taxa occurred most frequently in T plots. Four taxa occurred most frequently during the first LSEF drawdown, six during the SPG drawdown, and two during the second LSEF drawdown.

Cattail and black willow occurred most frequently within the flooded zone (0.35 and 0.06, respectively) and T plots (0.18 and 0.07, respectively) (Table 1). However, cattail and black willow occurred most frequently during the second LSEF (0.22) and SPG (0.06) drawdowns, respectively.

Soil-moisture effects on vegetation

Emergent taxon richness revealed a significant ($P = 0.03$) interaction between soil moisture and drawdown timing (Figure 5). During the first LSEF drawdown, taxon richness was higher ($\alpha = 0.05$) in MSZII and MSZI ($\bar{x} =$ 8.5 taxa, SE = 0.4, $n = 24$ and $\bar{x} = 7.38$ taxa, SE = 0.5, $n = 24$, respectively) than the flooded zone ($\bar{x} = 3.5$, SE = 0.3, $n = 24$) (Figure 5). However, taxon richness was not significantly ($\alpha = 0.05$) different between moisture regimes during the other two drawdowns.

Grass PC was higher ($P = 0.0498$) in MSZII and MSZI than in the flooded zone (Table 2). Sedge PC revealed a significant ($P = 0.0003$) interaction between soil moisture and drawdown timing, but no differences were detected in PC between the three soil-moisture regimes in each drawdown (Figure 6a). Finally, forb PC was significantly ($P = 0.003$) higher in MSZI than in MSZII and the flooded zone (Table 2).

Grass AGB did not differ ($P = 0.07$) between the three soil-moisture regimes (Table 2). The soil-moisture regime and drawdown timing interaction was significant ($P = 0.0001$) for sedge AGB (Figure 6b). Within the SPG drawdown, sedge AGB was higher ($\alpha = 0.05$) in the flooded zone ($\bar{x} =$ 240.7 g/m^2, SE = 35.8, $n = 24$) than in either MSZI or MSZII ($\bar{x} = 48.7$ g/m^2, SE = 9.5, $n = 24$ and $\bar{x} = 23.7$ g/m^2, SE = 6.1, $n = 24$, respectively). The moisture regime and drawdown timing interaction also was significant ($P =$ 0.02) for forb AGB (Figure 7). During the SPG drawdown, forb AGB was

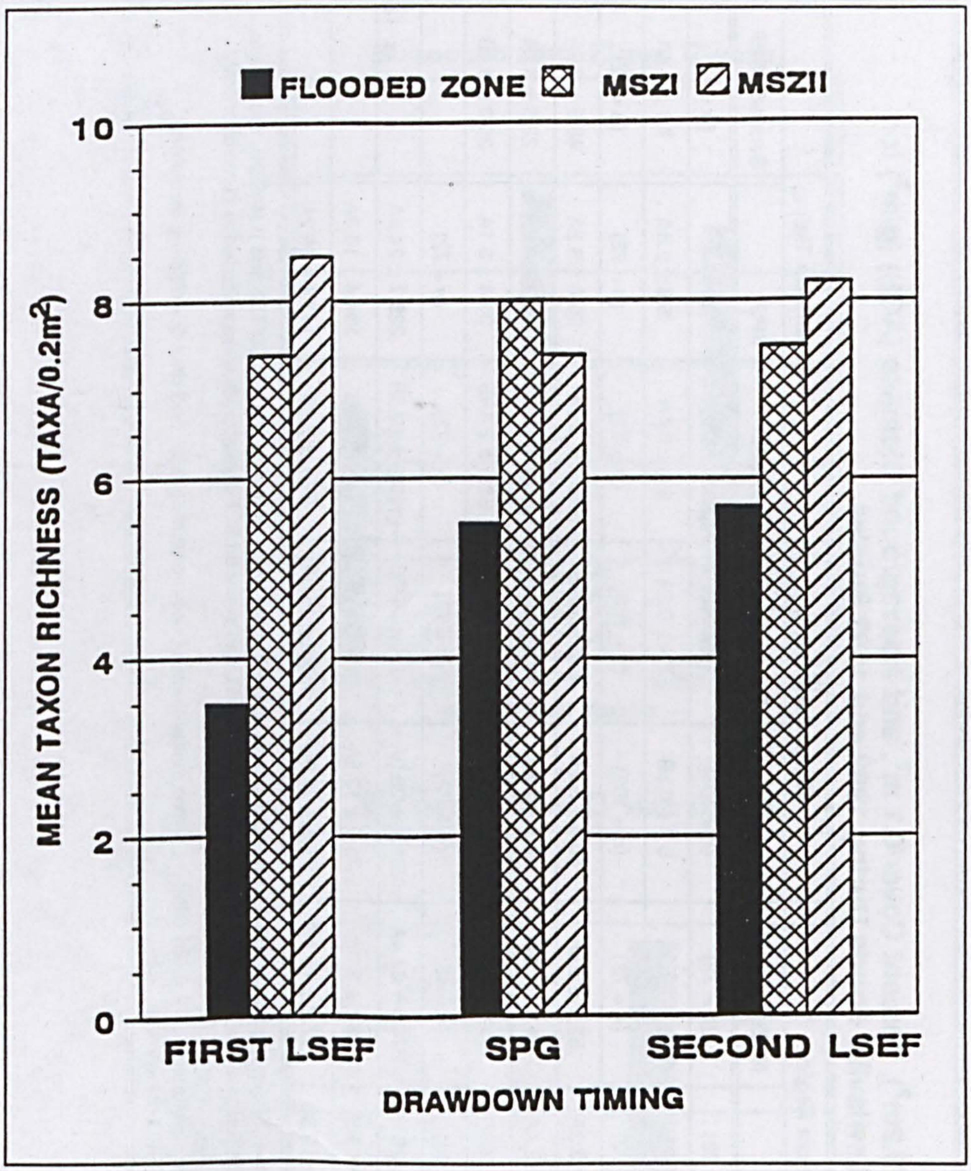


Figure 5. Mean taxon richness for emergent plants within the flooded zone and moist-soil zones I and II (MSZI and MSZII, respectively) during both first and second late-summer/early-fall (LSEF) and spring (SPG) drawdowns

higher ($\alpha = 0.05$) in MSZI than in the flooded zone ($\bar{x} = 242.7$ g/m^2, SE = 30.1, $n = 24$ versus $\bar{x} = 34.7$ g/m^2, SE = 8.5, $n = 24$, respectively).

Tillage effects on vegetation

Taxon richness was higher ($P = 0.02$) in T than NT plots (Table 2). Grass PC ($P = 0.009$) and AGB ($P = 0.001$) were higher in NT than T plots (Table 2). Sedge PC ($P = 0.2$) and AGB ($P = 0.16$) did not differ between

Table 2
Mean (± SE) Taxon Richness (Taxa/0.2m^2), Percent Cover/0.1 m^2, and Aboveground Biomass (AGB) (g/m^2) for Emergent Plant Taxa Within Three Lewisville Ponds During 1992 and 1993 Studies

	Soil-Moisture Regime			Tillage Treatment		Drawdown Timing		
Independent Variables	**Flooded Zone**	**MSZI**	**MSZII**	**Nontilled**	**Tilled**	**First LSEF**	**SPG**	**Second LSEF**
Taxon richness	(*n* = 72)	(*n* = 72)	(*n* = 72)	(*n* = 108)	(*n* = 108)	(*n* = 72)	(*n* = 72)	(*n* = 72)
	4.9 ± 0.3A[1]	7.6 ± 0.3A	8.0 ± 0.2A	6.3 ± 0.3B	7.4 ± 0.2A	6.5 ± 0.4A	6.9 ± 0.3A	7.1 ± 0.3A
Percent cover	(*n* = 72)	(*n* = 72)	(*n* = 72)	(*n* = 108)	(*n* = 108)	(*n* = 72)	(*n* = 72)	(*n* = 72)
Grass	29.7 ± 3.7B	45.2 ± 3.3A	52.9 ± 3.5A	50.9 ± 3.2A	34.3 ± 2.6B	39.4 ± 4.0A	39.6 ± 3.3A	48.8 ± 3.7A
Sedge	39.4 ± 3.9A	17.5 ± 2.1A	8.9 ± 1.0A	24.9 ± 2.6A	19.1 ± 2.3A	18.4 ± 2.7A	24.9 ± 3.2A	22.6 ± 3.2A
Forb	9.8 ± 1.3C	44.3 ± 2.9A	35.8 ± 2.9B	22.6 ± 2.2B	37.3 ± 2.5A	31.5 ± 2.8AB	33.4 ± 3.1A	25.0 ± 3.1B
AGB[2]	(*n* = 48)	(*n* = 48)	(*n* = 48)	(*n* = 72)	(*n* = 72)	(*n* = 72)	(*n* = 72)	
Grass	116.1 ± 27.9A	178.1 ± 26.0A	224.5 ± 27.4A	233.7 ± 26.0A	112.1 ± 15.7B	120.0 ± 19.0B	225.7 ± 24.3A	
Sedge	141.5 ± 23.5A	37.1 ± 6.0B	15.1 ± 3.4B	75.0 ± 13.5A	54.2 ± 12.8A	24.8 ± 4.5B	104.4 ± 16.9A	
Forb	29.3 ± 5.5C	167.7 ± 19.3A	117.2 ± 15.1B	75.6 ± 11.0B	133.9 ± 15.0A	62.1 ± 7.6B	147.4 ± 16.2A	

Note: Plants are categorized by grass, sedge, and forb. Data are presented for the main effects of the flooded zone, moist-soil zones I (MSZI) and II (MSZII), two tillage treatments, and three drawdown timings. Data for the first late-summer/early-fall (LSEF), spring (SPG), and second LSEF drawdowns were collected in November 1992, July 1993, and November 1993, respectively.

[1] Means sharing the same letter within a row are not significantly ($P \geq 0.05$) different within main effects of soil-moisture, tillage, and drawdown-timing treatments.

[2] AGB was collected only during the first LSEF and SPG drawdowns.

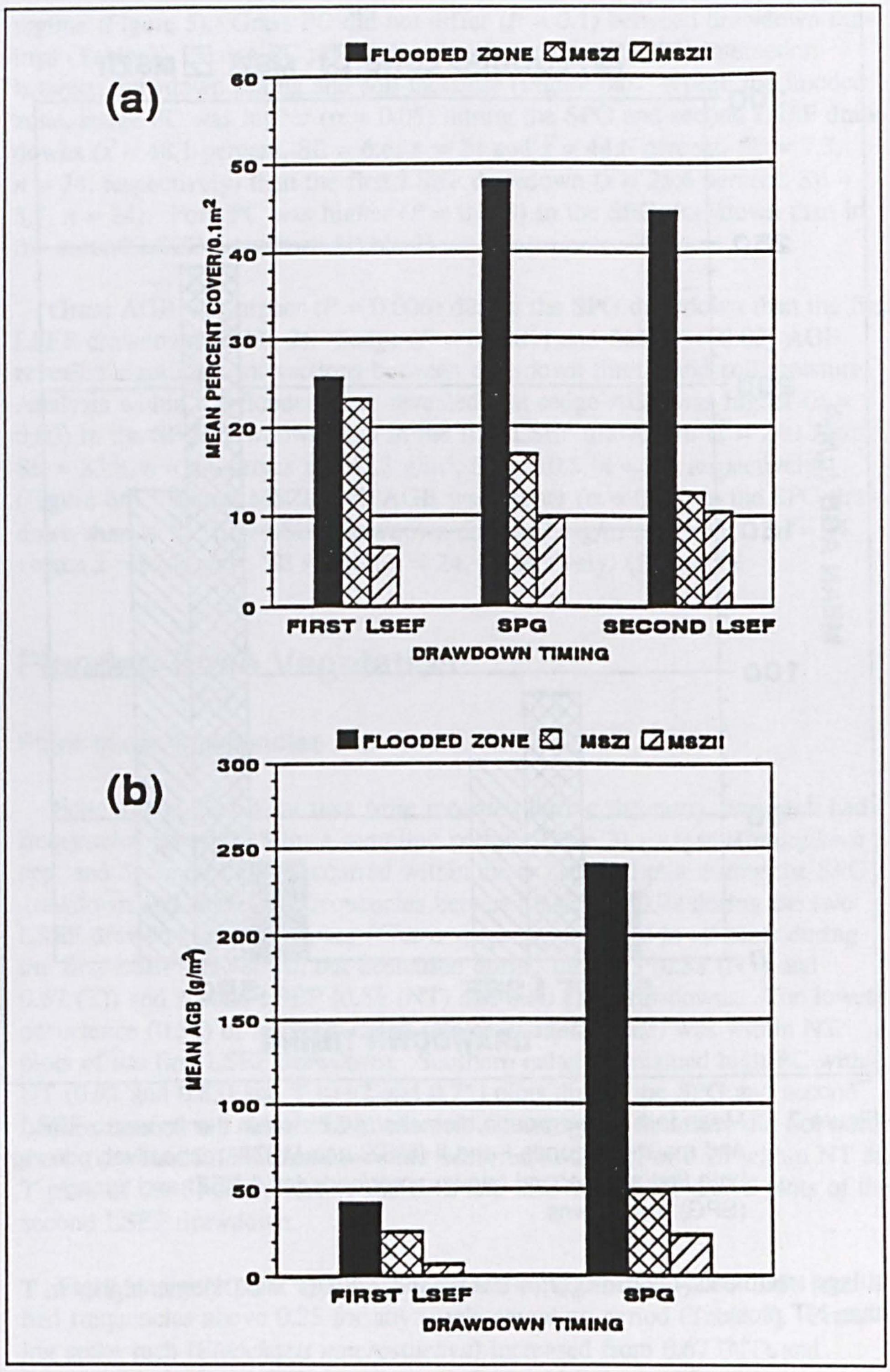


Figure 6. Mean sedge (a) percent cover (PC) and (b) aboveground biomass (AGB) within the flooded zone and moist-soil zones I and II (MSZI and MSZII, respectively) during both first and second late-summer/early-fall (LSEF) and spring (SPG) drawdowns

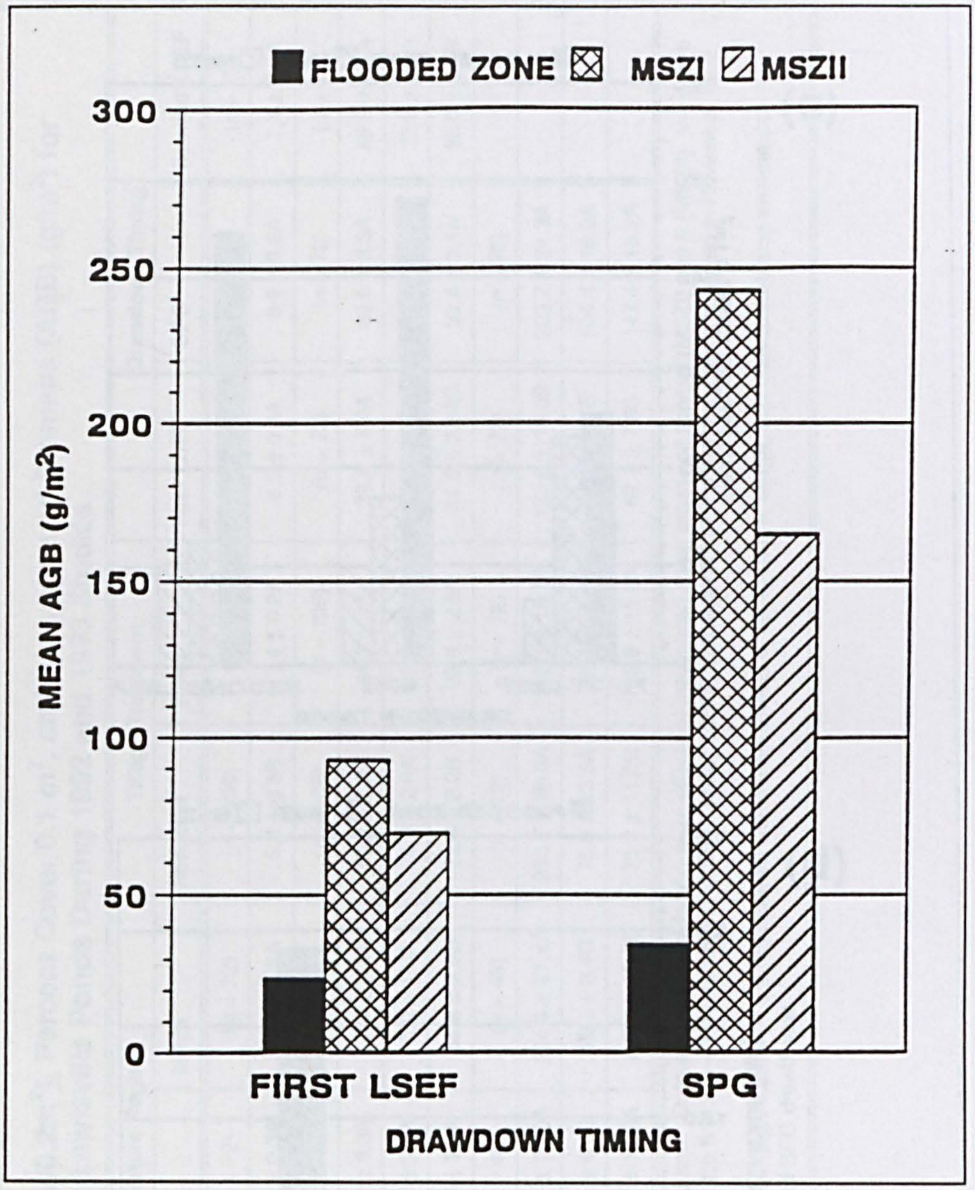


Figure 7. Mean forb aboveground biomass (AGB) within the flooded zone and moist-soil zones I and II (MSZI and MSZII, respectively) during both first and second late-summer/early-fall (LSEF) and spring (SPG) drawdowns

tillage treatments. Forb PC ($P = 0.006$) and AGB ($P = 0.01$) was higher in T than NT plots.

Drawdown timing effects on vegetation

Emergent taxon richness revealed a significant interaction ($P = 0.03$) between drawdown timing and soil moisture, but no differences were detected in taxon richness between the three drawdown timings of each soil-moisture regime (Figure 5). Grass PC did not differ ($P = 0.1$) between drawdown timings (Table 2). Sedge PC revealed a significant ($P = 0.0003$) interaction between drawdown timing and soil moisture (Figure 6a). Within the flooded zone, sedge PC was higher ($\alpha = 0.05$) during the SPG and second LSEF drawdowns ($\bar{x} = 48.1$ percent, SE = 6.6, $n = 24$ and $\bar{x} = 44.6$ percent, SE = 7.3, $n = 24$, respectively) than the first LSEF drawdown ($\bar{x} = 25.6$ percent, SE = 5.7, $n = 24$). Forb PC was higher ($P = 0.003$) in the SPG drawdown than in the second LSEF drawdown (Table 2).

Grass AGB was higher ($P = 0.006$) during the SPG drawdown than the first LSEF drawdown (Table 2). Sedge ($P = 0.0001$) and forb ($P = 0.02$) AGB revealed significant interactions between drawdown timing and soil moisture. Analysis within the flooded zone revealed that sedge AGB was higher ($\alpha = 0.05$) in the SPG drawdown than in the first LSEF drawdown ($\bar{x} = 240.7$ g/m^2, SE = 35.8, $n = 24$ versus $\bar{x} = 42.3$ g/m^2, SE = 10.5, $n = 24$, respectively) (Figure 6b). Within MSZI, forb AGB was higher ($\alpha = 0.05$) in the SPG drawdown than in the first LSEF drawdown ($\bar{x} = 242.7$ g/m^2, SE = 30.1, $n = 24$ versus $\bar{x} = 92.8$ g/m^2, SE = 11.3, $n = 24$, respectively) (Figure 7).

Flooded-Zone Vegetation

Plant taxon frequencies

Four submergent plant taxa were recorded during the study, and each had frequencies above 0.25 for a sampling period (Table 3). Algae (*Cladophora* spp. and *Spirogyra* spp.) occurred within every sampled plot during the SPG drawdown and ranged in frequencies between 0.42 and 0.92 during the two LSEF drawdowns. Muskgrass (*Chara vulgaris*) occurred in all plots during the first LSEF drawdown, but decreased during the SPG (0.58 (NT) and 0.67 (T)) and second LSEF (0.58 (NT) and 0.50 (T)) drawdowns. The lowest occurrence (0.58) of southern naiad (*Najas guadalupensis*) was within NT plots of the first LSEF drawdown. Southern naiad maintained high PC within NT (0.92 and 0.83) and T (0.92 and 0.75) plots during the SPG and second LSEF drawdowns. American pondweed (*Potamogeton nodosus*) did not occur during the first LSEF drawdown, but occurred at a level of 0.25 within NT and T plots of the SPG drawdown and 0.42 and 0.33 within NT and T plots of the second LSEF drawdown.

Eight emergent plant taxa were recorded during the study, but only four had frequencies above 0.25 for any single sampling period (Table 3). Creeping spike rush (*Eleocharis macrostachya*) increased from 0.67 (NT) and 0.17 (T) in the first LSEF drawdown to 0.92 within both NT and T plots in the second LSEF drawdown. Smartweed (*Polygonum* sp.) had its highest occurrence (0.25) within NT and T plots during the first LSEF drawdown and then decreased within NT (0.17) and T (0.17) plots of the other two drawdowns. Bermuda grass (*Cynodon dactylon*) occurred more frequently in NT than T plots within each drawdown season. Within NT (first LSEF (0.83),

Table 3
Frequencies of Plant Taxa Within the Flooded Zone of Three Lewisville Ponds During 1992 and 1993 Studies

Common Name	Scientific Name	Drawdown Timing					
		First LSEF		SPG		Second LSEF	
		NT (n = 12)	T (n = 12)	NT (n = 12)	T (n = 12)	NT (n = 12)	T (n = 12)
Submergents							
Algae (combined)	*Cladophora* sp. and *Spirogyra* sp.	0.83	0.42	1.00	1.00	0.92	0.83
Muskgrass	*Chara vulgaris*	1.00	1.00	0.58	0.67	0.58	0.50
Southern naiad	*Najas guadalupensis*	0.58	0.92	0.92	0.92	0.83	0.75
American pondweed	*Potamogeton nodosus*	0.00	0.00	0.25	0.25	0.42	0.33
Emergents							
Creeping spike rush	*Eleocharis macrostachya*	0.67	0.17	0.75	0.42	0.92	0.92
Smartweed	*Polygonum* sp.	0.25	0.25	0.17	0.17	0.17	0.17
Paspalum	*Paspalum* sp.	0.08	0.08	0.08	0.08	0.08	0.08
Bermuda grass	*Cynodon dactylon*	0.83	0.25	0.50	0.08	0.25	0.00
Panicum	*Panicum* sp.	0.08	0.00	0.00	0.00	0.00	0.00
Tooth-cup	*Ammannia coccinnea*	0.00	0.25	0.00	0.00	0.00	0.00
Cattail	*Typha* sp.	0.00	0.00	0.00	0.08	0.17	0.42
Arrowhead	*Sagittaria platyphylla*	0.00	0.00	0.00	0.00	0.08	0.00
Floating							
Duckweed	*Lemna* sp.	0.00	0.00	0.00	0.00	0.17	0.25

Note: Taxa are categorized by being either submergents, emergents, or floating plants. Frequencies for plants in nontilled (NT) and tilled (T) plots within the first late-summer/early-fall (LSEF), spring (SPG), and second LSEF drawdowns were collected in November 1992, July 1993, and November 1993, respectively.

SPG (0.50), second LSEF (0.25)) and T (first LSEF (0.25), SPG (0.08), second LSEF (0.00)) plots, bermuda PC decreased over time. Cattail first occurred within T (0.08) plots of the SPG drawdown and then increased to 0.17 (NT) and 0.42 (T) during the second LSEF drawdown. Duckweed (*Lemna* sp.) occurred in NT (0.17) and T (0.25) plots within the second LSEF drawdown, but did not have frequencies above 0.25 for the drawdown.

Tillage effects on vegetation

Total taxon richness ($P = 0.07$), submergent taxon richness ($P = 0.53$), and emergent taxon richness ($P = 0.11$) did not differ between tillage treatments (Table 4). Taxon richness interactions were not significant ($0.05 \leq P \leq 0.81$).

Table 4
Mean (± SE) Submergent, Emergent, and Total Taxon Richness (Taxa/0.1 m^2) Within Two Tillage Treatments and Three Drawdown Timings

	Tillage Treatment		Drawdown Timing		
Taxon	Nontilled ($n = 36$)	Tilled ($n = 36$)	First LSEF ($n = 24$)	SPG ($n = 24$)	Second LSEF ($n = 24$)
Submergent	2.6 ± 0.1A[1]	2.5 ± 0.1A	2.4 ± 0.1A	2.8 ± 0.2A	2.6 ± 0.2A
Emergent	1.8 ± 0.2A	1.1 ± 0.2A	1.5 ± 0.2A	1.2 ± 0.2A	1.6 ± 0.2A
Total	4.5 ± 0.2A	3.8 ± 0.2A	3.9 ± 0.2A	4.0 ± 0.3A	4.4 ± 0.2A

Note: First late-summer/early-fall (LSEF), spring (SPG), and second LSEF data were collected in November 1992, July 1993, and November 1993, respectively.
[1] Means within a row sharing the same letter are not significantly ($P \geq 0.05$) different within the main effects of tillage treatment and drawdown timing.

Algae and muskgrass PC did not differ between NT and T plots ($P = 0.051$ and $P = 0.47$, respectively) (Table 5). However, southern naiad PC was higher ($P = 0.03$) in T than NT plots. American pondweed PC did not differ ($P = 0.44$) in tillage treatments within the SPG and second LSEF drawdowns. No interactions were significant ($0.10 \leq P \leq 0.57$) for submergent PC. Creeping spike rush ($P = 0.20$) and smartweed ($P = 0.43$) PC did not differ between tillage treatments. Bermuda grass PC was higher in NT than T plots. Cattail PC did not differ ($P = 0.07$) between tillage treatments. Interactions were not significant ($0.37 \leq P \leq 0.51$) for emergent PC.

Drawdown timing effects on vegetation

Total taxon richness ($P = 0.59$), submergent taxon richness ($P = 0.45$), and emergent taxon richness ($P = 0.08$) did not differ among drawdown timings (Table 4). Taxon richness interactions were not significant ($0.05 \leq P \leq 0.81$).

Table 5
Mean (± SE) Percent Cover/0.1 m^2 for Plants with Frequencies Above 0.25 for a Sampling Period Within the Flooded Zone of Three Lewisville Ponds During 1992 and 1993 Studies

Common Name	Tillage Treatment		Drawdown Timing		
	NT (*n* = 36)	T (*n* = 36)	First LSEF (*n* = 24)	SPG (*n* = 24)	Second LSEF (*n* = 24)
Submergents					
Algae	37.7 ± 5.1A[1]	20.8 ± 4.9A	16.4 ± 4.9B	56.2 ± 5.7A	15.1 ± 4.2B
Muskgrass	25.1 ± 5.2A	19.6 ± 3.8A	40.6 ± 5.7A	15.4 ± 4.7B	11.1 ± 4.4B
Southern naiad	15.7 ± 3.3B	49.4 ± 6.5A	35.9 ± 7.8A	36.5 ± 6.8A	25.2 ± 6.9A
American pondweed	19.2 ± 6.2A	17.8 ± 6.3A	0.0 ± 0.0	11.4 ± 4.6A	25.7 ± 7.2A
Emergents					
Creeping spike rush	10.5 ± 2.1A	14.4 ± 3.9A	3.4 ± 1.3B	9.7 ± 3.0B	24.2 ± 5.0A
Smartweed	3.7 ± 1.4A	0.7 ± 0.4A	3.5 ± 1.8A	1.9 ± 1.1A	1.2 ± 0.8A
Bermuda grass	3.2 ± 1.0A	0.2 ± 0.2B	3.6 ± 1.3A	1.4 ± 0.8A	0.1 ± 0.1A
Cattail	0.4 ± 0.4A	0.5 ± 0.4A	0.0 ± 0.0	-----[2]	0.5 ± 0.3

Note: Taxa are categorized as being either submergents or emergents. Percent cover is given for plants in nontilled (NT) and tilled (T) plots, and the first late-summer/early-fall (LSEF), spring (SPG), and second LSEF drawdowns. Measurements were collected in December 1992, July 1993, and November 1993.

[1] Means within a row sharing the same letter are not significantly ($P \geq 0.05$) different within the main effects of tillage treatment and drawdown timing.

[2] A mean was not figured for cattail because it occurred at a frequency below 0.25.

Algae PC was higher ($P = 0.0002$) in the SPG drawdown than in the first and second LSEF drawdowns (Table 5). Muskgrass PC was higher ($P = 0.006$) in the first LSEF drawdown than in the SPG and second LSEF drawdowns. However, southern naiad PC did not differ ($P = 0.49$) between drawdown timings. American pondweed did not differ ($P = 0.11$) in PC between the SPG and second LSEF drawdowns. Interactions were not significant ($0.10 \leq P \leq 0.57$) for submergent PC.

Creeping spike rush PC was higher ($P = 0.003$) in the second LSEF drawdown than in the SPG and first LSEF drawdowns (Table 5). Smartweed ($P = 0.34$) and bermuda grass ($P = 0.05$) PC did not differ between drawdown timings. Interactions were not significant ($0.24 \leq P \leq 0.51$) for emergent PC.

Water-depth effects on vegetation

Algae PC increased with increasing water depths in all tillage and drawdown treatments except SPG T and NT (Table 6). Muskgrass water-depth correlations were negative for every tillage and drawdown treatment. Southern naiad increased in PC with increasing water depths in all tillage and drawdown treatments except for SPG NT. American pondweed did not occur during the first LSEF drawdown, but within the SPG and second LSEF drawdowns, its PC was positively correlated with water depths in T plots and negatively correlated in NT plots.

Creeping spike rush and smartweed PC decreased with increased water depths in every tillage and drawdown treatment (Table 6). Bermuda grass did not occur within second LSEF T plots, and its PC decreased with water depths in every other tillage and drawdown treatment. Cattail did not occur during the first LSEF drawdown or within NT plots of the SPG drawdown. However, within the T SPG drawdown plots and all second LSEF plots, cattail PC decreased with increased water depths.

Seed Production

Seed taxon frequencies

Seeds from 11 grass taxa were collected during the LSEF and SPG drawdowns, but only 7 taxa had frequencies greater than 0.20 for a single drawdown (Table 7). Barnyard grasses (*Echinochloa* spp.) occurred most frequently within MSZI (0.65), T plots (0.56), and the LSEF drawdown (0.58). Knot-root bristle grass (*Setaria geniculata*) had its highest frequencies of occurrence within MSZII (0.63), T plots (0.40), and the LSEF drawdown (0.50). Fall panicum (*Panicum dichotomiflorum*) and hairy crabgrass (*Digitaria sanguinalis*) seeds also occurred most frequently in MSZII (0.44 and 0.35, respectively) and the LSEF drawdown (0.39 and 0.28, respectively), but fall

Table 6
Correlation Coefficients and P-Values for Associations of Plant Coverage and Water Depth for Eight Plants Within Three Lewisville Ponds During 1992 and 1993 Studies

Common Name	Drawdown Timing					
	First LSEF		SPG		Second LSEF	
	NT (*n* = 36)	T (*n* = 36)	NT (*n* = 36)	T (*n* = 36)	NT (*n* = 36)	T (*n* = 36)
Submergents						
Algae	0.4168[1] (*P* = 0.01)	0.3910 (*P* = 0.02)	0.1778 (*P* = 0.30)	-0.0270 (*P* = 0.88)	0.3605 (*P* = 0.03)	0.4747 (*P* = 0.003)
Muskgrass	-0.1167 (*P* = 0.50)	-0.2083 (*P* = 0.22)	-0.4768 (*P* = 0.003)	-0.5806 (*P* = 0.0002)	-0.1886 (*P* = 0.27)	-0.1046 (*P* = 0.54)
Southern naiad	0.3331 (*P* = 0.047)	0.3789 (*P* = 0.02)	-0.3792 (*P* = 0.02)	0.7661 (*P* = 0.0001)	0.2638 (*P* = 0.12)	0.7520 (*P* = 0.0001)
American pondweed	----[2]	----	-0.2313 (*P* = 0.17)	0.0209 (*P* = 0.90)	-0.0038 (*P* = 0.98)	0.1540 (*P* = 0.37)
Emergents						
Creeping spike rush	- 0.2819 (*P* = 0.10)	-0.4084 (*P* = 0.01)	-0.2311 (*P* = 0.18)	-0.5821 (*P* = 0.0002)	-0.2524 (*P* = 0.14)	-0.7380 (*P* = 0.0001)
Smartweed	-0.0571 (*P* = 0.74)	-0.2823 (*P* = 0.10)	-0.2252 (*P* = 0.19)	-0.0843 (*P* = 0.63)	-0.4381 (*P* = 0.008)	-0.3125 (*P* = 0.06)
Bermuda grass	-0.2494 (*P* = 0.14)	-0.4276 (*P* = 0.009)	-0.4477 (*P* = 0.006)	-0.1546 (*P* = 0.37)	-0.2958 (*P* = 0.08)	----
Cattail	----	----	----	-0.2360 (*P* = 0.17)	-0.2440 (*P* = 0.15)	-0.6053 (*P* = 0.0001)

Note: Data for plants in nontilled (NT) and tilled (T) plots within the first late-summer/early-fall (LSEF), spring (SPG), and second LSEF drawdowns were collected in November 1992, July 1993, and November 1993, respectively.

[1] *r*-value for Spearman's rank correlation.

[2] Hyphens indicate treatments in which a taxon was not recorded.

Table 7
Frequency of Occurrence of Emergent Plant Seeds in Traps Within Three Lewisville Ponds During 1992 and 1993 Studies

Common Name	Scientific Name	Soil-Moisture Regime			Tillage Treatment		Drawdown Timing	
		Flooded Zone (*n* = 48)	MSZI (*n* = 48)	MSZII (*n* = 48)	Nontilled (*n* = 72)	Tilled (*n* = 72)	LSEF (*n* = 72)	SPG (*n* = 72)
Grasses								
Barnyard grasses	*Echinochloa* spp.	0.46	0.65	0.54	0.53	0.56	0.58	0.50
Knot-root bristle grass	*Setaria geniculata*	0.06	0.38	0.63	0.31	0.40	0.50	0.21
Fall panicum	*Panicum dichotomiflorum*	0.10	0.23	0.44	0.32	0.19	0.39	0.13
Hairy crabgrass	*Digitaria sanguinalis*	0.04	0.19	0.35	0.17	0.22	0.28	0.11
Bermuda grass	*Cynodon dactylon*	0.13	0.23	0.23	0.19	0.19	0.24	0.15
Dallis grass	*Paspalum dilatatum*	0.19	0.35	0.73	0.40	0.44	0.21	0.64
Johnson grass	*Sorghum halepense*	0.00	0.19	0.42	0.18	0.22	0.17	0.24
Knotgrass	*Paspalum distichum* var. *distichum*	0.02	0.00	0.04	0.03	0.01	0.04	0.00
Prairie cup grass	*Eriochloa contracta*	0.00	0.08	0.08	0.04	0.07	0.06	0.06
Brome	*Bromus* sp.	0.00	0.00	0.02	0.01	0.00	0.00	0.01
Bluestem	*Andropogon* sp.	0.04	0.00	0.02	0.04	0.00	0.04	0.00
Sedges								
Creeping spike rush	*Eleocharis macrostachya*	0.33	0.25	0.19	0.26	0.25	0.11	0.40
Britton's sedge	*Carex brittoniana*	0.19	0.40	0.35	0.40	0.24	0.00	0.63

(Continued)

Note: Seeds are categorized by grass, sedge, and forb. Frequencies of occurrence (per 0.2 m^2) are presented for the flooded zone, moist-soil zones I (MSZI) and II (MSZII), two tillage treatments, and late-summer/early-fall (LSEF) and spring (SPG) drawdowns. Seeds were collected from traps in November 1992 and July 1993.

Table 7 (Concluded)

Common Name	Scientific Name	Soil-Moisture Regime Flooded Zone (*n* = 48)	MSZI (*n* = 48)	MSZII (*n* = 48)	Tillage Treatment Nontilled (*n* = 72)	Tilled (*n* = 72)	Drawdown Timing LSEF (*n* = 72)	SPG (*n* = 72)
Sedges (Continued)								
Flatsedge	*Cyperus acuminatus*	0.08	0.02	0.06	0.01	0.10	0.03	0.08
Yellow nut sedge	*Cyperus esculentus*	0.00	0.00	0.06	0.03	0.01	0.00	0.04
Forbs								
Pigweed	*Amaranthus palmeri*	0.41	0.63	0.54	0.46	0.60	0.83	0.22
Yellow wood sorrel	*Oxalis stricta*	0.02	0.23	0.67	0.29	0.32	0.24	0.38
Smartweeds	*Polygonum* spp.	0.06	0.21	0.08	0.07	0.17	0.24	0.01
Aster	*Aster subulatus*	0.25	0.29	0.25	0.24	0.29	0.53	0.00
Texas frog fruit	*Phyla incisa*	0.31	0.19	0.13	0.17	0.25	0.40	0.01
Spurge	*Chamaesyce* sp.	0.17	0.31	0.50	0.29	0.36	0.64	0.01
Curly dock	*Rumex crispus*	0.17	0.44	0.46	0.31	0.40	0.00	0.71
Unknown composite	Asteraceae	0.06	0.13	0.38	0.21	0.17	0.00	0.38
Ground cherry	*Physalis pubescens* var. *integrifolia*	0.00	0.02	0.00	0.01	0.00	0.01	0.00
Vetch	*Vicia* sp.	0.00	0.08	0.13	0.10	0.04	0.00	0.14
Bur-clover	*Medicago* sp.	0.00	0.04	0.04	0.04	0.01	0.00	0.06
Unknown		0.10	0.27	0.50	0.33	0.25	0.00	0.58

panicum occurrence was highest in NT plots (0.32) while hairy crabgrass occurrence was highest in T plots (0.22). Bermuda grass seeds had equal occurrences in MSZI (0.23) and MSZII (0.23), NT (0.19), and T (0.19) plots and highest occurrences during the LSEF drawdown (0.24). Both dallis grass and Johnson grass (*Sorghum halepense*) seeds occurred most frequently in MSZII (0.73 and 0.42, respectively), T plots (0.44 and 0.22, respectively), and the SPG drawdown (0.64 and 0.24, respectively).

Four sedge taxa were collected but only two had frequencies of occurrence higher than 0.20 for a drawdown timing (Table 7). Creeping spike rush seeds occurred most frequently in the flooded zone (0.33), NT plots (0.26), and the SPG drawdown (0.40). Britton's sedge (*Carex brittoniana*) seeds, however, had higher occurrence in MSZI (0.40) and NT plots (0.40). Britton's sedge seeds were not trapped during the LSEF drawdown, but occurred at a frequency of 0.63 during the SPG drawdown.

Thirteen forb taxa were collected during the study, but only eight taxa had frequencies above 0.20 for either drawdown (Table 7). Pigweed (*Amaranthus palmeri*) occurred most frequently in MSZI (0.63), T plots (0.60), and the LSEF drawdown (0.83). Yellow wood sorrel (*Oxalis stricta*) occurred most frequently in MSZII (0.67), T plots (0.32), and the SPG drawdown (0.38). Both smartweed and aster (*Aster subulatus*) seeds occurred most frequently in MSZI (0.21 and 0.29, respectively), T plots (0.17 and 0.29, respectively), and the LSEF drawdown (0.24 and 0.53, respectively). Texas frog fruit (*Phyla incisa*) seeds occurred most frequently within the flooded zone (0.31), T plots (0.25), and the LSEF drawdown (0.40). However, spurge (*Chamaesyce* sp.) seeds occurred most frequently within MSZII (0.50), T plots (0.36), and the LSEF drawdown (0.64). Finally, curly dock (*Rumex crispus*) seeds occurred most frequently within MSZII (0.46), T plots (0.40), and the SPG drawdown (0.71).

Soil-moisture effects on seed production

Barnyard grasses had a significant ($P = 0.0007$) interaction between soil moisture and drawdown timing, but did not differ ($\alpha = 0.05$) in SN among soil-moisture regimes within either LSEF or SPG drawdowns (Figure 8a). The interaction between soil moisture and drawdown timing also was significant ($P = 0.006$) for knot-root bristle grass with SN higher in MSZII than in the flooded zone ($\bar{x} = 1{,}192.4$ seeds/m^2, SE = 324.3, $n = 24$ and $\bar{x} = 1.5$ seeds/m^2, SE = 1.5, $n = 24$, respectively, $\alpha = 0.05$) during the LSEF drawdown (Figure 8b). Fall panicum showed a significant ($P = 0.02$) interaction between soil moisture and drawdown timing with SN being higher ($\alpha = 0.05$) in MSZII ($\bar{x} = 2{,}224.0$ seeds/m^2, SE = 960.9, $n = 24$) than both MSZI and the flooded zone ($\bar{x} = 477.6$ seeds/m^2, SE = 413.8, $n = 24$ and $\bar{x} = 9.0$ seeds/m^2, SE = 3.9, $n = 24$, respectively) during the LSEF drawdown (Figure 9a). The interaction ($P = 0.0004$) between soil moisture and drawdown timing for hairy crabgrass revealed that, during the LSEF drawdown, SN were higher in MSZII than the

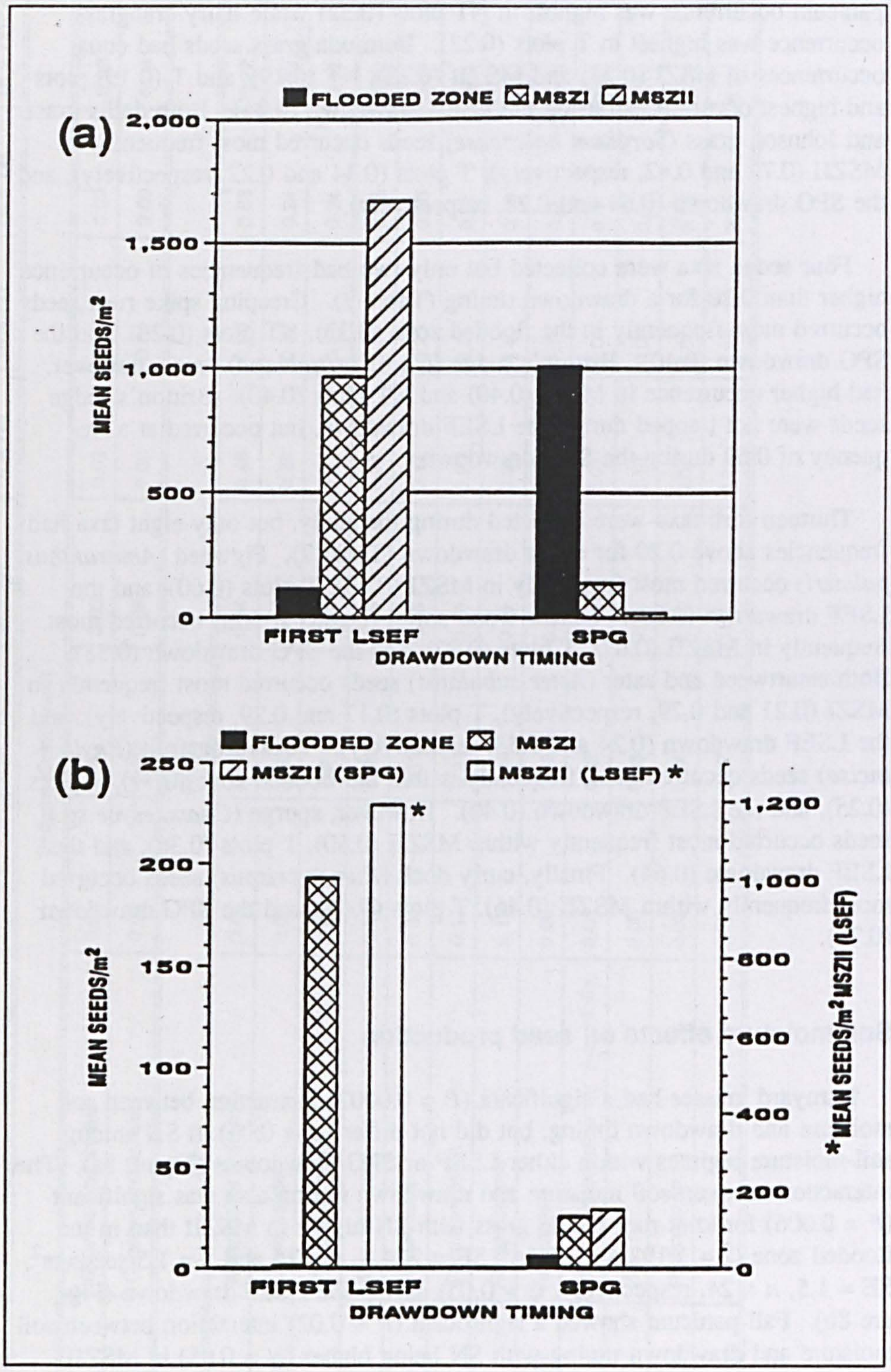


Figure 8. Mean seed numbers for (a) barnyard grass (*Echinochloa* spp.) and (b) knot-root bristle grass (*Setaria geniculata*) within the flooded zone and moist-soil zones I and II (MSZI and MSZII, respectively) during the first late-summer/early-fall (LSEF) and spring (SPG) drawdowns

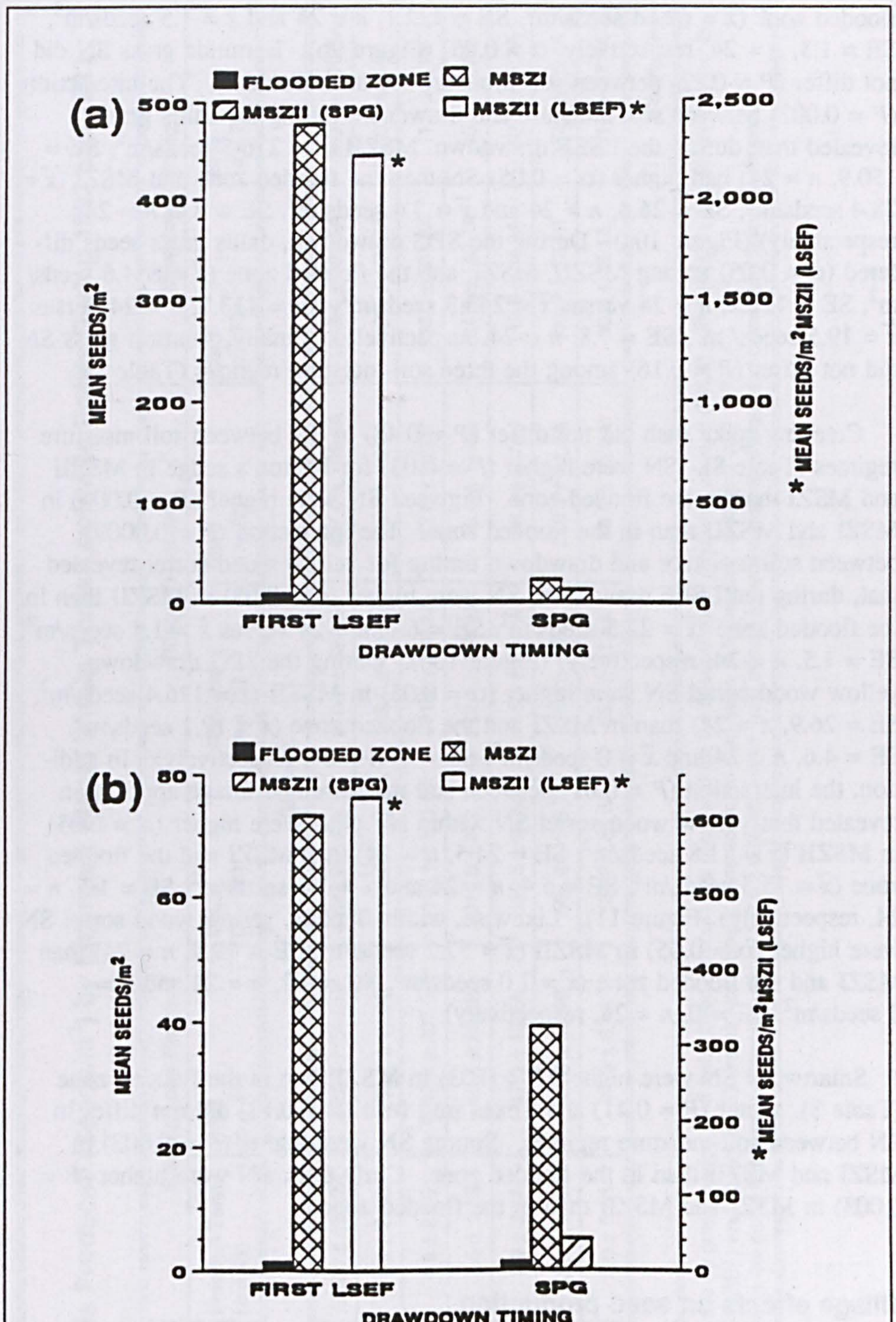


Figure 9. Mean seed numbers for (a) fall panicum (*Panicum dichotomiflorum*) and (b) hairy crabgrass (*Digitaria sanguinalis*) within the flooded zone and moist-soil zones I and II (MSZI and MSZII, respectively) during the first late-summer/early-fall (LSEF) and spring (SPG) drawdowns

flooded zone ($\bar{x}$ = 629.4 seeds/m^2, SE = 422.1, n = 24 and $\bar{x}$ = 1.5 seeds/m^2, SE = 1.5, n = 24, respectively, α = 0.05) (Figure 9b). Bermuda grass SN did not differ (P = 0.22) between soil-moisture regimes (Table 8). The interaction (P = 0.002) between soil moisture and drawdown timing for dallis grass revealed that, during the LSEF drawdown, MSZII ($\bar{x}$ = 276.5 seeds/m^2, SE = 150.9, n = 24) had higher (α = 0.05) SN than the flooded zone and MSZI ($\bar{x}$ = 28.4 seeds/m^2, SE = 26.8, n = 24 and $\bar{x}$ = 3.4 seeds/m^2, SE = 3.4, n = 24, respectively) (Figure 10a). During the SPG drawdown, dallis grass seeds differed (α = 0.05) among MSZII, MSZI, and the flooded zone ($\bar{x}$ = 854.6 seeds/m^2, SE = 128.2, n = 24 versus $\bar{x}$ = 242.3 seeds/m^2, SE = 113.7, n = 24 versus $\bar{x}$ = 19.5 seeds/ m^2, SE = 7.8, n = 24, respectively). Finally, Johnson grass SN did not differ (P = 0.16) among the three soil-moisture regimes (Table 8).

Creeping spike rush did not differ (P = 0.43) in SN between soil-moisture regimes (Table 8). SN were higher (P = 0.04) for Britton's sedge in MSZII and MSZI than in the flooded zone. Pigweed SN were higher (P = 0.006) in MSZI and MSZII than in the flooded zone. The interaction (P = 0.0009) between soil moisture and drawdown timing for yellow wood sorrel revealed that, during the LSEF drawdown, SN were higher (α = 0.05) in MSZII than in the flooded zone ($\bar{x}$ = 22.5 seeds/m^2, SE = 6.1, n = 24 versus $\bar{x}$ = 1.5 seeds/m^2, SE = 1.5, n = 24, respectively) (Figure 10b). During the SPG drawdown, yellow wood sorrel SN were higher (α = 0.05) in MSZII ($\bar{x}$ = 126.4 seeds/m^2, SE = 26.9, n = 24) than in MSZI and the flooded zone ($\bar{x}$ = 12.1 seeds/m^2, SE = 4.6, n = 24 and $\bar{x}$ = 0 seeds/m^2, SE = 0, n = 24, respectively). In addition, the interaction (P = 0.01) between soil moisture and tillage application revealed that yellow wood sorrel SN within NT plots were higher (α = 0.05) in MSZII ($\bar{x}$ = 71.8 seeds/m^2, SE = 24.5, n = 24) than MSZI and the flooded zone ($\bar{x}$ = 15.5 seeds/m^2, SE = 5.4, n = 24 and $\bar{x}$ = 1.5 seeds/m^2, SE = 1.5, n = 24, respectively) (Figure 11). Likewise, within T plots, yellow wood sorrel SN were higher (α = 0.05) in MSZII ($\bar{x}$ = 77.1 seeds/m^2, SE = 19.9, n = 24) than MSZI and the flooded zone ($\bar{x}$ = 7.0 seeds/m^2, SE = 3.2, n = 24 and $\bar{x}$ = 0 seeds/m^2, SE = 0, n = 24, respectively).

Smartweed SN were higher (P = 0.03) in MSZI than in the flooded zone (Table 8). Aster (P = 0.41) and Texas frog fruit (P = 0.13) did not differ in SN between soil-moisture regimes. Spurge SN were higher (P = 0.003) in MSZI and MSZII than in the flooded zone. Curly dock SN were higher (P = 0.003) in MSZI and MSZII than in the flooded zone.

Tillage effects on seed production

Barnyard grass (P = 0.79) and knot-root bristle grass (P = 0.37) did not differ in SN between tillage treatments (Table 8). Fall panicum, however, had higher SN in NT than T plots ($\bar{x}$ = 871.4 seeds/m^2, SE = 362.5, n = 72 versus $\bar{x}$ = 43.6 seeds/m^2, SE = 20.2, n = 72, respectively, P = 0.049). Hairy

Table 8
Mean (± SE) Seeds Produced (Seeds/m²) by Emergent Plants Within Three Lewisville Ponds During 1992 and 1993 Studies

	Soil-Moisture Regime			Tillage Treatment		Drawdown Timing	
Common Name	Flooded Zone (*n* = 48)	MSZI (*n* = 48)	MSZII (*n* = 48)	Nontilled (*n* = 72)	Tilled (*n* = 72)	LSEF (*n* = 72)	SPG (*n* = 72)
Grasses							
Barnyard grasses	563.0 ± 254.7A[1]	552.7 ± 244.1A	845.9 ± 424.7A	870.7 ± 324.5A	437.0 ± 168.6A	918.4 ± 322.5A	389.4 ± 170.5A
Knot-root bristle grass	3.8 ± 2.5C	109.2 ± 32.8B	610.8 ± 181.6A	346.6 ± 122.8A	135.9 ± 40.3A	462.2 ± 124.9A	20.2 ± 6.4B
Fall panicum	4.5 ± 2.0B	249.8 ± 207.5B	1,118.1 ± 501.9A	871.4 ± 362.5A	43.6 ± 20.2B	903.5 ± 361.9A	11.4 ± 5.1B
Hairy crabgrass	1.5 ± 1.1B	56.3 ± 29.0B	317.3 ± 213.7A	212.1 ± 143.2A	38.0 ± 18.4A	234.8 ± 143.7A	15.3 ± 8.7B
Bermuda grass	8.9 ± 3.8A	47.0 ± 18.2A	159.5 ± 96.6A	115.4 ± 65.1A	28.2 ± 9.7A	112.9 ± 64.9A	30.7 ± 11.7A
Dallis grass	23.9 ± 13.8B	122.8 ± 58.9B	565.6 ± 106.7A	226.5 ± 65.7A	248.4 ± 62.3A	102.7 ± 52.5B	372.1 ± 70.3A
Johnson grass	0.0 ± 0.0A	17.9 ± 6.4A	180.8 ± 56.5A	55.7 ± 21.4A	76.8 ± 33.9A	80.8 ± 36.1A	51.7 ± 17.3A

(Continued)

Note: Seeds are categorized by grass, sedge, and forb. Seed numbers are presented for the flooded zone, moist-soil zones I (MSZI) and II (MSZII), two tillage treatments, and late-summer/early-fall (LSEF) and spring (SPG) drawdowns. Seeds were collected from traps in November 1992 and July 1993.
[1] Means within a row sharing the same letter are not significantly ($P \geq 0.05$) different within main effects for soil-moisture, tillage, and drawdown-timing treatments.

Table 8 (Concluded)

Common Name	Soil-Moisture Regime: Flooded Zone (*n* = 48)	Soil-Moisture Regime: MSZI (*n* = 48)	Soil-Moisture Regime: MSZII (*n* = 48)	Tillage Treatment: Nontilled (*n* = 72)	Tillage Treatment: Tilled (*n* = 72)	Drawdown Timing: LSEF (*n* = 72)	Drawdown Timing: SPG (*n* = 72)
Sedges							
Creeping spike rush	763.6 ± 376.3A	777.8 ± 338.2A	71.6 ± 34.4A	838.8 ± 324.7A	236.5 ± 92.6A	6.7 ± 2.8B	1,068.6 ± 329.6A
Britton's sedge[2]	247.6 ± 117.8B	494.7 ± 191.6A	665.2 ± 203.3A	767.9 ± 178.5A	170.4 ± 70.6B	0.0 ± 0.0	469.2 ± 101.7
Forbs							
Pigweed	38.2 ± 10.2B	4,097.4 ± 1,141.7A	3,889.1 ± 1,922.5A	677.0 ± 349.4B	4,672.8 ± 1,438.7A	5,322.0 ± 1,451.6A	27.8 ± 9.7B
Yellow wood sorrel	0.8 ± 0.8C	11.2 ± 3.2B	74.4 ± 15.6A	29.6 ± 9.0A	28.0 ± 7.8A	11.5 ± 2.7B	46.1 ± 11.2A
Smartweeds[3]	4.6 ± 2.5B	279.8 ± 158.4A	262.7 ± 245.1AB	57.9 ± 52.2B	306.8 ± 186.0A	182.3 ± 97.1	----
Aster	22.5 ± 5.2A	46.1 ± 11.4A	30.9 ± 7.9A	35.3 ± 8.3A	31.3 ± 5.6A	33.2 ± 5.0	0.0 ± 0.0
Texas frog fruit	393.7 ± 150.4A	49.5 ± 23.3A	30.8 ± 12.9A	81.2 ± 30.0A	234.8 ± 102.9A	158.0 ± 54.0	----
Spurge	32.8 ± 11.8B	929.5 ± 558.3A	835.5 ± 422.7A	225.3 ± 94.2B	973.3 ± 455.3A	599.3 ± 235.1	----
Curly dock	137.3 ± 81.2B	857.9 ± 235.9A	796.7 ± 189.1A	295.1 ± 64.8B	899.5 ± 199.0A	0.0 ± 0.0	597.3 ± 109.9

[2] For taxon only trapped in one season, soil moisture and tillage main-effect means were determined within the season they were trapped.
[3] SPG drawdown data were not used in mean measurements because of 0.01 frequencies of occurrence for taxon.

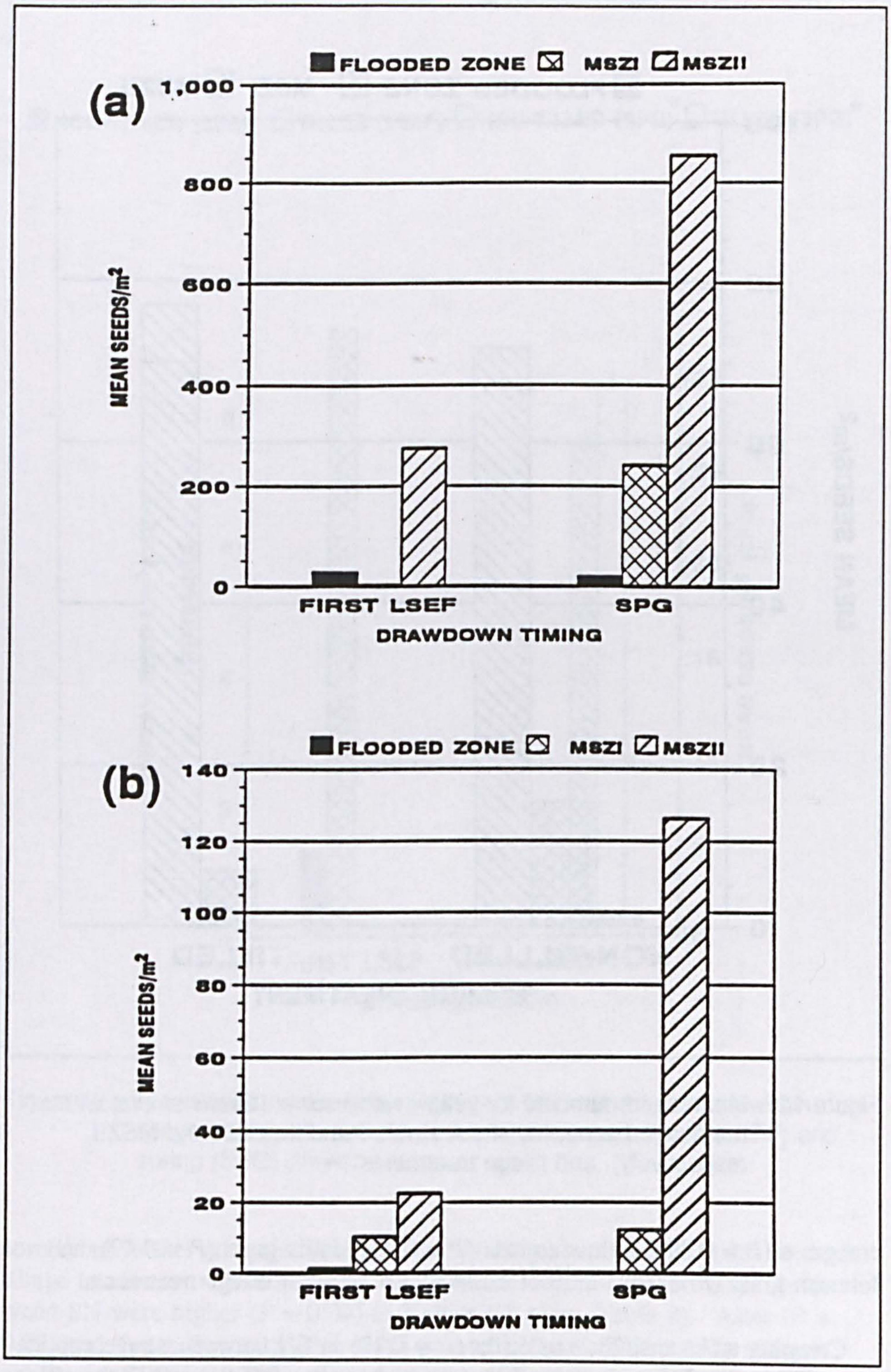


Figure 10. Mean seed numbers for (a) dallis grass (*Paspalum dilatatum*) and (b) yellow wood sorrel (*Oxalis stricta*) within the flooded zone and moist-soil zones I and II (MSZI and MSZII, respectively) during the first late-summer/early-fall (LSEF) and spring (SPG) drawdowns

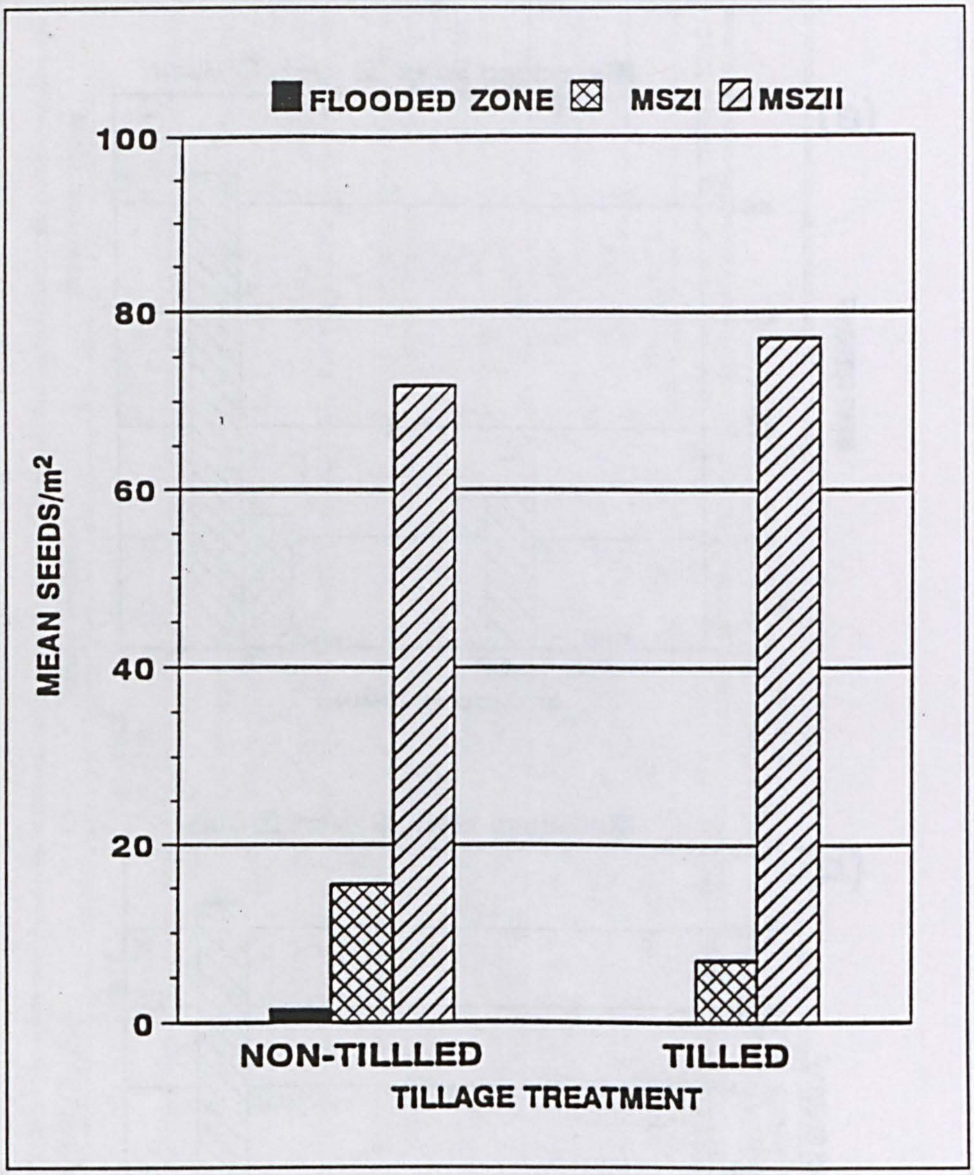


Figure 11. Mean seed numbers for yellow wood sorrel (*Oxalis stricta*) within the flooded zone, moist-soil zones I and II (MSZI and MSZII, respectively), and tillage treatments

crabgrass (P = 0.89), bermuda grass (P = 0.76), dallis grass (P = 0.49), and Johnson grass (P = 0.51) did not differ in SN between tillage treatments.

Creeping spike rush did not differ (P = 0.10) in SN between tillage applications (Table 8). Britton's sedge SN were higher (P = 0.0001) in NT than T plots. Pigweed had a significant (P = 0.03) interaction between tillage and drawdown timing with higher SN in T than NT plots ($\bar{x}$ = 9,316.2 seeds/m^2, SE = 2,676.9, n = 36 versus $\bar{x}$ = 1,327.8 seeds/m^2, SE = 686.2, n = 36, respectively, α = 0.05) during the LSEF drawdown (Figure 12). The interaction between tillage and soil moisture was significant (P = 0.01) for yellow wood

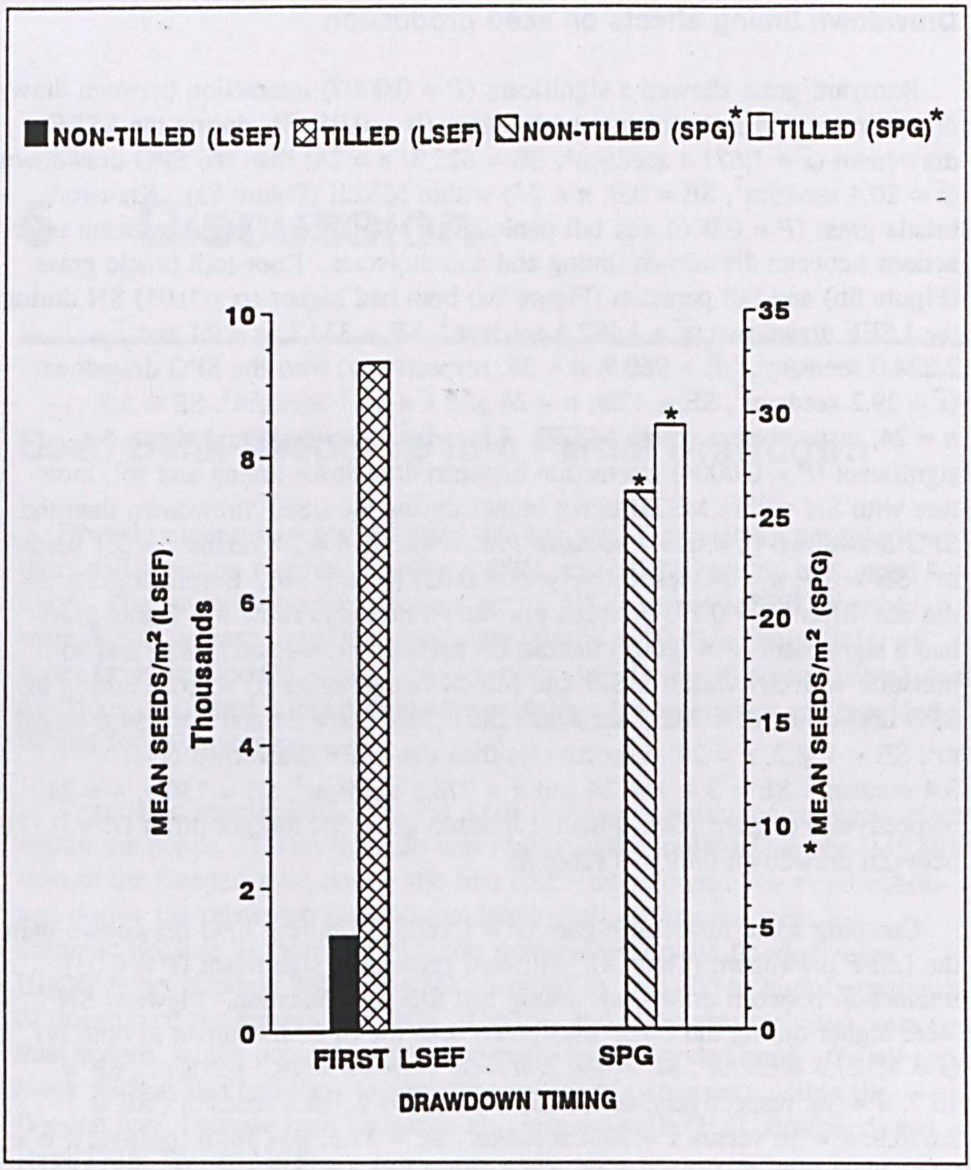


Figure 12. Mean seed numbers for pigweed (*Amaranthus palmeri*) within tillage treatments and the first late-summer/early-fall (LSEF) and spring (SPG) drawdowns

sorrel, but further analysis revealed that SN did not differ ($\alpha = 0.05$) between tillage treatments within the three soil-moisture regimes (Figure 11). Smartweed SN were higher ($P = 0.04$) in T than NT plots (Table 8). Aster ($P = 0.58$) and Texas frog fruit ($P = 0.06$) did not differ in SN between tillage applications. Spurge SN were higher ($P = 0.02$) in T than NT plots. Curly dock had higher ($P = 0.006$) SN in T than NT plots.

Drawdown timing effects on seed production

Barnyard grass showed a significant (P = 0.0007) interaction between drawdown timing and soil moisture with higher (α = 0.05) SN during the LSEF drawdown ($\bar{x}$ = 1,671.4 seeds/m^2, SE = 823.3, n = 24) than the SPG drawdown ($\bar{x}$ = 20.4 seeds/m^2, SE = 6.9, n = 24) within MSZII (Figure 8a). Knot-root bristle grass (P = 0.006) and fall panicum (P = 0.02) also had significant interactions between drawdown timing and soil moisture. Knot-root bristle grass (Figure 8b) and fall panicum (Figure 9a) both had higher (α = 0.05) SN during the LSEF drawdown ($\bar{x}$ = 1,192.4 seeds/m^2, SE = 324.3, n = 24 and $\bar{x}$ = 2,224.0 seeds/m^2, SE = 960.9, n = 24, respectively) than the SPG drawdown ($\bar{x}$ = 29.2 seeds/m^2, SE = 12.9, n = 24 and $\bar{x}$ = 12.1 seeds/m^2, SE = 5.8, n = 24, respectively) within MSZII. Likewise, hairy crabgrass showed a significant (P = 0.0004) interaction between drawdown timing and soil moisture with SN within MSZII being higher during the LSEF drawdown than the SPG drawdown ($\bar{x}$ = 629.4 seeds/m^2, SE = 422.1, n = 24 versus $\bar{x}$ = 5.1 seeds/m^2, SE = 3.7, n = 24, respectively, α = 0.05) (Figure 9b). Bermuda grass SN did not differ (P = 0.29) between drawdown timings (Table 8). Dallis grass had a significant (P = 0.002) interaction between drawdown timing and soil moisture with SN within MSZI and MSZII being higher (α = 0.05) during the SPG drawdown ($\bar{x}$ = 242.3 seeds/m^2, SE = 113.7, n = 24 and $\bar{x}$ = 854.6 seeds/m^2, SE = 128.2, n = 24, respectively) than the LSEF drawdown ($\bar{x}$ = 3.4 seeds/m^2, SE = 3.4, n = 24 and $\bar{x}$ = 276.5 seeds/m^2, SE = 150.9, n = 24, respectively) (Figure 10a). Finally, Johnson grass SN did not differ (P = 0.17) between drawdown timings (Table 8).

Creeping spike rush had higher (P = 0.003) SN during SPG drawdown than the LSEF drawdown (Table 8). Pigweed revealed a significant (P = 0.03) interaction between drawdown timing and tillage application. Pigweed SN were higher during the LSEF drawdown than the SPG drawdown in both NT ($\bar{x}$ = 1,327.8 seeds/m^2, SE = 686.2, n = 36 versus $\bar{x}$ = 26.2 seeds/m^2, SE = 15.7, n = 36, respectively, α = 0.05) and T ($\bar{x}$ = 9,316.2 seeds/m^2, SE = 2,676.9, n = 36 versus $\bar{x}$ = 29.4 seeds/m^2, SE = 11.5, n = 36, respectively, α = 0.05) plots (Figure 12). Yellow wood sorrel had a significant (P = 0.0009) interaction between drawdown timing and soil moisture with SN within MSZII being higher during the SPG drawdown than the LSEF drawdown ($\bar{x}$ = 126.4 seeds/m^2, SE = 26.9, n = 24 versus $\bar{x}$ = 22.5 seeds/m^2, SE = 6.1, n = 24, respectively, α = 0.05) (Figure 11).

5 Discussion

Seed Bank Response to a Partial Drawdown

Biweekly measurements indicated that the partial drawdown produced three soil-moisture regimes (flooded, MSZI, and MSZII) within each pond basin. Higher soil-moisture readings within MSZI versus MSZII probably were due to upward, capillary movement (Brady 1990:125; Gerla 1992) of water from the flooded zone. In this experiment, the flooded zone served dual functions; it created a moisture gradient upslope for emergents and provided habitat for submergents.

Vegetation species lists, PC, and AGB revealed zonation of emergent plants within the ponds. Taxon richness was higher in the moist-soil zones (MSZS) than in the flooded zone during the first LSEF drawdown. The trend continued during the other two drawdowns, but overall differences were less dramatic because of increases in taxon richness within the flooded zone. Higher taxon richness within the MSZS probably was due to high frequencies of occurrence for grasses and forbs. Grasses and forbs also included more taxa than sedges, which occurred most frequently in the flooded zone. Cattail and black willow also had their highest frequencies of occurrence within the flooded zone because both germinate in saturated soils (Hall, Penfound, and Hess 1946; Weller 1975).

Grass and forb PC and AGB were highest within MSZII and MSZI, respectively. Sedge AGB was significantly higher in the flooded zone than in the MSZS. Sedge PC revealed the same trend, but differences were not significant. Though some of the measurements varied among drawdowns, trends suggest that plants within the ponds were distributed in zones driven by soil moisture. Previous studies of wetlands under both stable and drawdown conditions have reported similar plant distributions along a continuum from water tolerant aquatics (e.g., cattail and bulrush (*Scirpus* spp.)) to marsh sedges, moist-soil grasses and forbs, and finally upland vegetation (Brumsted and Hewitt 1952; Harris and Marshall 1963; Weller and Spatcher 1965; Weller and Fredrickson 1974).

Kadlec (1962) reported that aerobic nitrification during a drawdown increased soil nitrates. The effect of drawdown on other nutrients was less dramatic, but the highest increases in fertility occurred when soils stayed moist during the drawdown to facilitate bacterial decomposition of organic matter. Therefore, maintaining a flooded zone within the ponds could increase soil nutrients by providing moisture to organic portions of exposed soils. In this study, soils were analyzed to test for differences in nutrients within and between ponds rather than predrawdown and postdrawdown. The three ponds each had nitrogen levels of 1 ppm (Appendix E). Other soil nutrients appear to be fairly evenly distributed between the ponds.

Seed production

SN were used as indices to test the effects of soil moisture, tillage, and drawdown timing on seed production within the ponds. Seeds were trapped only during drawdown periods. Other investigators interested in the production of wetland plants stripped seeds directly from plants as they matured (Low and Bellrose 1944; Singleton 1951; McKnight 1991) or used low-lying seed catchpans (Knauer 1977). Logistics did not permit the stripping technique in this project. Likewise, seed traps in this project stood at higher elevations than Knauer's (1977) to prevent seed loss during unexpected flooding events. Therefore, direct comparisons in seed production between this study and other studies were not feasible because of differences in collection techniques and geographical locations of projects.

Knot-root bristle grass, fall panicum, and hairy crabgrass produced their highest SN within MSZII during the first LSEF drawdown. Dallis grass produced significantly higher SN within MSZII during both the first LSEF and SPG drawdowns. No significant differences in bermuda grass and Johnson grass SN were detected, but the data indicated that each had highest production in MSZII. Barnyard grass did not indicate a significant difference in SN among moisture regimes; but, during the first LSEF drawdown, it produced its highest SN in MSZII; during the SPG drawdown, it produced its highest SN in the flooded zone. The switch in location of highest production for barnyard grass may have been due to drier soils during the SPG drawdown or perhaps due to a difference in the timing of seeding between the two species trapped. Knauer (1977) had similar results, noting that hairy crabgrass, fall panicum, and barnyard grass grew together in "high and dry" locations where the water receded first. In addition, fall panicum and barnyard grass also occurred with other plants within zones of intermediate elevations that were neither very wet nor very dry.

The two sedge species analyzed in this study differed in SN because of soil moisture. Britton's sedge was higher in MSZII and MSZI than in the flooded zone. Creeping spike rush production, though not significant, was nearly even between the flooded zone and MSZI. Yellow wood sorrel was the only forb species analyzed that had the highest SN within MSZII. Pigweed, smartweed, spurge, and curly dock had highest SN within MSZI. Texas frog fruit and aster SN did not differ between the soil-moisture regimes. The majority of forb seed distributions are consistent with the characteristic soil-moisture regimes in which the plants grow (Correll and Correll 1975).

Flooded-zone vegetation

Percent cover of all emergents within the flooded zone decreased with increasing water depths. However, PC of most submergent macrophytes increased with increasing water depths. These results agree with past research, which indicated that emergents decrease and submergents increase when flooding occurs and fairly stable water levels are maintained (Harris and Marshall 1963; Spence 1982; Thomas 1994). Muskgrass was the only submergent species to decrease with increased water depths. However, Thomas (1994) recorded increased coverage of muskgrass with increased water depths. Therefore, factors (e.g., competition or light) other than water depth may have been affecting muskgrass growth.

Soil-Disturbance Effects on Seed Banks

Rototilling created diversity within the ponds by encouraging annuals and discouraging perennials. Emergent taxon richness was higher in T than NT plots during this study. The majority of grass, sedge, and forb taxa occurred more frequently in T than NT plots. Kirkman and Sharitz (1994) also reported increased species richness in tilled areas within Carolina bays. However, Knauer (1977) noted that disking decreased species diversity in Missouri moist-soil units. The increased taxon richness in our T plots probably was due to surface exposure of buried seeds. Results were not likely due to soil moisture because the biweekly measurements indicated that soil moisture did not differ between T and NT plots. Soil bulk-density means also showed that tillage did not affect the degree of compaction in disturbed plots. There are two possible explanations for the bulk density results. Flooding the ponds soon after tilling in 1992 may have caused soil particles in T plots to settle during the drawdown. Moreover, because of procedure flaws, only a relative bulk density was obtained.

Tilling increased the PC and AGB of forbs, decreased the PC and AGB of grasses, and did not affect the PC and AGB of sedges. The majority of forbs within the ponds were annuals, and most grasses were perennials. Therefore, tilling within the ponds encouraged annual plant production and discouraged perennial plant production. Other researchers have advocated disking or tilling to discourage perennials and encourage annuals (Fredrickson and Reid 1988b; Kirkman and Sharitz 1994). In addition, cattail and black willow frequencies were highest within tilled plots. Cattail and black willow germinated best in T areas probably because of quality habitat created by disturbing soil adjacent to water (Hall, Penfound, Hess 1946; Galinato and van der Valk 1986).

Seed production

Tilling decreased fall panicum SN, but did not affect other grasses in the study. Although data were not statistically significant, tilling appeared to decrease the SN of barnyard grass, knot-root bristle grass, hairy crabgrass, and bermuda grass and increased the SN of dallis grass and Johnson grass. These findings conflict with Knauer (1977), who found that disking increased the seed production of barnyard grass, hairy crabgrass, and fall panicum.

Tilling decreased SN of Britton's sedge, but did not affect creeping spike rush SN. Pigweed SN were highest in T plots during the first LSEF drawdown, but production differences were less dramatic between T and NT plots during the SPG drawdown. Tilling also increased SN of smartweed, spurge, and curly dock, but did not affect yellow wood sorrel, aster, or Texas frog fruit SN. However, Knauer (1977) reported that curly dock was eliminated by disking. Differences in results between this study and Knauer's (1977) may be due to differences in geographical locations of study sites, pond slopes, or perhaps the fact that ponds in this study were flooded and dewatered soon after tilling.

Flooded-zone vegetation

Tillage did not affect total taxon richness or submergent or emergent richness within the flooded zone. Algae, muskgrass, and American pondweed PC also were not affected by tilling. However, tilling increased the PC of southern naiad, possibly because of the stimulation of dormant seeds. Submergent plants are characterized by van der Valk (1981) as having long-lived propagules that remain in the seed bank and become established during suitable environmental conditions.

Similar to submergents, the majority of emergents within the flooded zone were not affected by soil disturbance. Tilling did not affect the PC of creeping spike rush, smartweed, or cattail, but decreased the PC of bermuda grass. The combined stress from tilling and flooding was probably more than bermuda grass could tolerate.

Drawdown Timing Effects on Seed Banks

Drawdown timing has been shown to affect the germination, growth, and seed production of plants in moist-soil impoundments (Knauer 1977; Fredrickson 1991; McKnight 1991, 1992). Different timing can affect soil temperature (Knauer 1977) and moisture (Knauer 1977; McKnight 1991, 1992). Soil temperatures were not measured in this project, but soil moisture was higher during the first LSEF drawdown than during the SPG drawdown. McKnight (1992) reported similar findings during an August drawdown with higher soil moisture than an April drawdown. Total rainfall was higher during the LSEF drawdown (17.4 cm) versus the SPG drawdown (9.9 cm). Therefore, in addition to drawdown timing, soil moisture may have been affecting plant growth during the first LSEF and SPG drawdowns.

Drawdown timing did not affect taxon richness of emergent plants within the drawdown region. The majority of grasses and sedges occurred most frequently during the LSEF drawdowns, but forbs were equally frequent between the SPG and LSEF drawdowns. The effect of drawdown timing on species richness and diversity is variable between moist-soil impoundments. McKnight (1992) reported highest taxon richness during an early (April) drawdown on an east Texas mine-spoil pond, but Knauer (1977) had lower species diversity during an early (May-June) drawdown in Missouri.

Drawdown timing did not affect grass PC, but grass AGB was highest during the SPG drawdown. Within the flooded zone, sedge PC was higher during the SPG and second LSEF drawdowns than during the first LSEF drawdown. Sedge AGB also was highest during the SPG drawdown. The higher PC and AGB values for sedge in the SPG and second LSEF drawdowns probably was due to the germination of creeping spike rush, Britton's sedge, and flatsedge during the SPG drawdown and persistence throughout the summer and fall. Forb PC was highest during the SPG drawdown, and forb AGB was significantly higher during the SPG drawdown than the first LSEF drawdown within MSZI. The flooded zone and MSZII also showed similar patterns in forb AGB.

Seed production

Drawdown timing did not affect the SN of Johnson grass or bermuda grass. The combination of drawdown timing and soil moisture did affect the other five grasses analyzed. Barnyard grass, knot-root bristle grass, fall panicum, and hairy crabgrass had higher SN during the first LSEF drawdown versus the SPG drawdown. Within MSZI and MSZII, dallis grass had highest SN during the SPG drawdown. McKnight (1991) reported that barnyard grass (*Echinochloa crusgalli* var. *crusgalli*) only produced seeds during a spring drawdown in east Texas, and Knauer (1977) noted higher seed production for barnyard grass, fall panicum, and hairy crabgrass during an early drawdown. However, Knauer's (1977) figures included cumulative seed production throughout the summer and into the fall, whereas this study only measured early-drawdown (April) seed production through 7 July.

The SPG drawdown was more effective than the LSEF drawdown in producing sedge seeds. Creeping spike rush and Britton's sedge produced their highest SN during the SPG drawdown. Previous researchers also reported higher spike rush growth and seed production following early drawdowns (Connelly 1979; Fredrickson 1991). The first LSEF drawdown produced the highest SN for pigweed in both NT and T plots. Pigweed SN drastically decreased during the SPG drawdown. High pigweed SN during the first LSEF drawdown probably were due to drawdown timing and invasion of the plant into newly tilled plots. Yellow wood sorrel, affected by the combination of drawdown timing and soil moisture, had its highest SN within MSZII during the SPG drawdown. Smartweeds, Texas frog fruit, and spurge produced their highest SN during the LSEF drawdown. Aster and curly dock were the only forbs analyzed that produced seeds solely during the first LSEF and SPG drawdowns, respectively. Seed production data indicated that the LSEF drawdown was more effective than the SPG drawdown in producing large numbers of seeds from a variety of plant species.

Flooded-zone vegetation

Drawdown timing did not affect total taxon richness or taxon richness of emergents or submergents. Southern naiad PC was not affected by drawdown timing, but algae PC was highest during the SPG drawdown. American pondweed was not detected during the first LSEF, but it increased in coverage during subsequent drawdowns. Muskgrass PC was highest during the first LSEF drawdown and subsequently decreased. Though this study did not directly test for competition between plants, muskgrass coverage may have decreased because of competition with southern naiad and American pondweed.

Drawdown timing did not affect smartweed and bermuda grass PC within the flooded zone. However, creeping spike rush PC was highest during the second LSEF drawdown. Creeping spike rush coverage was probably higher because of increased coverage from vegetative reproduction. Cattail was not detected within the flooded zones of the ponds until the SPG drawdown. Cattail had a frequency of 0.08 within T plots during the SPG drawdown. By the second LSEF drawdown, cattail frequencies increased in T (0.17) and NT (0.42) plots. Previous studies have reported similar results of cattail invasion (Brumsted and Hewitt 1952; Weller and Fredrickson 1974).

6 Waterfowl Feeding Patterns

Introduction

Nearly 50 percent of waterfowl using North America's Central Flyway winter in Texas (Buller 1964). Although the gulf coast and playa lakes are regarded as the two most important regions for wintering waterfowl in Texas (Buller 1964), north-central Texas is an important area where waterfowl use a variety of habitats including reservoirs, flood-prevention lakes, and farm ponds (Texas Parks and Wildlife 1982).

Migrant and wintering waterfowl in east Texas selected created wetlands based upon size, depth, and amount and type of vegetation (Reynolds 1989; DeRoia 1993). In other locations, researchers found that migrant and wintering waterfowl selected feeding locations according to water depth and emergent and submergent plant communities within wetlands (White and James 1978; Chabreck 1979; Paulus 1982). Observations were conducted on the LAERF in north-central Texas to determine if migrant and wintering waterfowl were partitioning feeding locations according to water depth and plant communities. Three ponds on the LAERF had been managed to provide emergent and submergent vegetation and seeds (Chapter 3).

Methods

The highest water level used in each pond during the experiment was at step 6 on the control structure (Figure 3). During partial drawdowns, ponds were maintained at base water levels (step 4) to provide suitable conditions for submergent vegetation. Exposed soils between step 4 and step 6 water lines supported moist-soil emergents. To delineate the boundary between the continuously flooded pool and moist-soil zone, PVC pipes (2-in. diam) were placed along the step 4 water line.

Ponds were reflooded to step 6 after vegetation and seed data were collected for 1992 and 1993 LSEF drawdowns to allow waterfowl access to remaining seeds, vegetation, and invertebrates. Water depths at the PVC pipes averaged 32 cm. Therefore, the zone upslope from the pipes was fairly shallow (<32 cm) and supported mainly emergent vegetation, while the zone downslope from the pipes was deep (>32 cm) and supported predominantly submergent vegetation. Ponds remained flooded to step 6 from 18 December 1992 to 4 April 1993 and 16 November 1993 to 1 May 1994.

Waterfowl observations were conducted during peak-use periods: 5 days between 5 and 17 March 1993 and 2 days (12-13) in January 1994. Waterfowl were viewed with a spotting scope and binoculars from either of two constructed blinds. Position of the first blind allowed simultaneous viewing of ponds 1 and 2 while pond 3 was viewed from the second blind. A sampling period (2 days) consisted of 4 bouts lasting approximately 2 hr in the morning, beginning one-half hour before sunrise, and 2 hr before sunset. Blinds were randomly selected the first morning and evening of a sampling period. Order of blind use was reversed on the second day of the sampling period to ensure that equal numbers of morning and evening observations were conducted on each pond. Scan sampling (Altmann 1974) was used to record waterfowl species, numbers, and zone of use (shallow or deep) at 10-min intervals within each pond.

Mean number of ducks per scan was calculated for individual species according to the zone and pond in which they occurred (e.g., emergent zone and pond 1). Only scans in which the species occurred were used in mean calculations. Analysis of variance (PROC ANOVA, SAS Institute, Inc. 1987) was used to test for differences in mean ducks per scan by species between the two zones. Because analyses revealed that mean ducks per scan did not differ by species between ponds, mean number of ducks per scan was tested for differences between zones, regardless of pond.

Results

Blue-winged teal (*Anas discors*), mallards (*A. platyrhyncos*), and green-winged teal (*A. crecca*) had the first, second, and third highest frequencies of occurrence per scanning period, respectively (Table 9). However, mean blue-winged teal ($P = 0.15$), mallards ($P = 0.98$), and green-winged teal ($P = 0.29$) per scan did not differ between the two water depths. American wigeon (*A. americana*) were observed only within the deep zone of the ponds. Gadwall (*A. strepera*) were observed least and had higher ($P = 0.002$) mean numbers per scan in the deep versus shallow zone.

Discussion

Higher mean American wigeon and gadwalls per scan in the deep versus shallow zone were consistent with observations by previous workers (White

Table 9
Frequency of Occurrence for Waterfowl Species During Scanning Bouts in Which Waterfowl Were Present and Mean (± SE) Waterfowl per Scan Within Deepwater and Shallow-Water Zones of Three Lewisville Ponds During 1993 and 1994 Observation Periods

Common Name	Scientific Name	Frequency of Occurrence (n = 21)	Water Zone: Deep	Water Zone: Shallow
Blue-winged teal	*Anas discors*	0.67	3.06 ± 0.67A[1] (n = 14)[2]	5.69 ± 1.66A (n = 14)
Mallard	*A. platyrhyncos*	0.57	1.59 ± 0.78A (n = 12)	1.56 ± 0.55A (n = 12)
Green-winged teal	*A. crecca*	0.43	2.86 ± 1.61A (n = 9)	7.13 ± 3.52A (n = 9)
American wigeon	*A. americana*	0.24	2.02 ± 0.04 (n = 5)	0.00 (n = 5)
Gadwall	*A. strepera*	0.14	1.87 ± 0.18A (n = 3)	0.13 ± 0.13B (n = 3)

[1] Means within a row sharing the same letter are not significantly ($P \geq 0.05$) different.
[2] Number of observation bouts in which individual species occurred.

and James 1978; Chabreck 1979; DeRoia 1993). The deep zone primarily supported submergent vegetation (e.g., muskgrass, southern naiad, and American pondweed) and filamentous algae (Chapter 3), which are the major foods of nonbreeding American wigeon and gadwall (White and James 1978; Paulus 1982; DeRoia 1993). Mallards occurred in relatively equal proportions between deep and shallow zones, probably because mallards use a wide array of vegetation and seeds (Chabreck 1979; Bellrose 1980; Jorde, Krapu, and Crawford 1983).

Although blue-winged and green-winged teal numbers per scan did not differ statistically between water depths, their mean values indicated that more ducks of each species occurred in the shallow versus deep zone. The shallow zone consisted solely of emergent vegetation and presumably seeds from previous drawdowns. Other researchers reported similar results with teal feeding in waters less than 32 cm in depth and dominated by emergent vegetation (Taylor 1978; White and James 1978; Euliss and Harris 1987). However, DeRoia (1993) noted blue-winged teal feeding primarily in mean water depths of 53 cm, presumably in search of invertebrates in submergent vegetation growing to the water surface. Other research has indicated that migrant and wintering waterfowl consume both plant and animal matter (Taylor 1978; Paulus 1982; DuBowy 1988). Therefore, waterfowl utilizing the ponds during spring observations may have been influenced by the type and distribution of vegetation and associated invertebrates within the two water zones.

7 Conclusions and Management Recommendations

Partial drawdowns, drawdown timing, and soil disturbance were effective tools in creating diverse habitats in shallow impoundments to satisfy the needs of a diversity of waterfowl. Partial drawdowns resulted in soil-moisture regimes in the ponds that produced a typical zonation of wetland plants: (a) submergents in deeper regions of the flooded zone; (b) cattail, black willow, and sedges in shallow regions of the flooded zone; (c) forbs in the moist zone adjacent to the water; and (d) grasses in the upper, drier zone. Waterfowl managers must consider target vegetation when designing impoundments and determining the extent of drawdowns. Results suggested that, during partial drawdowns, impoundments with gradual slopes would retain higher soil moisture over greater distances from the water's edge, thus producing larger patches of beneficial moist-soil plants such as smartweed, curly dock, barnyard grass, fall panicum, and hairy crabgrass. Designing impoundments with extensive shallow-sloped areas and a deeper pool would increase plant diversity by providing habitat for both moist-soil and submergent plant production. Presence of a deep continuously flooded pool also could limit cattail to a narrow band within shallow regions (Weller 1975) along the flooded margin.

Water availability, control structures, and the precision of water-level control in an impoundment ultimately determine drawdown timing and the number of possible drawdowns per year. In north Texas, if only a single drawdown is feasible, an LSEF drawdown is suggested for high barnyard grass, fall panicum, hairy crabgrass, and smartweed seed production. The LSEF drawdown allows the plants to drop their seeds just prior to the time of reflooding for waterfowl use. An SPG drawdown initially stimulates growth and high seed production of Britton's sedge, creeping spike rush, and curly dock, as well as minimal seed production of barnyard grass, fall panicum, and hairy crabgrass. However, if drought conditions develop and the impoundment cannot be reflooded, warm season grasses may experience stress conditions limiting summer/fall growth and seed production (Fredrickson 1991). Results also suggested that, if water is available, the ideal situation would be two drawdowns during a growing season; an SPG drawdown for early-season plant growth and seed production, reflooding (irrigation) for 1 to 2 days in August, and then an LSEF drawdown for late-season plant growth and seed production.

Soil disturbance by rototilling proved to be an effective means of creating diversity within shallow impoundments by increasing richness of emergent taxa, encouraging annuals, and discouraging perennials. Tilling increased seed production of beneficial forbs (e.g., smartweed and curly dock), but decreased seed production of barnyard grass, fall panicum, hairy crabgrass, and Britton's sedge. Results of this project and others indicated that pigweed, cattail (Sojda and Solberg 1993), and black willow (Hall, Penfound, and Hess 1946) colonize bare-soil sites provided by tilling and possibly limit the growth of other beneficial plants through competition for space and light.

Rototilling did not appear to affect the majority of submergent plants in research ponds; however, southern naiad percent cover increased with tilling. Additional research is needed to determine the effects of soil disturbance on other submergent species beneficial to waterfowl. Soil consistency in tilled plots within the flooded region remained relatively noncoherent throughout the study, suggesting that rototilling could impact rooted submergent plants that produce rhizomes and tubers for vegetative reproduction.

Finally, observations revealed that a diversity of waterfowl used the variety of water depth and plant communities within each pond. Gadwall and American wigeon utilized deeper sites characterized by submergent vegetation, while blue-winged and green-winged teal occurred most in shallow sites with predominantly emergent vegetation. Although not directly tested in this project, other researchers noted differences in waterfowl response to drawdown timing (Fredrickson 1991) and soil disturbance (Kaminski and Prince 1981). Through consideration of individual site characteristics and by conducting partial drawdowns, varying drawdown timing, and disturbing soils, managers can provide a variety of vegetation and seeds for migrant and wintering waterfowl.

References

Altmann, J. (1974). "Observational study of behavior: Sampling methods," *Behav*. 49, 227-267.

Bailey, A. W., and Poulton, C. E. (1968). "Plant communities and environmental interrelationships in a portion of the Tillamook burn, northwestern Oregon," *Ecology* 49, 1-13.

Baldassarre, G. A. (1980). "Residual seeds as potential spring waterfowl foods in small, man-made impoundments," *Prairie Nat.* 12, 1-8.

Bellrose, F. C. (1980). *Ducks, geese, and swans of North America.* Stackpole Books, Harrisburg, PA.

Bellrose, F. C., and Low, J. B. (1978). "Advances in waterfowl management research," *Wildl. Soc. Bull.* 6, 63-72.

Brady, N. C. (1990). *The nature and properties of soils.* 10th ed., Macmillan Publishing Co., New York.

Brumsted, H. B., and Hewitt, O. H. (1952). "Early investigations on artificial marsh development in New York," *North Amer. Wildl. Conf., Wildl. Manage. Inst.* 17, 259-268, Washington, DC.

Buller, R. F. (1964). "Central flyway." *Waterfowl tomorrow.* J. P. Linduska, ed., U.S. Department of Interior, Washington, DC, 209-232.

Burgess, H. H. (1969). "Habitat management on a mid-continent waterfowl refuge," *J. Wildl. Manage.* 33, 843-847.

Chabreck, R. H. (1979). "Winter habitat of dabbling ducks--physical, chemical, and biological aspects." *Waterfowl and wetlands--an integrated review.* T. A. Bookhout, ed., The Wildlife Society North Central Section, Lacrosse, WI, 133-142.

Connelly, D. P. (1979). "Propagation of selected native marsh plants in the San Joaquin Valley," California Fish and Game, Sacramento, California Wildlife Management Leaflet No. 15.

Correll, D. S., and Correll, H. B. (1975). *Aquatic and wetland plants of the southwestern United States*. Vol. 1 and 2, Stanford University Press, Stanford, CA.

Correll, D. S., and Johnston, M. C. (1970). *Manual of the vascular plants of Texas*. Texas Research Foundation, Penner, TX.

Dahl, T. E. (1990). "Wetlands losses in the United States 1780's to 1980's," U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC.

Delorit, R. J. (1970). *An illustrated taxonomy manual of weed seeds*. Agronomy Publications, River Falls, WI.

DeRoia, D. M. (1993). "Feeding ecology of nonbreeding ducks on strip-mine sediment ponds in east-central Texas," Ph.D. diss., Texas A&M University, College Station.

DuBowy, P. J. (1988). "Waterfowl communities and seasonal environments: Temporal variability in interspecific competition," *Ecology* 69, 1439-1453.

Euliss, N. H., Jr., and Harris, S. W. (1987). "Feeding ecology of northern pintails and green-winged teal wintering in California," *J. Wildl. Manage.* 51, 724-732.

Ford, A., and Pauls, E. (1980). "Soil survey of Denton County, Texas," U.S. Department of Agriculture Soil Conservation Service.

Fredrickson, L. H. (1991). "Strategies for water level manipulations in moist-soil systems," U.S. Fish and Wildlife Leaflet 13.4.6.

Fredrickson, L. H., and Drobney, R. D. (1979). "Habitat utilization by post-breeding waterfowl." *Waterfowl and wetlands--an integrated review*. T. A. Bookhout, ed., The Wildlife Society North Central Section, Lacrosse, WI, 119-131.

Fredrickson, L. H., and Reid, F. A. (1988a). "Invertebrate response to wetland management," U.S. Fish and Wildlife Leaflet 13.3.1.

__________. (1988b). "Preliminary considerations for manipulating vegetation," U.S. Fish and Wildlife Leaflet 13.4.9.

__________. (1988c). "Waterfowl use of wetland complexes," U.S. Fish and Wildlife Leaflet 13.2.1.

Fredrickson, L. H., and Taylor, T. S. (1982). "Management of seasonally flooded impoundments for wildlife," U.S. Fish and Wildlife Resource Publication 148.

Galinato, M. I., and van der Valk, A. G. (1986). "Seed germination traits of annuals and emergents recruited during drawdowns in the Delta marsh Manitoba, Canada," *Aquatic Bot.* 26, 89-102.

Gerla, P. J. (1992). "The relationship of water-table changes to the capillary fringe, evapotranspiration, and precipitation in intermittent wetlands," *Wetlands* 12, 91-98.

Givens, L. S., and Atkenson, T. Z. (1957). "The use of dewatered land in southeastern waterfowl management," *J. Wildl. Manage.* 21, 465-467.

Gomez, K. A., and Gomez, A. A. (1984). *Statistical procedures for agriculture research.* 2d ed., John Wiley and Sons, Inc., New York.

Gould, F. W. (1975a). "Texas plants--a checklist and ecological summary," Texas Agricultural Experiment Station, Texas A&M University, College Station.

__________. (1975b). *The grasses of Texas.* Texas A&M University Press, College Station.

Hall, T. F., Penfound, W. T., and Hess, A. D. (1946). "Water level relationships of plants in the Tennessee Valley with particular reference to malaria control," *J. Tenn. Acad. Sci.* 21, 18-59.

Harris, S. W., and Marshall, W. H. (1963). "Ecology of water level manipulations on a northern marsh," *Ecology* 44, 331-343.

Haukus, D. A., and Smith, L. M. (1993). "Moist-soil management of playa lakes for migrating and wintering ducks," *Wildl. Soc. Bull.* 21, 288-298.

Heitmeyer, M. E., and Vohs, P. A., Jr. (1984). "Distribution and habitat use of waterfowl wintering in Oklahoma," *J. Wildl. Manage.* 48, 51-62.

Hillel, D. (1980). *Fundamentals of soil physics.* Academic Press, New York.

Hobaugh, W. C., and Teer, J. G. (1981). "Waterfowl use characteristics of flood prevention lakes in north-central Texas," *J. Wildl. Manage.* 45, 16-26.

Huenneke, L. F., and Graham, C. (1987). "A new sticky trap for monitoring seed rain in grasslands," *J. Range Manage.* 40, 370-372.

Hutchings, M. J. (1986). "Plant population biology." *Methods in plant ecology.* P. D. Moore and S. B. Chapman, ed., Blackwell Scientific Publications, Inc., Palo Alto, CA, 377-435.

Johnson, C. K., and West, N. E. (1987). "Laboratory comparisons of five seed-trap designs for dry, windy environments," *Can. J. Bot.* 66, 346-348.

Jorde, G. D., Krapu, G. L., and Crawford, R. D. (1983). "Feeding ecology of mallards wintering in Nebraska," *J. Wildl. Manage.* 47, 1044-1053.

Kadlec, J. A. (1962). "Effects of drawdown on a waterfowl impoundment," *Ecology* 43, 267-281.

Kaminski, R. M., and Prince, H. H. (1981). "Dabbling duck and aquatic macroinvertebrate responses to manipulated wetland habitat," *J. Wildl. Manage.* 45, 1-15.

Kelley, J. R., Jr., and Fredrickson, L. H. (1991). "Chufa biology and management," U.S. Fish and Wildlife Leaflet 13.4.18.

Kirkman, L. K., and Sharitz, R. R. (1994). "Vegetation disturbance and maintenance of diversity in intermittently flooded Carolina bays in South Carolina," *Ecol. Appl.* 4, 177-188.

Knauer, D. F. (1977). "Moist soil plant production on Mingo National Wildlife Refuge," M.S. thesis, University of Missouri, Columbia.

Krapu, G. L. (1974). "Foods of breeding pintails in North Dakota," *J. Wildl. Manage.* 38, 408-417.

Krull, J. (1970). "Aquatic plant macroinvertebrate associations and waterfowl," *J. Wildl. Manage.* 34, 707-715.

Low, J. B., and Bellrose, F. C., Jr. (1944). "The seed and vegetative yield of waterfowl food plants in the Illinois River Valley," *J. Wildl. Manage.* 8, 7-22.

Martin, A. C., and Barkley, W. D. (1961). *Seed identification manual.* University of California Press, Berkeley.

Martin, A. C., Zim, H. S., and Nelson, A. L. (1951). *American wildlife and plants: A guide to wildlife food habits.* Dover Publications, Inc., New York.

McKnight, S. K. (1991). "Establishment of wetland vegetation on east Texas mine spoil," M.S. thesis, Texas A&M University, College Station.

__________. (1992). "Transplanted seed bank response to drawdown time in a created wetland in east Texas," *Wetlands* 12, 79-90.

Meeks, R. L. (1969). "The effect of a drawdown date on wetland plant succession," *J. Wildl. Manage.* 33, 817-821.

Milford, M. H. (1991). "Physical characterization of soils: Part 1." *Introduction to soils and soil science: Laboratory exercises.* M. H. Milford, ed., Kendall/Hunt Publishing Company, Dubuque, IA, 10-18.

Murkin, H. R., and Kadlec, J. A. (1986). "Relationships between waterfowl and macroinvertebrate densities in a northern prairie marsh," *J. Wildl. Manage.* 50, 212-217.

Owenby, J. R., and Ezell, D. S. (1992). "Monthly station normals of temperature, precipitation, and heating and cooling degree days (1961-1990): Texas." *Climatography of the U.S. No. 81.* U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC.

Paulus, S. L. (1982). "Feeding ecology of gadwalls in Louisiana in winter," *J. Wildl. Manage.* 46, 71-79.

Reid, F. A., Kelley, J. R., Jr., Taylor, T. S., and Fredrickson, L. H. (1989). "Upper Mississippi valley wetlands--refuges and moist-soil impoundments." *Habitat management for migrating and wintering waterfowl in North America.* L. M. Smith, R. L. Pederson, and R. M. Kaminski, ed., Texas Tech University Press, Lubbock, 181-202.

Reynolds, L. A. (1989). "Waterfowl use of sediment ponds on an east Texas coal mine," M.S. thesis, Texas A&M University, College Station.

Riley, T. Z., and Bookhout, T. A. (1990). "Response of macroinvertebrates to early-spring drawdown in nodding smartweed marshes," *Wetlands* 10, 173-185.

SAS Institute, Inc. (1987). "SAS/STAT guide for personal computers." Version 6 ed., SAS Institute Inc., Cary, NC.

Singleton, J. R. (1951). "Production and utilization of waterfowl food plants on the east Texas gulf coast," *J. Wildl. Manage.* 15, 46-56.

Smith, L. M., Pederson, R. L., and Kaminski, R. M., ed. (1989). *Habitat management for migrating and wintering waterfowl in North America.* Texas Tech University Press, Lubbock.

Soil Survey Staff. (1984). "Procedures for collecting soil samples and methods of analysis for soil survey," U.S. Department of Agriculture, Soil Conservation Service, U.S. Government Printing Office, Washington, DC, Soil Survey Investigation Report No. 1.

Sojda, R. S., and Solberg, K. L. (1993). "Management and control of cattails," U.S. Fish and Wildlife Leaflet 13.4.13.

Spence, D. H. N. (1982). "The zonation of plants in freshwater lakes," *Adv. Ecol. Res.* 12, 37-125.

Taylor, T. S. (1978). "Spring foods of migrating blue-winged teals on seasonally flooded impoundments," *J. Wildl. Manage.* 42, 900-903.

Texas Parks and Wildlife Department. (1982). "Future of waterfowl in Texas: An issue of habitat," Wildlife Division, Federal Aid Project W-106-R, Austin, TX.

Thomas, J. A. (1994). "Establishment of submergent vegetation and invertebrates in a wetland constructed on mine spoil," M.S. thesis, Texas A&M University, College Station.

van der Valk, A. G. (1981). "Succession in wetlands: A Gleasonian approach," *Ecology* 62, 688-696.

van der Valk, A. G., and Pederson, R. L. (1989). "Seed banks and the management and restoration of natural vegetation." *Ecology of soil seed banks.* M. A. Leck, V. T. Parker, and R. L. Simpson, ed., Academic Press, Inc., San Diego, CA, 329-346.

Weller, M. W. (1975). "Studies of cattail in relation to management for marsh wildlife," *Iowa State J. Res.* 49, 383-412.

__________. (1990). "Waterfowl management techniques for wetland enhancement, restoration and creation useful in mitigation procedures." *Wetland creation and restoration.* J. A. Kusler and M. E. Kentula, ed., Island Press, Washington, DC, 517-528.

Weller, M. W., and Fredrickson, L. H. (1974). "Avian ecology of a managed glacial marsh." *The Living Bird.* Cornell Laboratory of Ornithology, Ithaca, NY, 269-291.

Weller, M. W., and Spatcher, C. S. (1965). "Role of habitat in the distribution and abundance of marsh birds," Iowa Agricultural Home Economics Experiment Station Special Report No. 43.

Welling, C. H., Pederson, R. L., and van der Valk, A. G. (1988). "Temporal patterns in recruitment from the seed bank during drawdowns in a prairie wetland," *J. Appl. Ecol.* 25, 999-1007.

Werner, P. A. (1975). "A seed trap for determining patterns of seed deposition in terrestrial plants," *Can. J. Bot.* 53, 810-813.

White, D. H., and James, D. (1978). "Differential use of fresh water environments by wintering waterfowl of coastal Texas," *Wilson Bull.* 90, 99-111.

Appendix A Soil Textures for Nontilled and Tilled Plots in Research Ponds at the Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX

Soil sampling procedures followed those specified by the Extension Soil, Water, and Forage Testing Laboratory, Soil and Crop Sciences, Texas A&M University, College Station, TX. Twenty soil samples were randomly taken from each pond on 23 July 1993; ten from the tilled and nontilled stretches, respectively. The samples from each pond were pooled by tillage application, and a subsample was extracted for analysis. Texture was determined using the hydrometer method and a textural triangle (Milford 1991).[1]

Soil Textures for Nontilled and Tilled Plots in Each of Four Experimental Ponds Used for Research at the Lewisville Aquatic Ecosystem Research Facility in Lewisville, TX

Pond	Tillage	% Sand	% Clay	% Silt	Textural Class
1	Nontilled	57.1	27.2	15.7	Sandy clay loam
1	Tilled	55.1	27.2	17.7	Sandy clay loam
2	Nontilled	47.1	34.2	18.7	Sandy clay loam
2	Tilled	48.0	34.2	17.8	Sandy clay loam
3	Nontilled	57.3	30.2	12.5	Sandy clay loam
3	Tilled	57.3	30.4	12.3	Sandy clay loam
4	Nontilled	49.0	34.4	16.7	Sandy clay loam
4	Tilled	55.5	32.9	11.6	Sandy clay loam

[1] References cited in this appendix are located at the end of the main text.

Appendix B
Bailey and Poulton Rating Scale Used to Estimate Percent Cover for Vegetation Within Ponds at the Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX

Bailey and Poulton (1968) Rating Scale for Percent Cover Estimates[1]

Rank	Percent Cover Interval	Interval Midpoints
1	0 - 1	0.5
2	1 - 5	3.0
3	5 - 25	15.0
4	25 - 50	37.5
5	50 - 75	62.5
6	75 - 95	85.0

1 References cited in this appendix are located at the end of the main text.

Appendix C
Mean Seed Weights of 16 Emergent Plants Within Three Ponds During 1992 and 1993 Studies at the Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX

Mean Seed Weights (Oven-Dried) of 16 Emergent Plants Within Three Lewisville Ponds During 1992 and 1993 Studies

		LSEF			SPG		
Common Name	**Scientific Name**	**No. of Seeds**	**% Total**	**g/100 Seeds**	**No. of Seeds**	**% Total**	**g/100 Seeds**
			Grasses				
Barnyard grasses	*Echinochloa* spp.	2,831	14.5	0.0869	848	10.0	0.1420
Knot-root bristle grass	*Setaria parviflora*	954	4.9	0.0995	66	0.8	0.1167
Fall panicum	*Panicum dichotomiflorum*	2,057	10.5	0.0737	31	0.4	0.0710
Hairy crabgrass	*Digitaria sanguinalis*	460	2.4	0.0596	27	0.3	0.0593
Bermuda grass	*Cynodon dactylon*	200	1.0	0.0165	54	0.6	0.0093
Dallis grass	*Paspalum dilatatum*	227	1.2	0.1110	941	11.1	0.1386
Johnson grass	*Sorghum halepense*	145	0.7	0.2062	117	1.4	0.2795

(Continued)

Note: Seeds are categorized by grass, sedge, and forb. Seeds were collected during the first late-summer/early-fall (LSEF) and spring (SPG) drawdowns, November 1992 and July 1993, respectively.

Appendix C (Concluded)

Common Name	Scientific Name	LSEF			SPG		
		No. of Seeds	% Total	g/100 Seeds	No. of Seeds	% Total	g/100 Seeds
Sedges							
Creeping spike rush	*Eleocharis macrostachya*	12	0.1	0.0250	2,008	23.7	0.0488
Britton's sedge	*Carex brittoniana*	0	0.0	0.0	1,348	15.9	0.1299
Forbs							
Pigweed	*Amaranthus palmeri*	10,478	53.5	0.0238	53	0.6	0.0151
Yellow wood sorrel	*Oxalis stricta*	50	0.3	0.0180	102	1.2	0.0137
Smartweeds	*Polygonum* spp.	351	1.8	0.1795	2	T[1]	0.0015
Aster	*Aster subulatus*	71	0.4	0.0042	0	0.0	0.00
Texas frog fruit	*Phyla incisa*	361	1.8	0.0199	79	0.9	0.0278
Spurge	*Chamaesyce* sp.	1,107	5.7	0.0202	1	T	---[2]
Curly dock	*Rumex crispus*	0	0.0	0.00	1,272	15.0	0.2049
Total[3]		19,584			8,464		

[1] Counts less than 0.1% indicated by T (trace).
[2] Weight too small to be measured.
[3] Total includes taxa listed, plus 11 taxa not listed because of frequencies of occurrence below 0.23 for one collection period.

Appendix D
Mean Seed Biomass Produced by Emergent Plants Within Three Ponds During 1992 and 1993 Studies at the Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX

Appendix D
Mean (± SE) Seed Biomass (g/m^2) Produced by Emergent Plants Within Three Lewisville Ponds During 1992 and 1993 Studies

Common Name	Soil-Moisture Regime			Tillage Treatment		Drawdown Timing	
	Flooded Zone (n = 48)	MSZI (n = 48)	MSZII (n = 48)	Nontilled (n = 72)	Tilled (n = 72)	LSEF (n = 72)	SPG (n = 72)
Grasses							
Barnyard grasses	0.77 ± 0.36[1]	0.52 ± 0.21	0.74 ± 0.37	0.83 ± 0.29	0.55 ± 0.24	0.80 ± 0.28	0.55 ± 0.24
Knot-root bristle grass	0.004 ± 0.003	0.11 ± 0.03	0.61 ± 0.18	0.35 ± 0.12	0.14 ± 0.04	0.46 ± 0.12	0.02 ± 0.01
Fall panicum	0.003 ± 0.001	0.18 ± 0.15	0.82 ± 0.37	0.64 ± 0.27	0.03 ± 0.02	0.67 ± 0.27	0.008 ± 0.004
Hairy crabrass	0.001 ± 0.001	0.03 ± 0.02	0.19 ± 0.13	0.13 ± 0.09	0.02 ± 0.01	0.14 ± 0.09	0.009 ± 0.005
Bermuda grass	0.001 ± 0.001	0.006 ± 0.003	0.03 ± 0.02	0.02 ± 0.01	0.004 ± 0.001	0.02 ± 0.01	0.003 ± 0.001
Dallis grass	0.03 ± 0.02	0.17 ± 0.08	0.75 ± 0.14	0.30 ± 0.08	0.33 ± 0.08	0.11 ± 0.06	0.52 ± 0.10
Johnson grass	0.0 ± 0.0	0.04 ± 0.01	0.42 ± 0.12	0.13 ± 0.05	0.18 ± 0.07	0.17 ± 0.07	0.14 ± 0.05
Sedges							
Creeping spike rush	0.37 ± 0.18	0.38 ± 0.17	0.03 ± 0.02	0.41 ± 0.16	0.11 ± 0.05	0.002 ± 0.001	0.52 ± 0.16
Britton's sedge[2]	0.32 ± 0.15	0.64 ± 0.25	0.86 ± 0.26	1.00 ± 0.23	0.22 ± 0.09	0.0 ± 0.0	0.61 ± 0.13

(Continued)

Note: Seeds are categorized by grass, sedge, and forb. Seed numbers are presented for the flooded zone, moist-soil zones I (MSZI) and II (MSZII), two tillage treatments, and late-summer/early-fall (LSEF) and spring (SPG) drawdowns. Seeds were collected from traps in November 1992 and July 1993.

[1] Seed biomass was not statistically tested for differences between main-effect means for soil-moisture, tillage, and drawdown-timing treatments.

[2] For taxon trapped in one season, soil moisture and tillage means were determined within the season they were trapped.

Appendix D (Concluded)

Common Name	Soil-Moisture Regime			Tillage Treatment		Drawdown Timing	
	Flooded Zone (n = 48)	MSZI (n = 48)	MSZII (n = 48)	Nontilled (n = 72)	Tilled (n = 72)	LSEF (n = 72)	SPG (n = 72)
Forbs							
Pigweed	0.01 ± 0.002	0.97 ± 0.27	0.92 ± 0.46	0.16 ± 0.08	1.11 ± 0.34	1.27 ± 0.35	0.004 ± 0.001
Yellow wood sorrel	0.0001 ± 0.0001	0.002 ± 0.001	0.01 ± 0.002	0.004 ± 0.001	0.004 ± 0.001	0.002 ± 0.001	0.006 ± 0.002
Smartweeds[3]	0.008 ± 0.005	0.50 ± 0.28	0.47 ± 0.44	0.10 ± 0.09	0.55 ± 0.33	0.33 ± 0.17	---
Aster	0.001 ± 0.0002	0.002 ± 0.001	0.001 ± 0.0003	0.002 ± 0.0004	0.001 ± 0.0002	0.001 ± 0.0002	0.0 ± 0.0
Texas frog fruit	0.08 ± 0.03	0.01 ± 0.01	0.01 ± 0.003	0.02 ± 0.01	0.05 ± 0.02	0.03 ± 0.01	---
Spurge	0.007 ± 0.002	0.19 ± 0.11	0.17 ± 0.09	0.05 ± 0.02	0.20 ± 0.09	0.12 ± 0.05	---
Curly dock	0.28 ± 0.17	1.76 ± 0.48	1.63 ± 0.39	0.60 ± 0.13	1.84 ± 0.41	0.0 ± 0.0	1.22 ± 0.23

[3] Means were not determined for SPG drawdown data because of 0.01 frequencies of occurrence.

Appendix E
Chemical Analyses of Soils Collected in Three Experimental Ponds at the Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX

Procedures followed those specified by the Extension Soil, Water, and Forage Testing Laboratory, Soil and Crop Sciences, Texas A&M University, College Station, TX. Equal numbers of soil samples were taken from the tilled and nontilled stretches of each pond on 23 July 1993. The soils were analyzed for pH, salinity, macronutrients (NO_3, P, K, Ca, Mg, Na, and S), and micronutrients (Zn, Fe, Cu, and Mn).

Salinity, pH, Macronutrient, and Micronutrient Analyses for Soils Collected on 23 July 1993 in Nontilled and Tilled Stretches of Three Experimental Ponds Used for Research at the Lewisville Aquatic Ecosystem Research Facility in Lewisville, TX

Pond	Tillage	Salinity ppm	pH	Nitrogen ppm	Phosphorus ppm	Potassium ppm	Calcium ppm	Magnesium ppm	Zinc ppm	Iron ppm	Manganese ppm	Copper ppm	Sodium ppm	Sulphur ppm
1	Nontilled	260	7.5	1	73	172	3,400	164	0.56	19.54	0.86	2.68	28	11
1	Tilled	195	7.6	1	161	135	4,336	133	0.31	26.78	0.86	2.80	21	27
2	Nontilled	162	7.7	1	85	185	6,144	239	0.22	15.25	0.70	1.84	27	40
2	Tilled	175	7.7	1	112	165	6,336	197	0.24	13.78	0.64	2.05	25	39
3	Nontilled	195	7.6	1	53	146	3,174	145	0.20	17.14	0.83	1.15	17	12
3	Tilled	260	7.6	1	47	196	3,634	174	0.23	21.94	1.17	1.15	26	18

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1995	Final report

4. TITLE AND SUBTITLE

Management of Shallow Impoundments to Provide Emergent and Submergent Vegetation for Waterfowl

5. FUNDING NUMBERS

6. AUTHOR(S)

Len G. Polasek, Milton W. Weller, K. C. Jensen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of Wildlife and Fisheries Sciences
Texas A&M University, College Station, TX 77843-2258;
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

Technical Report
WRP-SM-8

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Effects of partial drawdowns, drawdown timing, and tilling on vegetation and seed production for waterfowl were tested in ponds at the Lewisville Aquatic Ecosystem Research Facility in north-central Texas. Vegetation lists, percent cover (PC), and aboveground biomass (AGB) revealed that partial drawdowns produced a typical zonation of wetland plants: submergent macrophytes in deep-flooded zones; cattail (*Typha* sp.), black willow (*Salix nigra*), and sedges in shallow-flooded zones; forbs in moist zones adjacent to water; and grasses in upper, drier zones. Seed production of grasses, sedges, and forbs generally reflected the vegetation present in each soil-moisture zone. Taxon richness of emergent plants was highest in dewatered zones.

Drawdown timing did not affect taxon richness of emergent plants within dewatered zones, but grass AGB and forb and sedge PC and AGB were highest during 1993 spring drawdown. The majority of grasses and forbs had higher seed production during 1992 late-summer/early-fall drawdown, whereas sedges produced more seeds during the spring drawdown. Black willow occurred most frequently, and cattail was first recorded during spring drawdown. Most submergent macrophytes were unaffected by drawdown timing.

(Continued)

14. SUBJECT TERMS		15. NUMBER OF PAGES
Moist-soil management	Wetland habitats, Texas	82
Waterfowl habitat management	Wintering waterfowl	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

Soil disturbance with rototilling created diversity in ponds by increasing taxon richness of emergent plants, encouraging annuals, and discouraging perennials. PC, AGB, and seed production of forbs and grasses generally increased and decreased, respectively, with tilling, whereas sedges were not affected. Cattail and black willow occurred most frequently in tilled areas. Most submergent macrophytes were not affected by tilling, except southern naiad (*Najas guadalupensis*), with higher PC in tilled plots.

Finally, observations revealed that waterfowl visiting ponds utilized regions according to water depth and plant communities. Gadwall (*Anas strepera*) and American wigeon (*A. americana*) were most often observed within deep zones supporting submergent vegetation. Although data were not statistically significant, blue-winged teal (*A. discors*) and green-winged teal (*A. crecca*) occurred most often in shallow zones supporting emergent vegetation and seeds. Therefore, partial drawdowns, variations in drawdown timing, and soil disturbance were effective in providing a variety of vegetation and seeds for a diversity of migrant and wintering waterfowl.