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# Wetland Biomass Production: Emergent Aquatic Management Options and Evaluations

## A Final Subcontract Report

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## FOREWORD

This report is the final technical report for FY83. This work was performed under subcontract to SERI with funds provided by the Biomass Energy Technology Divison of the U.S. Department of Energy, under a program investigating aquatic plant species as a source of renewable fuels.

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## SUMMARY


### Objective

The primary objective of the Wetland Biomass Production Project at the University of Minnesota has been that of identifying, testing, and evaluating production practices necessary to capitalize on the considerable potential of emergent aquatic plants as sources of biomass. In order to make use of existing European knowledge and technologies as well as develop biomass production practices suitable to North American wetlands, this project has been directed toward work on the following four tasks:

- Stand Management Research Objectives: Continued investigations of establishment methods, yields, nutrient and water requirements, and other management practices; investigations of promising genotypes of *Typha*, *Phragmites*, and other emergent plants.

- Relevant Emergent Technologies Survey Objectives: Continued investigations of relevant research findings, management practices, and costs from other programs working with emergent aquatic plants; investigations of methods of incorporating appropriate existing technologies into *Typha* management and harvest research.

- Rhizome Harvest Research Objectives: Evaluations of field characteristics in which harvesting equipment will need to operate; investigations of a variety of engineering conceptual designs for components of a belowground harvesting system for *Typha* rhizomes.

- Management Options Evaluation Objectives: Evaluation of production scenarios developed from information gathered in the first three tasks.

### Discussion

Wetlands dominated by *Typha* spp. (cattails) and other emergent vegetation, such as *Phragmites* (reeds) and *Scirpus* (rushes), are one of the most productive natural systems in the temperate zone (Westlake, 1965). Minnesota, with over 2 million hectares (95.2 million acres) of peatland and 1.4 million additional hectares (3.5 million acres) of wet mineral soils (Center for Urban and Regional Affairs, 1981), appears to have considerable potential for wetland crop production. Outside of Minnesota, an estimated 33 million hectares (82 million acres) of wetlands exist in the United States (excluding Alaska and Hawaii), some of which could be suitable for wetland bio-energy production (Frayer *et al.*, 1983). Among the attractive features of this system is the fact that wetland crops would not compete with traditional crops for prime agricultural land. The use of peatlands for the production of a renewable resource also offers an attractive alternative to peat mining.

The high yield potential and attractive chemical composition of *Typha* make it a particularly viable energy crop. The Minnesota research effort has demonstrated that total annual biomass yields equivalent to 30 dry tonnes/ha (13 tons/acre) are possible in planted stands (Andrews & Pratt, 1978). This compares with yields of total plant material between 9 and 16 dry tonnes/ha (4-7 tons/acre) in a typical Minnesota corn field (Minnesota Agricultural Statistics, 1979). At least 50% of the *Typha* plant is comprised of a belowground rhizome system containing 40% starch and sugar (Pratt *et al.*, 1981).

This high level of easily fermentable carbohydrate makes rhizomes an attractive feedstock for alcohol production. The aboveground portion of the plant is largely cellulose, and although it is not easly fermentable, it can be gasified or burned.

The high productivity of Typha can be explained in a number of ways. Of primary importance is the fact that cattails in a natural wetland are not limited by the availability of water. Also, the canopy architecture appears to increase the efficiency with which directly incident and reflected sunlight can be utilized in photosynthesis. Because of the upright leaf angle in the foliage canopy, a greater proportion of the leaf area is exposed to direct sunlight. In contrast with most crop plants, Typha begins growth early in the spring from shoots developed the previous fall, and remains active until the leaves are killed by frost in the fall. Because of their adaptability to a wide range of temperatures, they are able to remain active through a greater proportion of the growing season. Each of these factors undoubtedly contributes to Typha's success as a solar energy collector, but the relative importance of each has not, as yet, been carefully assessed.

The rate of Typha biomass accumulation is greatest, and almost constant, between June 15 and September 15 (Moss, 1977). Thus, the decreasing day length through July and August appears to be compensated for by increased photosynthetic capacity as the foliage canopy develops. Growth rates of Typha during the period of maximum production have been reported as high as 40 $g/m^2/day$ in agricultural soils (Moss, 1977), and about 30 $g/m^2/day$ in peat soils (Pratt et al., 1980). Growth rates for agricultural crops of nearly 50 $g/m^2/day$ have been reported, but normally for only relatively short periods of two or three weeks. A growth rate of 30-40 $g/m^2/day$ sustained for a period of more than two months is unusual. Thus the high seasonal yields of cattails are due more to a prolonged moderate level of growth than to an unusually high spurt of photosynthetic activity.

Based on maximum wetland area existing in Minnesota and demonstrated yield figures equivalent to 20-30 tonnes/ha (9-13 tons/acre) (Andrews & Pratt, 1978; Pratt et al., 1982), potential gross energy available from a Typha bio-energy system could be 1.3-1.8 quads per year. Estimates of net energy will depend on answers to research questions involving stand establishment and management practices, harvesting and drying methods, equipment needs and design, environmental and land use constraints, and the overall economics of wetland energy crop production.

Conclusion

- The Minnesota research effort has demonstrated that a total annual biomass yield equivalent to 30 dry tonnes/ha (13 tons/acre) are possible in planted stands.

- The rate of Typha biomass accumulation is greatest, and almost constant, between June 15 and September 15.

- Following the period of maximum biomass accrual, translocation of nutrients and dry weight compounds to the belowground tissue occurred. Harvesting at the end of September in Minnesota Typha stands would probably maximize aboveground biomass while minimizing nutrient removal.

- The modified potato harvester concept provides a primary basis for further development because of its demonstrated performance. Extrapolation of results from small scale tests to commercial size machines should be attempted to identify limiting factors.

- Based on maximum wetland area existing in Minnesota and demonstrated yield figures of equivalent to 20-30 tonnes/ha (9-13 tons/acre), potential gross energy available from Typha bioenergy system could be 1.3-1.8 quads per year.

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## ACKNOWLEDGEMENTS

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## DISCLAIMER

Mention of equipment manufacturers or commercial herbicides in this report in no manner constitutes an endorsement of manufacturers or their products by the authors or the University of Minnesota. Use of mentioned products was strictly experimental in nature and should be viewed as such by readers of this report.

# SECTION 1.0

# INTRODUCTION

The primary objective of the SERI-sponsored Wetland Biomass Production Project at the University of Minnesota has been that of identifying, testing, and evaluating production practices necessary to capitalize on the considerable potential of emergent aquatic plants as sources of biomass. Wetlands dominated by Typha spp. (cattails) and other emergent vegetation, such as Phragmites (reeds) and Scirpus (rushes), are one of the most productive natural systems in the temperate zone (Westlake, 1965). Minnesota, with over 2 million hectares (5.2 million acres) of peatland and 1.4 million additional hectares (3.5 million acres) of wet mineral soils (Center for Urban and Regional Affairs, 1981), appears to have considerable potential for wetland crop production. Outside of Minnesota, an estimated 33 million hectares (82 million acres) of wetlands exist in the United States (excluding Alaska and Hawaii), some of which could be suitable for wetland bio-energy production (Frayer et al., 1983). Among the attractive features of this system is the fact that wetland crops would not compete with traditional crops for prime agricultural land. The use of peatlands for the production of a renewable resource also offers an attractive alternative to peat mining.

The high yield potential and attractive chemical composition of Typha make it a particularly viable energy crop. The Minnesota research effort has demonstrated that total annual biomass yields equivalent to 30 dry tonnes/ha (13 tons/acre) are possible in planted stands (Andrews & Pratt, 1978). This compares with yields of total plant material between 9 and 16 dry tonnes/ha (4-7 tons/acre) in a typical Minnesota corn field (Minnesota Agricultural Statistics, 1979). At least 50% of the Typha plant is comprised of a belowground rhizome system containing 40% starch and sugar (Pratt et al., 1981). This high level of easily fermentable carbohydrate makes rhizomes an attractive feedstock for alcohol production. The aboveground portion of the plant is largely cellulose and although it is not easily fermentable, it can be gasified or burned.

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The rate of Typha biomass accumulation is greatest, and almost constant, between June 15 and September 15 (Moss, 1977). Thus, the decreasing day length through July and August appears to be compensated for by increased photosynthetic capacity as the foliage canopy develops. Growth rates of Typha during the period of maximum production have been reported as high as 40 g/m$^2$/day in agricultural soils (Moss, 1977), and about 30 g/m$^2$/day in peat soils (Pratt et al., 1980). Growth rates for agricultural crops of nearly 50 g/m$^2$/day have been reported, but normally for only relatively short periods of two or three weeks. A growth rate of 30-40 g/m$^2$/day sustained for a period of more than two months is unusual. Thus the high seasonal yields of cattails are due more to a prolonged moderate level of growth than to an unusually high spurt of photosynthetic activity.

Based on maximum wetland area existing in Minnesota and demonstrated yield figures equivalent to 20-30 tonnes/ha (9-13 tons/acre) (Andrews & Pratt, 1978; Pratt et al., 1982), potential gross energy available from a Typha bio-energy system could be 1.3-1.8 quads per year. Estimates of net energy will depend on answers to research questions involving stand establishment and management practices, harvesting and drying methods, equipment needs and design, environmental and land use constraints, and the overall economics of wetland energy crop production.

The potential of wetland vegetation for fuel and fiber production has been widely recognized in regions of northern and eastern Europe where research programs are investigating plant characteristics and production methods. Much of this research has focused on Phragmites australis which is a dominant wetland species in that area. In order to make use of existing European knowledge and technologies as well as develop biomass production practices suitable to North American wetlands, this project has been directed toward work on the following four tasks.

- Stand Management Research Objectives: Continued investigations of establishment methods, yields, nutrient and water requirements, and other management practices; investigations of promising genotypes of Typha, Phragmites, and other emergent plants.

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- Management Options Evaluation Objectives: Evaluation of production scenarios developed from information gathered in the first three tasks.

This report is organized in a manner that focuses on the evaluation of management options task. Results from stand management research performed at the University of Minnesota during 1982 and 1983 are integrated with findings from an extensive survey of relevant emergent aquatic plant research and utilization. These results and findings are then arranged in sections dealing with key steps and issues that need to be dealt with in the development of a managed emergent aquatic bio-energy system. A brief section evaluating the current status of rhizome harvesting is also included along with an indexed bibliography of the biology, ecology, and utilization of Typha which was completed with support from this SERI subcontract.

In addition to these SERI-supported tasks, the state-funded Bio-Energy Coordinating Office at the University of Minnesota is supporting associated work in areas of plant nitrogen fixation in wetlands, micropropagation of wetland species, economics, land use planning, and equipment development. This comprehensive approach to wetland biomass production research fits well with the stated SERI objective of timely development of technology in preparation for its transfer to the private sector. Ultimately, information gained from this project can be used to develop a bio-energy system that maximizes output while minimizing inputs, resulting in a renewable energy resource that is economically competitive and environmentally benign.

## SECTION 2.0

## WETLAND SPECIES COMPARISON

### 2.1 BACKGROUND

The first step in establishing a system for bio-energy production on wetlands is identification of appropriate plant species. Several criteria have been used to select potential wetland energy crops based on information gathered from literature reviews and natural stand surveys (Andrews & Pratt, 1981). Screening began by identifying productive species which are adapted to the wetland habitat and occur naturally in monoculture or in mixed stands with species of similar harvesting requirements. Of these species, those for which seed or vegetative propagation methods are known or would be easy to develop were selected.

Table 2-1. SUMMARY OF WETLAND PLANT YIELDS IN NATURAL STANDS OF THE NORTH CENTRAL UNITED STATES

| Species | Range of Aboveground Yields (tonnes/hectare) | Reference[a] |
|---|---|---|
| *Typha latifolia* | 4.3 - 14.9 | 5,6,7,8,9 |
| *Typha angustifolia* | 12.3 - 21.1 | 8,9 |
| *Typha* x *glauca*[b] | 6.7 - 23.2 | 1,2,3,8,9,11 |
| *Phragmites australis* | 7.8 - 11.8 | 9,10,11,12 |
| *Carex atherodes* | 7.9 - 22.3 | 4,6,9,10 |
| *Scirpus fluviatilis* | 4.5 - 9.8 | 6,9,10,11,12 |
| *Spartina pectinata* | 5.9 - 11.6[c] | 10 |
| *Sparganium eurycarpum* | 5.9 - 10.5 | 10,11,12 |
| *Phalaris arundinacea* | 7.6 - 13.5 | 6,9 |

[a]Reference numbers: 1) Bray, 1960. 2) Bray, 1962. 3) Bray *et al.*, 1959. 4) Gorham and Bernard, 1975. 5) Gustafson, 1976. 6) Klopatek and Stearns, 1978. 7) McNaughton, 1966. 8) Pratt, 1978. 9) Pratt *et al.*, 1980. 10) Pratt *et al.*, 1982. 11) van der Valk and Davis, 1978. 12) Van Dyke, 1972.
[b]a hybrid of *T. latifolia* and *T. angustifolia*
[c]mixed stand with *Carex* spp.

Using this screening process for wetland plant communities in the north central United States, nine species were identified as potential wetland bio-energy crops. Table 2-1 shows the productivity of natural stands of each species as reported in the literature.

## 2.2 WETLAND SPECIES PRODUCTIVITY COMPARISON

To test the feasibility of establishing stands of these potential wetland biomass species, and to compare their productivity under identical growing conditions, an experiment was established in artificial paddies in St. Paul (see Appendix A for experimental design). Phalaris arundinacea was not included in this comparison since extensive information on its productivity in managed stands is available from current forage crop research (Marten et al., 1973, 1979, 1980; Mason & Miltmore, 1970). Typha spp. were also not included in this trial since more extensive experiments concerning establishment, productivity, and genotypic variation were being carried out concurrently. Results of Typha studies are discussed elsewhere in this report.

Table 2-2. TWO YEAR PRODUCTIVITY IN WETLAND SPECIES COMPARISON PADDIES

| | Mean aboveground dry weight (tonnes/ha) | | Shoot density (per $m^2$)* | |
|---|---|---|---|---|
| Plant Species | 1981 | 1982 | 1981 | 1982 |
| Spartina pectinata | $5.6^{bc}$ | $14.1^{a}$ | $80^{b}$ | $264^{ab}$ |
| Carex atherodes | $4.4^{c}$ | $12.6^{a}$ | $105^{b}$ | $323^{a}$ |
| Scirpus fluviatilis I | $7.5^{ab}$ | $12.6^{a}$ | $168^{a}$ | $317^{a}$ |
| Scirpus fluviatilis II | $9.2^{a}$ | $12.3^{a}$ | $147^{a}$ | $273^{ab}$ |
| Phragmites australis | $0.5^{d}$ | $7.2^{b}$ | $26^{c}$ | $134^{c}$ |
| Sparganium eurycarpum | $6.0^{bc}$ | $6.0^{b}$ | $109^{b}$ | $182^{bc}$ |

* For each column, numbers with the same letter beside them are not significantly different according to Tukey's Honestly Significantly Different Test ($\alpha = 0.05$).

Table 2-2 shows the biomass yield of each species after one and two seasons of growth. For the biomass yields at the end of each season, values with the same letter beside them in the table are not significantly different according to Tukey's Honestly Significantly Different Test (HSD) ($\alpha = 0.05$). Scirpus fluviatilis was the most productive species in the first season. Scirpus II, which was planted with material collected from a natural stand at Fort Snelling State Park near St. Paul, did not produce significantly more than Scirpus I, which was planted with material purchased from a commercial nursery.[1]

During the first season, Scirpus and Sparganium biomass yields were similar to yields found in natural stands. Carex and Spartina, on the other hand, produced less than was expected based on natural stand values. Phragmites productivity was very low, although this appears to be an establishment problem rather than a measure of the potential productivity of this plant. Most of the rhizome material which was planted in these paddies died, so the yield represents productivity of very few shoots. (See SERI final report subcontract number XK-1-1087-1 for a full discussion of the first season results (Pratt et al., 1982)).

During the second season, as shown in Table 2-2, biomass yields were much more homogeneous, with the different species falling into two productivity groups based on Tukey's HSD test. Scirpus remained one of the most productive species with a mean yield increase of 33% in the second year. Carex and Spartina moved into the high productivity class in the second year with an increase of 65% and 60% respectively. Sparganium, on the other hand, made no advances in the second year, probably due to extensive flowering and early senescence. Despite problems with establishment, Phragmites biomass production increased substantially in the second season. Compared to natural stand productivity, Spartina and Scirpus performed better than expected, Carex performed in the middle of the range, and Phragmites and Sparganium produced amounts of biomass comparable to the least productive natural stands surveyed as shown in Tables 2-1 and 2-2.

In addition to this wetland species comparison trial set up in artificial paddies, plots of three of the potential biomass crops under consideration, Scirpus, Sparganium, and Phragmites, were planted at a field site near Zim in northeastern Minnesota to demonstrate the ability to establish stands under different land preparation schemes (see Pratt et al. (1982) for a full discussion of establishment season results). No statistical comparison of species productivity can be made from these demonstration plots since there is no replication. However, they do represent the only information on stand establishment under field conditions of other potential biomass crops besides Typha. The plots were established on a tilled site and on two sites with varying amounts of peat removed to simulate conditions after peat mining (see Appendix A for details of land preparation). There appeared to be no relationship between land preparation and success of stand establishment for these three species. On the average, all three species produced less at the field site where the planting density was nine rhizome pieces/$m^2$ than in the artificial paddies where rhizome pieces were planted at $17/m^2$. Sparganium produced 4.8 and 5.3 tonnes/ha in the first and second seasons in the field, respectively, and Scirpus produced 5.8 and 5.6 tonnes/ha in the two years. It was noticed in the third growing season that Scirpus plots in the two excavated areas had not survived, perhaps due to high water levels during the fall and spring. Phragmites showed very poor stand establishment, and consequently, low productivity, as was seen in the paddies.

## 2.3 WETLAND SPECIES NUTRIENT COMPARISON

In addition to a comparison of productivity of several potential wetland biomass crops, the study conducted in paddies in St. Paul provides some baseline information on nutrient

[1]Kester's Wild Game Food Nurseries, Inc., Omro, Wisconsin.

status of the species. Table 2-3 lists the concentration of several macro- and micronutrients in the plant tissue during early October of the second growing season. For each nutrient in the table, values with the same letter beside them are not significantly different according to Tukey's HSD test ( $\alpha$ = 0.05). Potassium and magnesium are the only nutrients which did not differ significantly in the tissue of the various species.

Sparganium contained among the highest tissue concentrations of all elements except sodium, with significantly more calcium and zinc than any other species. Sparganium also demonstrated one of the lowest mean yields in the second year as seen in Table 2-2. Low productivity is perhaps accounted for by the fact that Sparganium flowered more extensively than the other species, followed quickly by senescence in mid-August. High rates of nutrient removal coupled with low productivity as exhibited by Sparganium in this experiment would not be desirable for wetland bio-energy production since fertilization represents a large potential cost.

Phragmites did not produce significantly more biomass in the second year than Sparganium. Unlike Sparganium, however, tissue nutrient concentration in Phragmites was among the lowest for all elements. Since Phragmites received the same fertilizer treatment as the other species and there is evidence that its low productivity was due to establishment problems rather than some other factor such as nutrient stress, it is encouraging that Phragmites removed relatively small amounts of nutrients. Researchers investigating Phragmites as an energy crop in Sweden also found low levels of most nutrients in the aboveground tissue (Graneli, 1980). In fact, nutrient concentration in shoots sampled in the winter, the recommended harvest time for this species, were found to be lower than reported here.

Spartina also contained relatively low concentrations of most nutrients. This coupled with high second year productivity makes Spartina a promising potential wetland biomass crop. Limited flowering was observed in Spartina paddies in the second year, and it is not known what effect, if any, this might have had on yield.

The two planting stocks of Scirpus resulted in tissue which did not differ significantly from each other in the concentration of any element. The tissue concentration of all nutrients except phosphorus was in the middle of the range found over all species. Phosphorus was very low in Scirpus tissue.

The ash content of potential bio-energy crops is of interest because it decreases the effective energy yield per unit dry weight, and because it represents a waste product to be dealt with in any conversion system. Based on two samples from each species in the wetland species comparison paddies, Sparganium has the highest ash content at 6.7% ash, and Phragmites has the lowest at 2.0% ash. This ranking is similar to the ranking of nutrient concentrations in the plant tissue, probably due to the fact that elements such as potassium, calcium and magnesium contribute to the ash content of plant tissue. Other elements may contribute significantly to the ash content, however, such as silicon which reportedly serves as a structural element and represents up to 38% of the ash content in Phragmites shoots (Graneli, 1980). Spartina tissue contained 2.6% ash, the second lowest ash content. Carex and Scirpus I and II fell into the middle of the range with 3.6%, 4.7%, and 3.4% ash, respectively.

Table 2-3. MEAN NUTRIENT CONCENTRATION IN ABOVEGROUND TISSUE FROM WETLAND SPECIES COMPARISON TRIAL

| Plant Genus | Mean Nutrient Concentration* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent N | Percent P | Percent K | Percent Ca | Percent Mg | Percent Na | PPM Fe | PPM Mn | PPM Zn | PPM Cu | PPM B |
| *Sparganium* | $0.64^{ab}$ | $0.17^{a}$ | $1.29^{a}$ | $1.85^{a}$ | $0.18^{a}$ | $0.07^{bc}$ | $110^{a}$ | $694^{a}$ | $51^{a}$ | $0.9^{a}$ | $19^{a}$ |
| *Carex* | $0.99^{a}$ | $0.14^{ab}$ | $1.09^{a}$ | $0.62^{b}$ | $0.16^{a}$ | $0.02^{c}$ | $69^{bc}$ | $435^{ab}$ | $26^{b}$ | $0.6^{ab}$ | $8^{bc}$ |
| *Scirpus* I | $0.46^{b}$ | $0.04^{d}$ | $0.86^{a}$ | $0.40^{bc}$ | $0.14^{a}$ | $0.10^{ab}$ | $62^{bc}$ | $369^{b}$ | $14^{bc}$ | $0.4^{bc}$ | $13^{ab}$ |
| *Scirpus* II | $0.54^{b}$ | $0.04^{cd}$ | $0.99^{a}$ | $0.45^{bc}$ | $0.14^{a}$ | $0.13^{a}$ | $85^{ab}$ | $315^{bc}$ | $15^{bc}$ | $0.5^{bc}$ | $13^{ab}$ |
| *Spartina* | $0.58^{ab}$ | $0.11^{abc}$ | $0.94^{a}$ | $0.29^{bc}$ | $0.11^{a}$ | $0.03^{c}$ | $56^{c}$ | $196^{bc}$ | $6^{c}$ | $0.3^{bc}$ | $3^{c}$ |
| *Phragmites* | $0.75^{ab}$ | $0.09^{bcd}$ | $0.55^{a}$ | $0.27^{c}$ | $0.10^{a}$ | $0.07^{bc}$ | $59^{bc}$ | $72^{c}$ | $9^{c}$ | $0.2^{c}$ | $3^{c}$ |

* For each column, numbers with the same letter beside them are not significantly different according to Tukey's HSD Test ( $\alpha = 0.05$).

## 2.4 PHRAGMITES PROPAGATION TRIALS

Despite low productivity of Phragmites australis in both paddy and field trials, it was decided to continue to investigate the potential of this plant for bio-energy production. First, based on natural stand productivity figures and observation of poor planting stock survival in field and paddy trials, it was determined that stand establishment problems, rather than low genetic yield potential, were responsible for low productivity. Interest in Phragmites was also sustained because some success has been achieved by Swedish researchers in growing and harvesting this plant for energy production, providing a base of information for propagation methods, nutrient requirements, and harvesting technology (Graneli, 1980). A winter harvesting scheme has been proposed for Phragmites which allows nutrient recycling through leaf fall, field drying of the erect shoots to about 25% moisture, and equipment operation on ice rather than saturated soils. Many other emergent aquatic plants being considered for biomass production lodge during the winter, making this harvest system fairly unique to Phragmites.

Two Phragmites propagation trials were carried out in an attempt to overcome previous problems with stand establishment. Selection of propagation methods was based on the experience of Graneli (1980). According to their trials, stand establishment by seeding was generally not successful; planting shoot cuttings with a portion of rhizome attached represented the most successful propagation method. The material which was successfully transplanted was collected before flowering when the shoots had two to four leaves. This represented the period of maximum meristematic activity. Also, a portion of the shoot was allowed to extend above the water level after transplanting to ensure oxygen supply. Graneli also found that rhizome pieces, cut shoots without rhizome attached, and whole plants represented viable planting materials, although survival was somewhat lower using these methods.

A Phragmites propagation trial was established in artificial paddies in St. Paul to test four of the more promising establishment methods. Material was collected and transplanted in late May, 1982, when two to four leaves had emerged on the shoots. A representative diagram of the Phragmites plant at this developmental stage in shown in Fig. 2-1. Treatments included rhizome pieces, rhizome pieces attached to shoot sections with the shoot tip removed, rhizome pieces attached to intact shoots, and shoot tip sections. Table 2-4 shows the success of the various methods as indicated by initial survival of planting material, periodic shoot density over the course of two growing seasons, and final yield at the end of the second growing season. Significant differences according to Tukey's HSD test ($\alpha = 0.05$) between initial survival of planting stocks and final densities and yields are shown by different letters in Table 2-4. Survival of planting material was comparable in all treatments except the shoot cuttings where only 8% survived. Planting material which had at least one live shoot was said to have survived. More than one shoot grew from many of the survivors, which accounts for the fact that most shoot densities had increased beyond the planting density of $10/m^2$ within one month, even though there was less than 100% survival.

Shoot cuttings produced new shoots which were much smaller in height and diameter than those produced by all other planting stocks. New, greenhouse rooted shoot cuttings were planted after removing old cuttings in an attempt to increase survival and produce normal shoots. Aberrant shoots were observed soon after replanting, and again in the spring of the following year. The shoot cutting paddies were replanted once again in July, 1983, and this time, none of the cuttings survived.

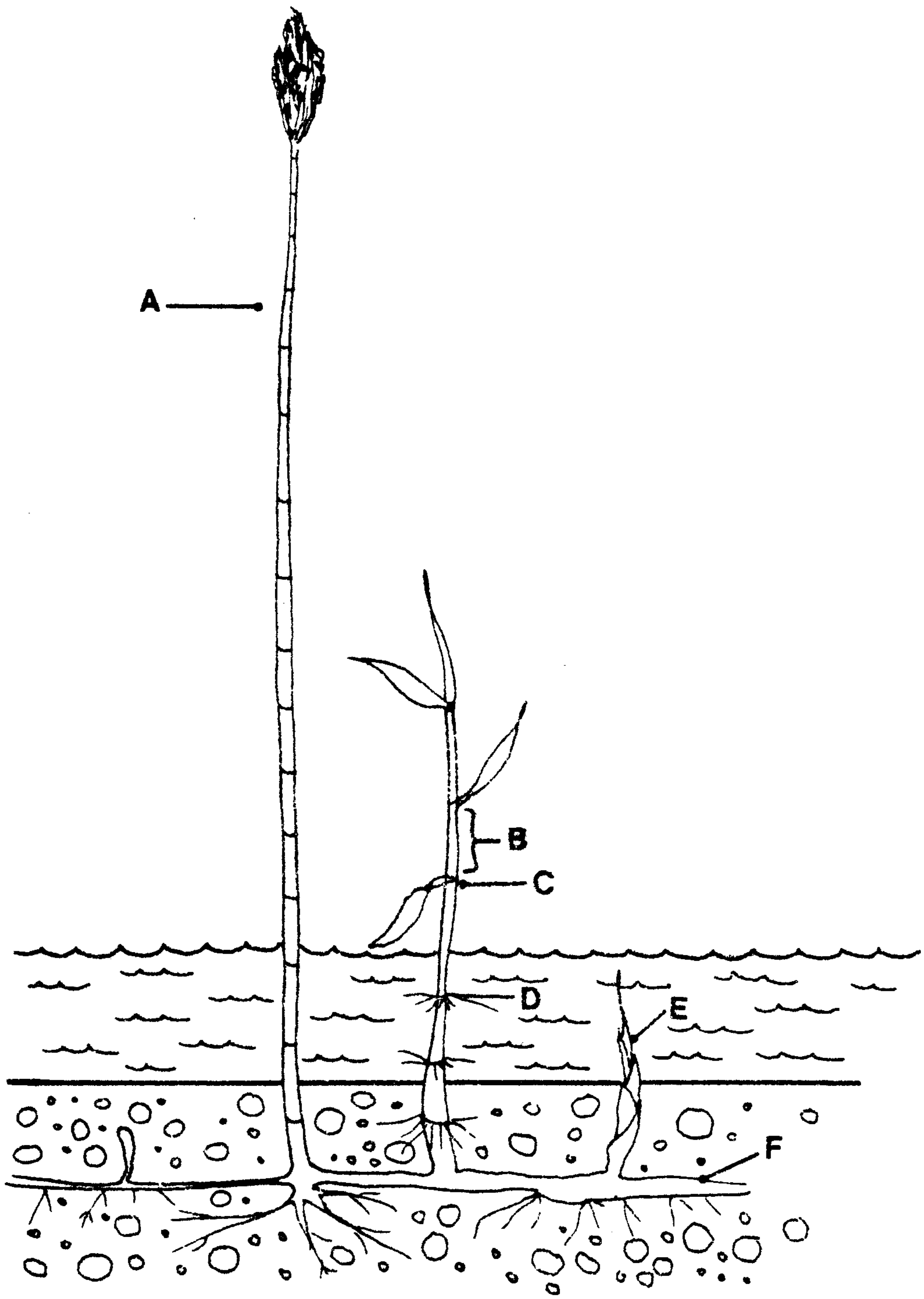


Figure 2-1. PHRAGMITES AUSTRALIS WITH FOUR LEAFED SHOOTS AS USED FOR VEGETATIVE PROPAGATION

A. Previous year's shoot (leaves dropped in the fall).
B. Internode.
C. Node.
D. Adventitious roots.
E. New shoot.
F. Rhizome.

The second season yield of 11.2 tonnes/ha aboveground biomass achieved with shoot/rhizome planting stock was significantly higher than with any other planting stock and is comparable to expected productivity based on natural stand surveys as presented in Table 2-1. A similar pattern was observed for final stand density at the end of two growing seasons when paddies established from shoot/rhizome planting stocks demonstrated a significantly higher mean density than any other planting stock. Yield was not measured at the end of the first growing season, but, based on first season densities, it appears that two seasons will be required to establish a productive stand. Granelli also observed that two growing seasons were required for successful Phragmites stand establishment (Graneli, 1980).

Table 2-4. PLANTING STOCK SURVIVAL AND PRODUCTIVITY IN PHRAGMITES PROPAGATION PADDIES

| | Rhizome | Shoot Cutting* | Cut Shoot/ Rhizome | Shoot/ Rhizome |
|---|---|---|---|---|
| Mean Survival Percentage (July, 1982) | 64[a] | 8[b] | 66[a] | 72[a] |
| Mean Shoot Density (per $m^2$) | | | | |
| July, 1982 | 12 | 1 | 11 | 19 |
| October, 1982 | 69 | 15 | 80 | 151 |
| July, 1983 | 150 | 54 | 120 | 153 |
| October, 1983 | 235[b] | 0[c] | 207[b] | 305[a] |
| Mean Aboveground Dry Wt ($g/m^2$), October, 1983 | 845[b] | 0[c] | 804[b] | 1119[a] |

* replanted after first measurement in July, 1982, and again after measurement in July, 1983.

Shoot material would be the easiest planting stock to obtain for Phragmites production, so a greenhouse trial was established to try to overcome the low survival encountered in transplanting shoot cuttings. Several factors were considered in determining treatments which might result in the best root and shoot development. Node maturity was considered since the developmental stage of the meristematic region can affect the potential for differentiation of root and shoot tissue (Salisbury & Ross, 1978). Presence or absence of leaves was considered since cuttings are subject to wilting before rooting occurs, and since the presence of leaves on cuttings is known to exert a stimulating influence on root initiation in some species (Hartmann & Kester, 1983). Response to auxin was of interest since auxins are known to promote formation of adventitious roots under some conditions (Esau,1977; Hartmann & Kester, 1983; Salisbury & Ross, 1978). Finally, wounding was considered because root formation is frequently observed as a wound response (Esau, 1977; Hartmann & Kester, 1983). To examine the affect of these various factors on survival of shoot cuttings, a factorial experiment was conducted in which all possible combinations of five different rooting stocks, auxin or no auxin, and wounding or no wounding are represented (see Appendix A for details). Four of the rooting stocks were tip cuttings with one or two nodes and leaves removed or present; the fifth was a stem section from the middle of the shoot. The auxin supplement was 0.8% IBA in talc and wounding was accomplished by lightly scoring the node with a razor blade. Cuttings were maintained in a temperature and humidity controlled chamber in the greenhouse to avoid wilting.

Table 2-5 shows the mean percent of shoot bud and root formation achieved with the various types of cuttings at the end of three weeks. In most cases, both roots and one or more new shoots formed on the cuttings which survived. Occasionally, new shoot buds would form on cuttings which had not successfully rooted. Root development without shoot formation was rare. Analysis of variance testing cutting type, auxin treatment, and wound treatment as main effects revealed that cutting type was the only factor which significantly affected root and shoot formation. Auxin and/or wound treatment did not significantly effect survival of the cuttings overall. For this reason, the auxin and wound treatments for each cutting type are averaged together in Table 2-5. Analysis of variance using a nested classification of the factors in this experiment showed that within each cutting type, auxin and/or wound treatment had no significant effect on survival.

Table 2-5. ROOT AND SHOOT DEVELOPMENT IN PHRAGMITES SHOOT CUTTINGS

| Cutting Type | Mean Percent Rooted | Mean Percent with Shoot Development | Mean Percent with Root and Shoot Development |
|---|---|---|---|
| S.T.* Single Node with Leaves | $36.7^{b}$ | $40.0^{bc}$ | $34.2^{bc}$ |
| S.T.* Single Node without Leaves | $13.3^{c}$ | $16.6^{c}$ | $13.3^{c}$ |
| S.T.* Double Node with Leaves | $40.0^{b}$ | $54.2^{bc}$ | $40.0^{b}$ |
| S.T.* Double Node without Leaves | $21.7^{bc}$ | $22.5^{c}$ | $20.0^{bc}$ |
| Mid-Shoot Section Double Node | $71.7^{a}$ | $89.2^{a}$ | $70.8^{a}$ |

* Shoot Tip

For each column, numbers with the same letter beside them are not significantly different according to Tukey's HSD test ( $\alpha$ = 0.05).

Table 2-5 shows that the cutting taken from the mid-section of a Phragmites shoot resulted in significantly better root and shoot bud development than any shoot tip cuttings according to Tukey's HSD test ( $\alpha = 0.05$). Among the shoot tip cuttings, presence or absence of leaves seemed to have more effect on survival of the cutting than number of nodes. There was no significant difference in root and shoot formation between single nodes with leaves and double nodes with leaves, or single nodes without leaves and double nodes without leaves. There was, however, generally better survival in cuttings which had leaves than in cuttings with leaves removed. For example, single nodes with leaves showed significantly more root formation than single nodes without leaves and double nodes with leaves showed significantly more shoot formation than double nodes without leaves.

Cuttings from the mid-section of Phragmites shoots gathered before flowering in the two to four leaf stage represent a potentially viable option for vegetative propagation. Rooting and shoot bud development have been successfully achieved in cuttings kept in a controlled humidity and temperature chamber. Transfer of the rooted cuttings to the outdoors has been less successful, however. Shoot cuttings were planted three times in the Phragmites paddy experiment discussed previously, twice using previously rooted cuttings from the greenhouse. Survival ranged from zero to 21 percent at each planting. Further experimentation is needed to determine a method to increase survival of cuttings transplanted from the greenhouse.

## 2.5 CONCLUSIONS

- Wetland species screening through literature review and paddy trials has identified Spartina pectinata, Carex atherodes, and Scirpus fluviatilis as highly productive, potentially viable wetland biomass crops. All are perennial plants with annual aboveground biomass yields ranging from 4.5-22.3 tonnes/ha in mature stands. Belowground biomass production is low in these species, and the small rhizomes are difficult to extract from the soil.

- Despite initial problems with propagation, Phragmites australis stands can be successfully established and represent another productive, potentially viable wetland biomass crop. Because of the potential advantages of the somewhat unique shoot harvesting system for Phragmites which allows equipment operation on frozen, rather than saturated, soils and recycling of some nutrients through leaf fall, Phragmites production research should continue even though it is a more difficult biomass system to establish.

- Investigations of shoot cutting propagation methods for Phragmites have identified mid-shoot sections from plants in the two to four leaf stage as a potentially successful cutting type. Methods to increase survival of cuttings after transplanting need to be worked out to provide a more cost efficient system for Phragmites stand establishment than planting rhizome pieces. Cost of transplanting would be high for either rhizome pieces or shoot cuttings, but these represent the only currently potentially viable stand establishment

# SECTION 3.0

# SITE SELECTION

## 3.1 INTRODUCTION

If *Typha* is to be developed as a biomass crop, it is important to know the range of site conditions under which it is most productive. This information could be used to select optimum sites to establish energy farms, and, conversely, to judge the potential value of *Typha* for energy production under a given set of conditions. Both natural stand surveys and experimental field trials can provide information to help define optimum site conditions for cattail production.

## 3.2 NATURAL STAND SURVEYS

Surveys of natural stands indicate that *Typha* spp. is adaptable to a wide range of physiographic conditions. One study conducted in Michigan (Segadas-Vianna, 1951) found *Typha latifolia*, *Typha angustifolia* and *Typha x glauca* growing on soils ranging from clay and sandy clay mineral soils to fibric and hemic peat soils. Soil pH ranged from 4.0 to 8.1, with the bulk of the sites clustered around pH 6. Lake edges, marshes, and roadside ditches represent the major sites where *Typha* spp. were found; water levels at these sites varied from no standing water during early summer and fall to 30 cm of standing water throughout the season. No correlation between species and the various site conditions was evident.

Other natural stand surveys conducted in Michigan and Wisconsin (Klopatek & Stearns, 1978; Veatch, 1933) verify the wide range of soil conditions under which cattails grow. One study concluded that *Typha* thrives in clayey and decomposed peat soils with a neutral to alkaline pH, although less productive stands on sandy soils and fibric, acid peats were also found. The only extensive natural stand survey conducted in Minnesota measured water, rather than soil factors associated with the stands (Bonnewell, 1981). This study found *Typha* stands growing on sites with 0 to 63 cm standing water. Levels of nitrate and phosphate in water were measured at each site, and found not to correlate with stand productivity.

## 3.3 FIELD TRIALS

Field experiments concerning *Typha* production practices also provide information on site conditions conducive to cattail growth. Experimental stands of *Typha* have been established on different soil types at two locations in Minnesota: near Aitkin in central Minnesota and near Zim in northeastern Minnesota.

Table 3-1 illustrates the range of soils on which *Typha* stands have been successfully established. This range is fairly representative of the estimated 1.4 million ha of wet mineral soils and 2.1 million ha of peatlands potentially available for bio-energy production in Minnesota (Anderson & Craig, 1983). Of the peatland area in Minnesota, 80% is reed sedge peat, 18% is sapric peat, and only 2% is fibric peat found in raised sphagnum bogs (Malterer *et al.*, 1979). The hemic peat described in Table 3-1 was formed from reed and sedge plant material. The sapric peat is a highly decomposed material of unidentifiable plant origin with a large degree of mineral contamination

Table 3-1. SITE CHARACTERISTICS OF THREE TYPHA FIELD SITES

| Location | Landform | Soil Type[a] | Soil pH[b] | Bulk Density ($g/cm^3$) |
|---|---|---|---|---|
| Zim | minerotrophic fen | hemic peat | 5.2 | 0.14 |
| Aitkin | river flood plain | sapric peat | 5.4 | 0.54 |
| Aitkin | river flood plain | loamy sand | 5.4 | __[c] |

[a]Soil Taxonomy 7th Approximation (Soil Survey Staff, 1960).
[b]pH in 0.01 M $CaCl_2$.
[c]Not determined. Typical value for a loamy sand is 1.6 $g/cm^3$ (Brady, 1974).

from river flooding. The loamy sand is the only mineral soil on which a *Typha* stand has been established in these studies. The soil pH at the three different sites was very similar and does not represent the wide range of soil pH found on wet mineral and organic soils. Soil pH on some wetland sites sampled in Minnesota ranged from 2.4 to 6.8 (pH in 0.01 m $CaCl_2$) (Minnesota DNR, 1982; Olson *et al.*, 1979; Severson *et al.*, 1980).

Table 3-2 illustrates that the range of *Typha* productivity achieved on the three different soil types overlap considerably. The range for each site represents mean aboveground yields in two-year-old stands established under different experimental conditions. Because different species of *Typha* and different methods of stand establishment were used in the various experiments at each site, it is difficult to make a strict comparison of productivity based on soil type. The most productive stand, for instance, is the only stand in our studies which was established by sowing seed rather than planting seedlings or rhizome pieces. It is also the only pure stand of the species *Typha angustifolia*. The planting method and/or species, rather than soil factors, may be primarily responsible for the yield difference. With this in mind, the data can only suggest that all three soil types may potentially provide a viable substrate for *Typha* production as a bio-energy crop.

In addition to productivity, effects of soil type on biomass quality characteristics such as ash content are of interest. Again, the data in Table 3-2 are not conclusive since many variables are inherent in the comparison, e.g., differences in climate, species, and cultural practices used. The values do suggest that the mineral content of the soil will not have a significant effect on biomass ash content.

In addition to primary energy production through establishment of energy farms, *Typha* may be valuable for reclaiming mined peatlands with energy production serving a supplementary function. A site preparation study conducted in 1980 by Pratt *et al.* near Zim, Minnesota suggests that cattail stands can be successfully established on sites with 20 cm of peat removed (Andrews *et al.*, 1981). To further assess the potential value of *Typha* spp. for reclamation of mined peatlands, another study was conducted near Zim in 1981 and 1982. The reed sedge peat deposits on this site are similar to 80% of the peat deposits in Minnesota, and represent the type of peat which is being most seriously considered for mining as an energy source (Malterer *et al.*, 1979).

Table 3-2. TYPHA PRODUCTIVITY AND ASH CONTENT ON THREE DIFFERENT SOILS

| Soil Type | Mean Soil Ash % | Mean % Ash in Aboveground *Typha* Tissue | Range of mean[a] Aboveground *Typha* Yield (tonnes/ha) |
|---|---|---|---|
| hemic peat | 11.7 | 5.3 | 4.7 - 8.1 |
| sapric peat | 57.7 | 5.3 | 5.8 - 10.5 |
| loamy sand | 93.6 | 5.8 | 6.1 - 13.8 |

[a]Second year stands sampled in late September/early October.

Three areas were prepared for this study, two by removing varying amounts of peat, and a third by simply tilling the soil surface. The two excavation depths were 1.5 m and 0.6 m. The hemic peat deposit at this site is about 1.8 m deep, so both excavated areas maintained a peat layer over the mineral sub-soil.

Table 3-3 illustrates differences in the soil at the three depths in the soil profile. The soil in the unexcavated area is more decomposed than the underlying soil, as indicated by the fiber content and bulk density. Drainage of this site for the past 25 years probably accounts for the accelerated decomposition of the surface soil. Along with decomposition comes mineralization of nutrients, explaining the elevated values for available N-P-K in the unexcavated area as compared to the 0.6 and 1.5 m excavation depths. To overcome productivity limitations due to nutrient deficiencies, all three areas were fertilized with macro- and micronutrients (see Appendix A for details).

Table 3-3. SOIL CHARACTERISTICS FOR PEATLAND RECLAMATION STUDY

| Excavation Depth | Fiber Content Rubbed | Fiber Content Unrubbed | Bulk Density | pH[a] | Native Available Nutrients in Soil (ppm)[b] N | P | K |
|---|---|---|---|---|---|---|---|
| Unexcavated | 33 | 12 | 0.18 | 5.3 | 272 | 24 | 248 |
| 0.6 m | 48 | 18 | 0.12 | 5.2 | 56 | 5 | 44 |
| 1.5 m | 48 | 12 | 0.12 | 5.0 | 63 | 0.1 | 25 |

[a]pH measured in 0.01 m $CaCl_2$
[b]Nitrogen measured as $NO_3^-$ and $NH_4^+$, Phosphorus is measured as water soluble P, Potassium is measured as exchangeable K. See appendix A for method.

Figure 3-1 shows that yields in the first and second season were not affected by these differences in native soil fertility, although tissue nutrient concentration may have been. Under the conditions created by mining peat at the Zim site, low initial soil fertility appears not to be ultimately limiting to growth under the fertilization regime used.

The probable cause of reduced yield on the unexcavated site as shown in Fig. 3-1 is the proliferation of weed species. Removal of the seed bed and roots and rhizomes of perennial plants with the surface peat greatly reduced the number of weeds present on the two excavated sites. In terms of competition from native plants, cattail stands established on mined sites might have an advantage over tilled sites, although promising cultural and chemical weed control methods which could mitigate that advantage are being studied and are discussed in Section 7.0 of this report.

In addition to soil factors, water availability and control will affect the selection of a site for cattail bio-energy production. Cattails grow under a wide range of wet soil conditions as reported in the natural stand surveys mentioned earlier. Field sites established at Aitkin and Zim were maintained with 10-20 cm of standing water throughout the growing season. This represents the middle of the range of water depths found in naturally occurring stands (Klopatak & Stearns, 1978; Segadas-Vianna, 1951; Veatch, 1933). The water depth on experimental plots occasionally fell to zero or rose to 45 cm for short periods of time. The effects of drawdown or high water levels on Typha spp. productivity is unknown.

The apparent tolerance of Typha to a wide range of water depths suggests that unaltered wetlands could potentially be used for commercial biomass production. Natural wetlands would have an advantage over ditched and drained areas since the cost of land preparation and subsequent irrigation to maintain flooded paddies would be much greater on prepared wetlands. Other factors need to be considered, however, to determine the potential of natural wetlands for commercial bio-energy production. Information on Typha water requirements and the effect of drawdown on productivity should be obtained. Availability and costs of planting, fertilizing, and harvesting equipment that can operate on submerged soils versus equipment that requires a drained site must also be considered.

## 3.4 CONCLUSIONS

- Managed and naturally occurring Typha stands have been established on hemic and sapric peats, and on a range of wet mineral soils, suggesting that these are potentially viable substrates for commercial bio-energy production.

- The pH tolerance of Typha spp. is not conclusively defined in the literature and should be further researched.

- Typha water requirements and the effect of extended periods of high or low water levels on productivity should be studied.

- The effect of native soil nutrient levels on the success and cost of Typha bio-energy production should be further researched. This topic is discussed more thoroughly in Section 6.0 of this report.

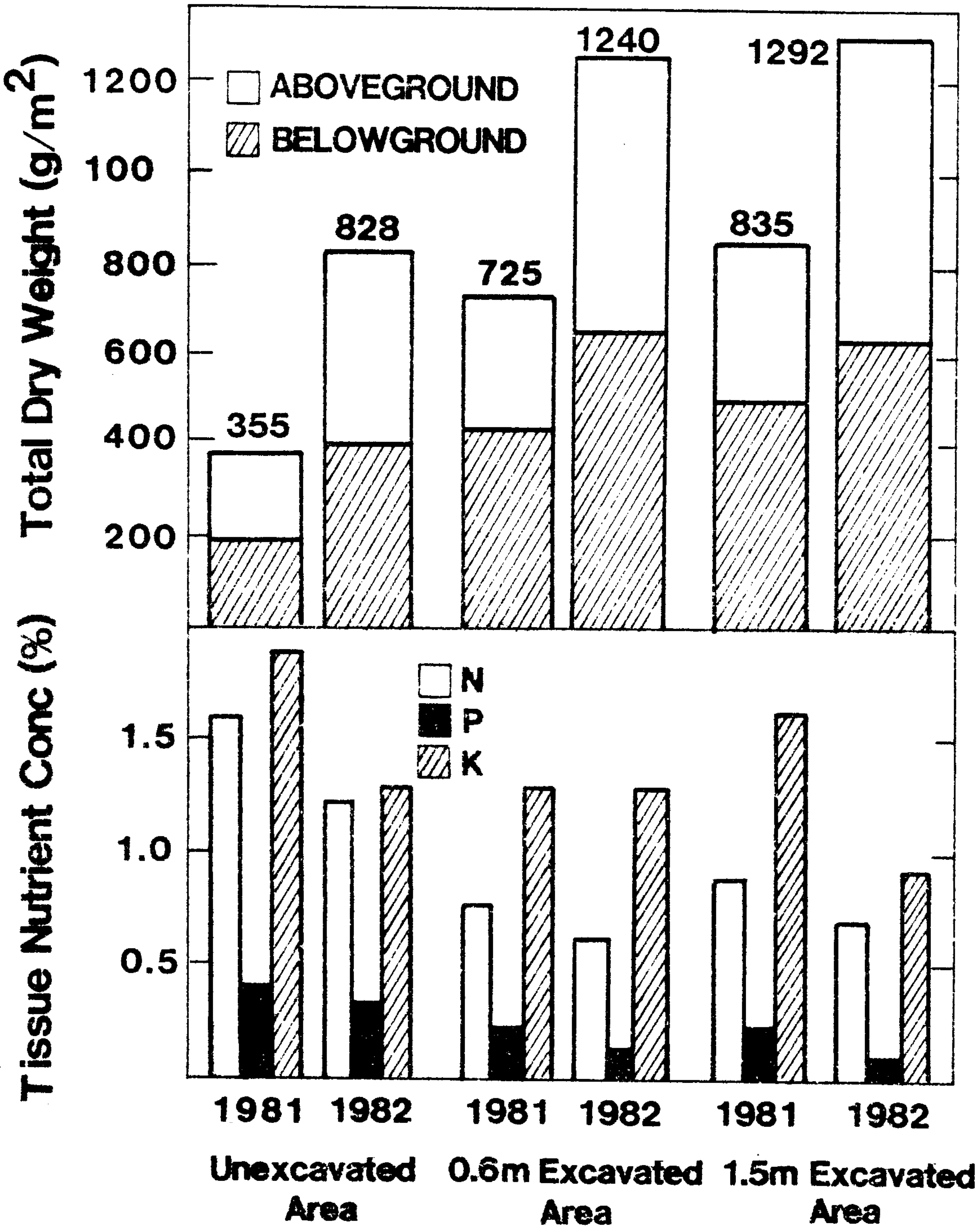


Figure 3-1. TYPHA PRODUCTIVITY AND TISSUE NUTRIENT CONCENTRATION IN PEATLAND EXCAVATION STUDY.

# SECTION 4.0

# STAND ESTABLISHMENT

## 4.1 INTRODUCTION

Following site selection and land preparation, a method of establishing stands of Typha must be employed. Three possible establishment methods have been examined: seeding, transplanting seedlings, and transplanting portions of the rhizome system. Each has advantages and disadvantages which are discussed below.

Criteria for selecting appropriate establishment methods are based on the goals of minimizing establishment costs and ensuring rapid, uniform, stand establishment and development. Costs include those for labor, equipment, materials, and, possibly, storage of plant material and greenhouse space. Additionally, the possible costs of forgone establishment season harvesting opportunities and productivity differences attributable to establishment method must be considered. A harvestable establishment season stand may warrant use of a more expensive establishment method. Also, since it is anticipated that establishment need only occur once for the perennial Typha plant, it may prove advantageous in the long term to use a more reliable, although more expensive, method of establishment.

The time required for stand establishment and development is related to the establishment method and affects productivity, weed control, nutrient requirements and application methods, and water level control. These variables will be addressed in more detail in this and later sections of the report.

Seeding would be the preferred method of establishment based on front end costs alone. Typha plants produce up to 200,000 seeds per inflorescence (Claasen, 1921) which are relatively simple to collect and process. Assuming 100% germination, a single inflorescence could provide enough seed to establish a stand of approximately one half hectare in size with a density of 50 plants per $m^2$. Seeding also offers the advantage of being able to use inexpensive rapid application methods. These include dry seeding using conventional agricultural equipment, hydroseeding, and, possibly, aerial seeding.

While seeding has several obvious advantages, it also has many disadvantages, some of which can probably be overcome with further research. The principle disadvantage, poor germination and development under field conditions (Andrews et al., 1981; Bedish, 1967; Pratt et al., 1982) appears to result from the sensitivity of Typha seed germination and development to certain environmental factors. It has been demonstrated that optimum germination rates for Typha seed occur under conditions of high temperature (35°C), reduced oxygen concentrations, and exposure to red light (Bonnewell et al., 1983). This is consistant with observations in nature of dense cattail seedling occuring primarily in shallow water or mudflats resulting from marsh drawdowns (Harris & Marshall, 1963; Ristich et al., 1976; van der Valk & Davis, 1980). Mudflat conditions provide good exposure to light, reduced $O_2$ concentrations, and warmer soil surface conditions than flooded marshes.

Other disadvantages of seeding include the slow rate of establishment season stand development leading to increased competition from weed species and relatively low establishment season productivity (Andrews et al., 1981; Pratt et al., 1982), the current limited control over genetic composition of seeds, and the difficulty in controlling seedling density resulting from inconsistant germination rates and problems associated with obtaining uniform suspensions of the tiny seeds (1-2 mm long and approximately 0.1 milligram) (Bonnewell et al., 1983).

Another method of stand establishment involves transplanting portions of the Typha rhizome system. This method has been successfully employed in small marsh restoration experiments (Ristich, et al., 1976), wetland wastewater treatment systems (Lakhsman, 1979; Wile et al., 1981), and experimental bio-energy research plots (Andrews et al., 1981; Pratt et al., 1982). Advantages of this method include a high survival rate of transplanted material (Andrews et al., 1981; Pratt et al., 1981, Ristich et al., 1976) and rapid growth during the establishment season. Rapid growth reduces competition from weed species and may allow for a biomass harvest during the establishment season. Optimum time of year for successful transplantation in northern climates has been reported to occur between the rapid leaf elongation stage in May and the beginning of flowering in June (Ristich et al., 1976).

Major disadvantages of the rhizome method are the costs involved in obtaining, storing, and transplanting rhizome material. Although costs could be reduced by establishing nurseries for production of planting material and developing equipment for collecting, cleaning, and sizing rhizome pieces, the land area required for production would be substantial since approximately 100 or fewer rhizome pieces and shoot bases are potentially available per $m^2$ (experimental observation), and planting densities of 5 to 10 pieces/$m^2$ are required for rapid stand establishment.[1] Additionally, collection of planting material is limited to early spring or late fall, possibly creating the need for special storage of this perishable material.

The need for transplantation of relatively large non-uniform rhizome pieces at high densities (5-10/$m^2$) poses another disadvantage. Current technology makes this a slow, labor intensive process. Some experiments have demonstrated successful establishment by simply placing rhizome pieces on a mudflat (Bedish, 1967), although initial growth rates were slower than transplanted material. Careful land preparation and water control would be required using this technique to ensure proper soil moisture conditions, preventing either redistribution of rhizomes if water became too deep or dessication if water supply was inadequate.

The final method of stand establishment that has been considered is that of transplanting Typha seedlings. Seedlings grown under mudflat conditions in a greenhouse for 75-100 days have been successfully used to establish Typha stands for experimental purposes (Pratt et al., 1982; White & Sinclair, 1979). White found establishment season yields in Florida to be in the range of 10-13 tonnes/ha for the total plant; Pratt et al. found total plant yields of 1 to 8 tonnes/ha on a Minnesota peatland during the establishment season.[2] During the second growing season, White found that productivity had increased by a factor of three and that differences in establishment season productivity resulting from different planting densities had disappeared. He had tested densities ranging from 3-12 seedlings per $m^2$ and found that 6-12 seedlings per $m^2$ was the optimum spacing in terms of establishment season productivity. Pratt et al. had used spacings of either 5 or 9 per $m^2$ depending on the experiment.

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1. Establishment season productivity has been shown to be highly correlated with initial planting density (Andrews et al., 1981).
2. A yield of 8 tonnes/ha was more typical. The 1 tonne/ha figure resulted from storm damage, weed competition, and insect damage.

Many of the same advantages described for stand establishment using rhizome pieces hold for the seedling establishment method. The method has proven to be reliable in terms of a high survival rate of transplanted material and rapid growth during the establishment season. Additionally, the uniformity of seedlings simplifies the actual transplanting process.

Disadvantages include the cost involved in producing seedlings, the perishable nature of seedlings, and the slow, labor intensive process of transplanting seedlings using current technology. Approximately 1,000 seedlings can be grown in one square meter of greenhouse space--enough to plant only 100-200 $m^2$ of land. This, coupled with the relatively long time required to reach transplantable size, will necessitate large amounts of greenhouse space.

Despite these formidable disadvantages, seedling transplantation may be required if it is found that genetic composition of Typha strongly influences biomass productivity. Because of the time required for conventional plant breeding and seed production, it may be necessary to employ micropropagation techniques to produce large numbers of genetically superior clones for transplantation. Micropropagation techniques have been investigated (Pratt et al., 1982) and demonstrated on a small scale (Zimmerman & Read, 1983) within the past several years.

## 4.2 RESULTS AND DISCUSSION

Table 4-1 presents aboveground, belowground, and total biomass yield for four major field experiments established and managed at different locations using different methods. Although a strict statistical comparison of establishment method and productivity is impossible since the experiments were originally designed for other purposes, the results do allow a qualitative comparison of methods and provide the most extensive multiseason information available on Typha productivity in managed stands. A complete description of methodology for each experiment is provided in the appendix.

Results show little difference in productivity between experiments established with rhizomes and those established with seedlings during the first two seasons. Mean total establishment season yield was 657 $g/m^2$ for rhizome established experiments and 429 $g/m^2$ for seedling established experiments. By the end of the second season, mean yields increased to 1,397 $g/m^2$ for rhizome experiments and 1,105 $g/m^2$ for seedling experiments. Although mean yield values for seedling established experiments tend to be lower than values for rhizome experiments, there is considerable overlap in the range of values between experiments.

Data gathered for the nutrient uptake experiment (discussed in Section 6.0) provide a detailed comparison of stand development versus time for seedling and rhizome established plots under virtually identical conditions. Adjacent paddies on a peatland in northern Minnesota (near Zim) were mechanically planted with either Typha latifolia seedlings or Typha x glauca rhizomes at a density of $5/m^2$ (see Fig. 4-1). Fig. 4-2 shows mean total biomass accumulation through two growing seasons for each establishment method. For both seedling and rhizome stands, there was an initial lag in growth rate of eight weeks following planting. During this time, seedling growth rate was 1.4 $g/m^2$/day and rhizome growth rate was 1.2 $g/m^2$/day. After this period, there was a large increase in growth rate with seedlings and rhizomes growing at rates of 10.2 $g/m^2$/day and 5.1 $g/m^2$/day, respectively, during the subsequent eight weeks. The lower rate for rhizomes was largely the result of poor anchorage of the rhizome

Table 4-1. SEASONAL COMPARISON OF MEAN ABOVEGROUND, BELOWGROUND, AND TOTAL DRY WEIGHT FOR DIFFERENT ESTABLISHMENT METHODS

| Experiment | Establishment Method* | Mean Dry Weight (g/m$^2$) | | |
|---|---|---|---|---|
| | | Establishment Season | Second Season | Third Season |
| ABOVEGROUND: | | | | |
| Fertilization Study | Rhizome | 369 | 806 | -- |
| Establishment Study | Seed: *T. angustifolia* | 49 | 1,385 | 1,160 |
| | *T. latifolia* | 0 | -- | -- |
| | Seedling | 69 | 616 | 636 |
| Peatland Excavation Study | Seedling | 190 | 465 | 333 |
| | Rhizome | 350 | 683 | 409 |
| Nutrient Uptake Study | Seedling | 348 | 816 | -- |
| | Rhizome | 209 | 568 | -- |
| BELOWGROUND: | | | | |
| Fertilization Study | Rhizome | 406 | -- | -- |
| Establishment Study | Seed: *T. angustifolia* | 37 | 776 | 1,352 |
| | *T. latifolia* | 0 | -- | -- |
| | Seedling | 95 | 538 | 472 |
| Peatland Excavation Study | Seedling | 283 | 444 | -- |
| | Rhizome | 450 | 733 | -- |
| Nutrient Uptake Study | Seedling | 302 | 436 | -- |
| | Rhizome | 188 | 687 | -- |
| TOTAL: | | | | |
| Fertilization Study | Rhizome | 775 | -- | -- |
| Establishment Study | Seed: *T. angustifolia* | 86 | 2,161 | 2,512 |
| | *T. latifolia* | 0 | -- | -- |
| | Seedling | 164 | 1,154 | 1,108 |
| Peatland Excavation Study | Seedling | 473 | 909 | -- |
| | Rhizome | 800 | 1,421 | -- |
| Nutrient Uptake Study | Seedling | 650 | 1,252 | -- |
| | Rhizome | 397 | 1,255 | -- |

* Rhizome stock = *Typha* x *glauca*; seedling stock = *Typha latifolia*. Planting density either 5 or 9/m$^2$ for rhizome and seedling, 700/m$^2$ for seed.

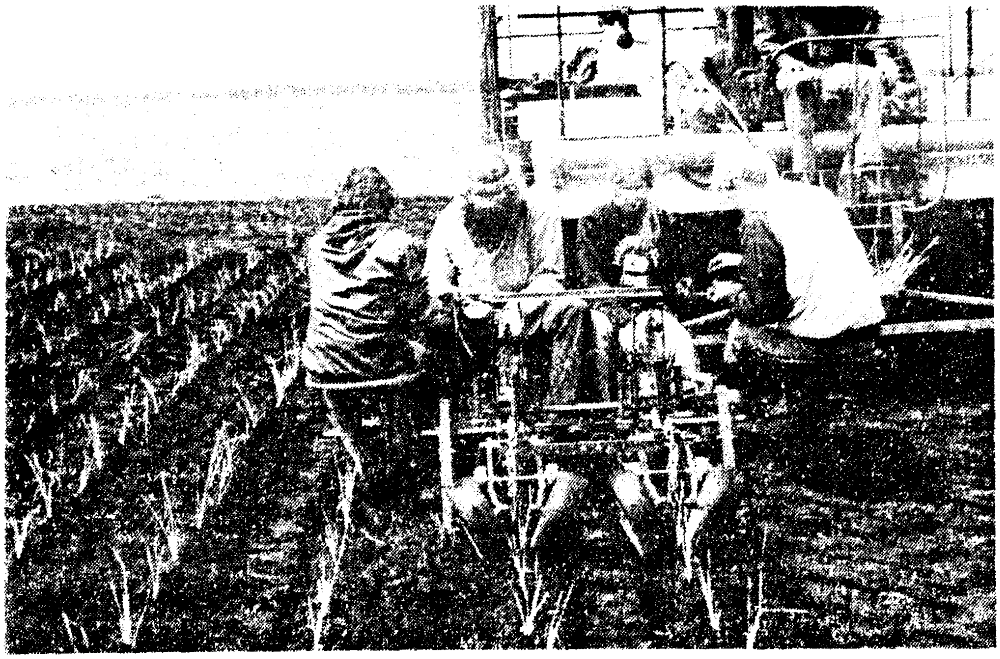

Figure 4-1. MECHANICAL TRANSPLANTER BEING USED FOR SEEDLING PLANTING IN EXPERIMENTAL FIELD PLOTS

planting pieces in several plots leading to floating and loss of planting material following flooding.

During the second growing season, growth rates were nearly identical for seedling and rhizome established stands for the main portion of the growing season. From June 9 through September 2, growth rates averaged 11.4 $g/m^2$/day for seedling planted plots and 10.3 $g/m^2$/day for rhizome plots. This growth rate, combined with lower growth rates prior to June 9 and subsequent to September 2, led to net second season productivities of 912 and 1,124 $g/m^2$ for seedling and rhizome established stands, respectively.

An establishment study begun under a previous SERI contract (Pratt et al., 1982) to compare seeding and seedling establishment methods was followed for two growing seasons past the establishment season. As shown in Table 4-1, total establishment season yields were very low to nonexistant for seeded plots. The Typha latifolia seed failed to develop at all. However, the Typha angustifolia stand, while having a total plant yield of only 86 $g/m^2$, did have a relatively high density of 42 shoots/$m^2$ by the end of the first season. It is believed that the high shoot density contributed to a tremendous increase in productivity in the second and third seasons when the stand had the highest biomass yields of any field experiment (an equivalent of 21 and 25 tonnes/ha in the second and third seasons, respectively). This result is particularly encouraging since it demonstrates that stand establishment using seed is feasible and can result in second season biomass yield actually exceeding yields of stands established using the more costly methods of transplanting rhizome pieces or seedlings. Also, this result emphasizes the need to examine the impact of genotypic variation[3] and initial plant

3. An experiment designed to determine productivity differences attributable to species differences proved unsuccessful because of herbivore damage to the Typha angustifolia seedlings (see Section 5.0).

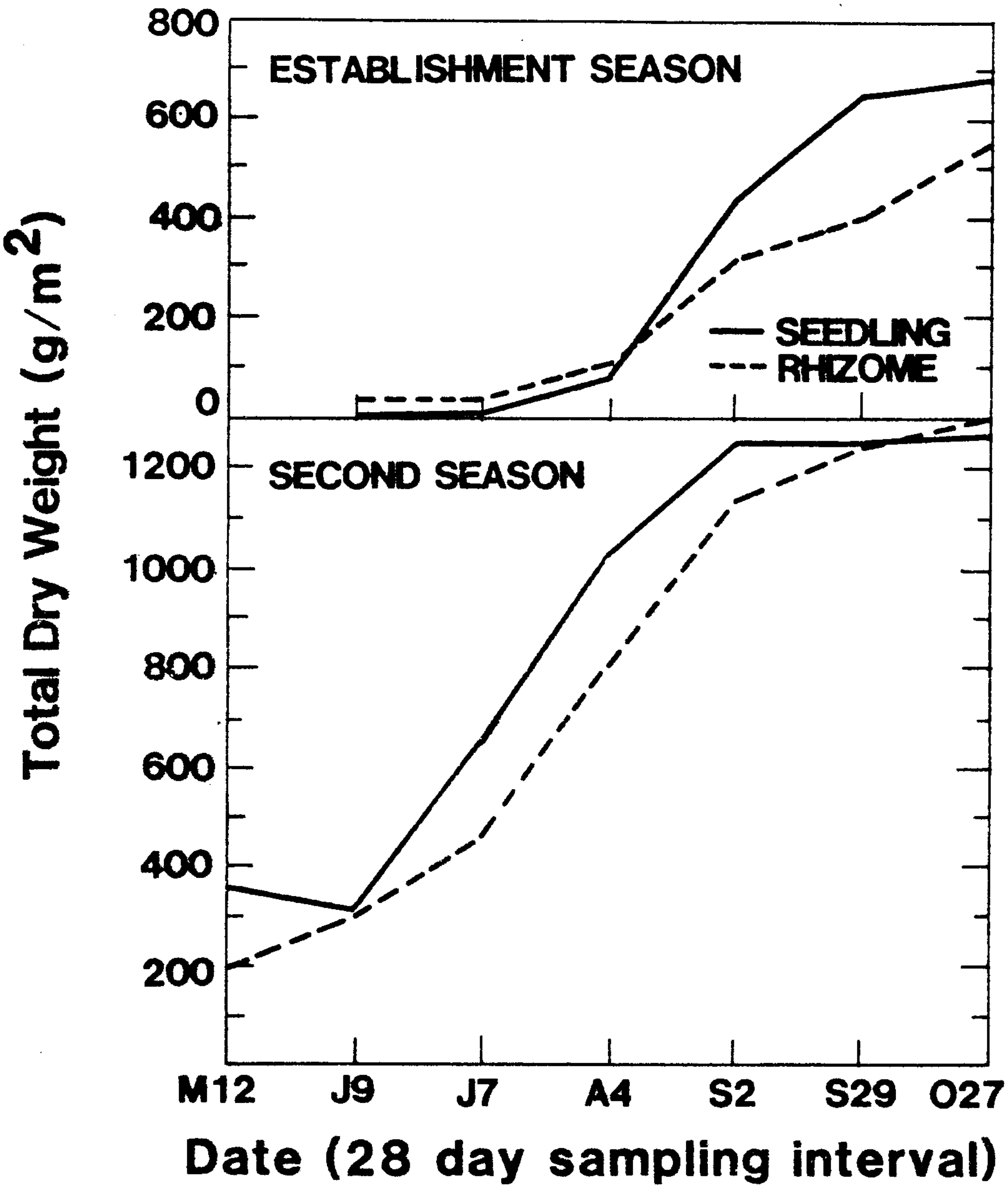


Figure 4-2. TWO YEAR COMPARISON OF BIOMASS ACCUMULATION THROUGHOUT THE GROWING SEASON FOR TYPHA PLOTS ESTABLISHED BY SEEDLING TRANSPLANTATION AND RHIZOME TRANSPLANTATION. INITIAL PLANTING DENSITY = 5/m$^2$.

density on productivity since, under identical field conditions, an adjacent stand of Typha latifolia established from seedlings planted at a density of $5/m^2$ had total yields of approximately half that of Typha angustifolia in the second and third seasons.

Substantial variability exists between experiments in the ratio of aboveground to belowground biomass. At the end of the second season, the Typha angustifolia seeded plot in the establishment study had the highest ratio with a value of 1.8; all other experiments established using seedlings or rhizome pieces had ratios close to 1.0. Whether this variability results from establishment method, genotypic differences or field conditions is still unknown, as is the stability of the ratio over time. By the end of the third season, for example, the ratio for the Typha angustifolia stand had changed to 0.9 indicating that the ratio may not be very stable or that several seasons are required to establish a stable ratio. Because of the significance of this ratio to various production scenarios, further studies of factors influencing this ratio are warranted.

One factor influencing productivity of Typha and, possibly, the ratio of above- to belowground biomass is that of plant density. Density has an impact on the plant canopy and, hence, the stand's efficiency as a solar collector. Density also influences the degree of competition from other plants. The effect of initial plant density at the time of establishment on a final equilibrium density in a managed stand is unclear. It is interesting to note that the Typha angustifolia seeded stand planted at a rate of 700 seeds/$m^2$ maintained a dnesity of approximately twice that of stands established from rhizomes or seedlings at a density of 5 or $9/m^2$ over three growing seasons. More research is needed to better understand factors affecting density.

## 4.3 CONCLUSIONS

- Little difference exists between seedling and rhizome establishment methods in terms of productivity over several growing seasons.
- Establishment methods using seed, if initially successful, result in low establishment season yields, but can lead to productivity exceeding that resulting from other establishment methods in the second and third seasons.
- A reliable method of stand establishment using seed must be developed to exploit the cost advantage of this method over others.
- The effects of establishment method and initial plant density on subsequent productivity, stand density, and ratios of above- to belowground biomass need to be evaluated in long term studies incorporating variables associated with harvesting methods.

## SECTION 5.0

## VARIATION IN TYPHA SPP.

### 5.1 BACKGROUND

Three species of Typha have been identified in the United States. T. latifolia is the most widely distributed, ranging throughout the continental United States as far north as Alaska and as far south as Mexico (Hotchkiss & Dozier, 1949; Lee, 1975; Morton, 1975). Typha angustifolia is found primarily in the north central and northeastern United States, extending south to Florida along the eastern seaboard. Pockets of T. angustifolia are also found in California, Idaho, and Oregon (Hotchkiss & Dozier, 1949; Lee, 1975; Morton, 1975). Typha domingensis is found in most of the southwest, in the Gulf States, and along the Atlantic coast (Morton, 1975). Typha x glauca has been identified as a hybrid of T. latifolia and T. angustifolia, and occurs in geographical regions where the two parent species are found (Fassett & Calhoun, 1952; Lee, 1975; Morton, 1975; Smith, 1967). This discussion will center on T. latifolia, T. angustifolia and the hybrid of the two since these are native to Minnesota.

Several morphological traits distinguish Typha latifolia and Typha angustifolia. T. angustifolia possesses a gap between the staminate and pistillate flowers, and a hair-like bract at the base of the pistillate flower; T. latifolia does not have either of these features. The shape of the stigma and aborted pistil are also different in the two species (Fassett & Calhoun, 1952). Leaves and flowering spikes are generally broader in T. latifolia than in T. angustifolia (Lee, 1975). Finally, in Typha latifolia, pollen grains are dispersed in tetrads, whereas single pollen grains are dispersed by T. angustifolia. Typha x glauca possesses morphological characteristics ranging anywhere in between the two parent species, although Lee (1975) indicated that morphology of the hybrid tends to be more like T. angustifolia. Pollen morphology in T. glauca represents a clear intermediate between the two parent species with grains from any one plant dispersed in combinations ranging from single to tetrads, making this one of the more conclusive features distinguishing between T. glauca and the parent species (Lee, 1975).

Habitat differences have been observed in naturally occurring stands of Typha spp. T. angustifolia is more tolerant of alkaline, saline environments than T. latifolia, although the range of pH and salt content is not well defined in the literature (Anderson, 1977; Fassett & Calhoun, 1952; Hotchkiss & Dozier, 1949; Lee, 1975; Mc Millan, 1959; Morton, 1975; Segadas-Vianna, 1951). T. latifolia can grow under more acid conditions than T. angustifolia (Fassett & Calhoun, 1952). Typha x glauca appears to have a competetive advantage over the two parent species in some habitats intermediate to those normally occupied by T. latifolia and T. angustifolia (Lee, 1975; Smith, 1967).

Water depth is another factor which segregates populations of T. latifolia and T. angustifolia. According to Grace and Wetzel (1981, 1982), T. angustifolia is competitively superior to T. latifolia in deeper water (50-115 cm) because of its taller leaves and larger rhizome storage system. Grace and Wetzel also suggest that T. angustifolia can grow in shallow water, but does not compete well with T. latifolia in water depths less than 50 cm because T. latifolia has more leaf area and is more shade tolerant than T. angustifolia (Grace & Wetzel, 1981).

Insect and animal herbivory appears to be another selective pressure which may occur differentially among Typha spp. Bellura obliqua (formerly Arzama obliqua) is a stem boring moth whose larvae are found frequently on T. latifolia but rarely on T. angustifolia (Classen, 1921; Penko et al., 1983; Tietz, 1972). This moth appears to be one of the main insect pests on Typha spp., and has been shown to reduce total plant productivity by 45% in affected shoots (Penko, 1984). Depending on the extent of infestation in a Typha stand, Bellura could significantly reduce productivity. Muskrats (Ondatra zibethicus) can also significantly reduce the extent of emergent aquatic vegetation, including Typha spp., in wetlands (Bishop et al., 1979). It has been reported that muskrats prefer T. latifolia and T. x glauca to T. angustifolia (Hotchkiss & Dozier, 1949). In our field studies, a 0.5 ha planted stand of T. latifolia contained two muskrat hutches at the end of the first growing season while an adjacent 0.25 ha area with plots of T. angustifolia and T. x glauca appeared to be untouched. At another field site, one month old plots of T. angustifolia and T. latifolia were growing side by side, and the T. angustifolia seedlings were preferentially eaten by some animal, probably muskrats. Adjacent stands of mature T. latifolia and T. angustifolia were untouched.

## 5.2 COMPARATIVE PRODUCTIVITY OF TYPHA SPP.

Productivities of different genotypes of Typha spp. grown under identical conditions were compared in an experiment established in artificial paddies. The planting stocks for this experiment were taken from five of the most productive Typha stands identified in a natural stand survey in Minnesota, and one planting stock was purchased from a commercial nursery.[1] Two of the natural stands were identified as Typha x glauca (Carlos Avery and Roseau) and the other three were identified as Typha angustifolia. The rhizomes supplied by the nursery were a mixture of Typha spp. Full results and discussion of this experiment were presented in the SERI final report subcontract number XK-1-1087 (Pratt et al., 1982). One genotype of T. angustifolia produced significantly more aboveground biomass than any other genotype in the study, however, the mean productivity of T. angustifolia genotypes and T. x glauca genotypes did not differ significantly as shown in Table 5-1, paddy values.

Natural stand surveys and stand establishment and management trials can provide some baseline numbers on productivity of Typha spp. Table 5-1 shows the mean above- and belowground yield of T. latifolia, T. angustifolia and T. x glauca stands established for various field trials, and the range of mean yields found in natural stands of the three. Strict comparisons of these yields cannot be made since many variables such as age of stand, planting density, planting stock, and substrate fertility and pH are inherent in the mean values given. Some of these factors are discussed in Section 4.0. The data do suggest, however, that T. latifolia is generally less productive than T. angustifolia or the hybrid of the two.

The data in Table 5-1 also illustrate that productivity in young (1 to 3 year) managed stands does not approach the upper end of the range of productivity reported in natural stands of each species. It is difficult to determine what factors account for this discrepancy. Although data on densities in natural stands are sparse, the range of 18 to 79 shoots/$m^2$ (Andrews & Pratt, 1981) found in some natural stands surveyed in the northcentral United States is less than the range of 38 to 90 shoots/$m^2$ found in the managed stands listed in Table 5-1. This would suggest that higher stand density does not account for higher yield in natural stands. Conflicting reports exist in the literature as to whether productivity is influenced more by stand density or individual shoot size (Boyd, 1971; Boyd & Hess, 1970; Dykjova et al., 1971; Ondok, 1971). Inconsistency in

1. Kesters Wild Game Food Nurseries, Inc., Omro, Wisconsin

Table 5-1. COMPARISON OF *TYPHA* SPP. PRODUCTIVITY

| Species | Source | Mean Above-ground Yield (tonnes/ha) | Mean Below-ground Yield (tonnes/ha) | Reference[a] |
|---|---|---|---|---|
| *TYPHA LATIFOLIA* | Natural stands of North Central U.S. | 4.3 - 14.9 | 5.0 - 9.1 | 6,7,8,9,10 |
| | 2-year-old stand, Aitkin, MN; establishment study | 6.2 | 5.4 | |
| | 2-year-old stand, Zim, MN; peatland excavation study | 4.6 | 4.4 | |
| | 2-year-old stand, Zim, MN; nutrient uptake study | 7.3 | 5.2 | |
| *TYPHA ANGUSTIFOLIA* | Natural stands of North Central U.S. | 12.3 - 21.1 | -- | 9,10 |
| | 3-year-old stand, Aitkin, MN; establishment study | 12.5 | 13.5 | |
| | 1-year-old paddies; St. Paul, MN; genotypic variation study | 9.4 | 10.7 | |
| *TYPHA X GLAUCA* | Natural stands of North Central U.S. | 6.7 - 23.2 | 10.2 - 31.0 | 1,2,3,4,5,9,10,11 |
| | 2-year-old stand, Zim, MN; peatland excavation study | 6.9 | 7.3 | |
| | 1-year-old paddies, St. Paul, MN; genotypic variation study | 9.4 | 11.9 | |
| | 2-year-old stand, Aitkin, MN; fertilization study[b] | 8.1 | -- | |

[a]References. 1) Andrews and Pratt, 1978. 2) Bernard and Bernard, 1973. 3) Bray *et al.*, 1959. 4) Bray, 1960. 5) Bray, 1962. 6) Gustafson, 1976. 7) Klopatek and Stearns, 1978. 8) McNaughton, 1966. 9) Pratt, 1978. 10) Pratt *et al.*, 1980. 11) van der Valk and Davis, 1978. No reference listed means values are from current work.

[b]Actually a mixed stand containing some individuals of all species, but predominantly *T.* x *glauca.*

sampling and drying methods could account, in part, for variation in measurements of productivity.

An experiment was established near Aitkin in June, 1983 to compare the productivity of T. latifolia and T. angustifolia seedlings grown under identical conditions in the field. In early August, all plots of T. angustifolia seedlings were heavily damaged by unidentified herbivores, probably muskrats. No damage was observed in T. latifolia plots. Because of this, no productivity comparison at the end of the first growing season was possible.

## 5.3 COMPARISON OF FUEL QUALITY FACTORS IN TYPHA SPP.

Based on analysis of some Typha tissue samples, it appears that T. angustifolia tissue may have a slightly lower energy content than T. latifolia or T. x glauca. The aboveground material from T. latifolia samples had a mean energy content of 4515 cal/g, T. x glauca aboveground tissue had 4451 cal/g, and T. angustifolia had 4220 cal/g. In all cases, the energy content of the belowground tissue was less than the aboveground tissue: 4020 cal/g of belowground T. latifolia tissue, 4069 cal/g of T. x glauca, and 3994 of T. angustifolia. For comparative purposes, average energy content values for bituminous coal and lignite are 7220 cal/g and 4030 cal/g respectively (Hall, 1981).

Ash represents an undesirable byproduct in any fuel conversion process, so ash content was measured for Typha spp. tissue samples. Mean ash percentage for aboveground T. latifolia tissue samples from various experiments was 6.3%. For T. angustifolia aboveground tissue, the mean ash concentration was 6.8%. Aboveground tissue from experimental plots established with T. x glauca contained 5.6% ash on the average. Since this is not an experimental comparison, it is not known if these differences are significant. For all Typha spp. samples, however, the ash content is low compared to other fuel sources. Coal contains 4 to 14% ash (Hall, 1981). Fuel grade peat has been tentatively defined according to several parameters by the United States Department of Energy, one of which is that the ash content does not exceed 25% (Kopstein, 1980).

## 5.4 CONCLUSIONS

- Known habitat differences in Typha latifolia, T. angustifolia and T. x glauca can be used to select the optimum species for a given location. Ranges of tolerance of each species and the hybrid to salinity, pH, and water depth needs to be more completely defined.

- Observed patterns of animal and insect herbivory should be considered in selecting a species of Typha for biomass production. Conflicting reports of muskrat preference for different Typha spp. should be clarified.

- There is some evidence that T. latifolia is less productive than T. angustifolia and T. x glauca. A direct comparison of these under managed paddy conditions should be made.

- An explanation of the observed difference in natural and managed stand productivity should be pursued with a thorough natural stand survey and continued attempts to increase managed stand productivity.

- Energy and ash contents vary slightly between Typha spp., but all are within the range of more conventional solid fuel sources.

## SECTION 6.0

## NUTRIENT REQUIREMENTS

### 6.1 INTRODUCTION

The selection of cattail (Typha spp.) as a candidate for a bio-energy crop was based on a number of factors described in the introduction of this report. The high productivity of these plants in natural stands coupled with the low opportunity costs of land which could be used to grow them has led to research into methods of production in newly established, managed stands. The ultimate goal is to develop a management system which maximizes yield and minimizes inputs, resulting in an energy resource that is economically competitive with other renewable and non-renewable sources of energy.

One component of production costs which could significantly affect the final cost of this resource is that of nutrients required to attain high yields. In a natural system, nutrient recycling can greatly reduce the need for additional nutrient inputs (van der Valk and Davis, 1978). In a bio-energy production system, nutrients are removed from the system when the biomass is harvested. High, sustained yields require that these nutrients be replaced. This can be accomplished to varying degrees by natural biological and physical processes (Biesboer, in press) and by application of fertilizers. The actual amounts and types of nutrients which need to be replaced through fertilizer application will depend on how much is replaced by natural processes, and the overall nutrient requirements of Typha.

In agronomic crops, nitrogen, phosphorus, and potassium are the macronutrients of major concern because of their cost and effect on yield. This will potentially be the case for Typha production as well. In addition to these macronutrients, other macro- and micronutrients could prove to be limiting, especially in anaerobic organic soils where cattails may be grown. Copper is an example of a micronutrient often found limiting in organic soil (Tisdale & Nelson, 1975).

The effort to define minimum nutrient requirements for high, sustained yields of Typha spp. begins most logically with establishing some baseline numbers on soil and tissue nutrient levels found in natural and established stands. An overview of the relationship of these nutrient levels with yield, density, and partitioning of biomass into above- and belowground portions of the plant can serve as a starting point for defining Typha nutrient requirements. The work of Boyd and Hess (1970), Boyd (1971, 1978), Kvet (1975), Mason and Bryant (1975) and the current work presented here provide some baseline values, and will be discussed in Section 6.2 of this report.

Nutrient requirements for optimizing Typha productivity can be further defined through controlled experimentation testing the response of Typha spp. to fertilization. Few Typha fertilization experiments have been reported in the literature. Boyd (1971) tested the effect of six incremental treatments of 6-12-12 fertilizer (6% N, 12% $K_2O$, 12% $P_2O_5$) on Typha latifolia plants grown in greenhouse pots containing a lake mud substrate. He found a significant increase in density, shoot height, above- and belowground yield, above- to belowground biomass ratio, and tissue nutrient concentration with increasing fertility levels. Bonnewell and Pratt (1978) conducted a similar experiment on Typha x glauca in a hydroponic greenhouse system using complete Hoagland's solution with varying reduced levels of nitrogen, phosphorus or potassium. They found a significant yield reduction with reduced nitrogen levels, but not with reduced phosphorus or potassium. Bonnewell and Pratt, like Boyd, found a higher ratio of above- to belowground biomass at higher levels of nitrogen and phosphorus fertility. Krolikowska (1982) tested the effect of nitrogen and potassium fertilization on T. latifolia plants grown in greenhouse pots on lake mud. He found that nitrogen fertilization alone, and nitrogen and potassium fertilizer together, caused an increase in aboveground biomass only and an increase in the above- to belowground biomass ratio. Potassium fertilization alone caused an increase in belowground biomass only, and an associated drop in the above- to belowground ratio. No treatment effect on density was observed, unlike the results of Boyd's study. Szczepanska and Szczepanski (1976) conducted a related experiment in which varying levels of nitrogen, phosphorus and potassium were supplied to Typha latifolia and T. angustifolia shoots grown in the greenhouse, not through fertilization but through altering the substrate from pure lake mud to different mixtures of lake mud and infertile sand. Szczepanska and Szczepanski also did not find an increase in density at higher fertility levels, but did see an increase in biomass production for both species attributable to larger shoot size in pots with a higher percentage of lake mud. In related field work reported in the same paper, Szczepanska and Szczepanski conclude that the effect of fertility is less obvious in natural wetlands, as it is concealed by other environmental factors such as water depth, allelopathy, and shading. It is clear from these four studies that some discrepancies in reports of Typha response to fertilizer treatment exist, and that interactions of soil fertility with environmental conditions in the field are not known. For this reason, a field fertilization experiment was established, and will be discussed in Section 6.3.

In addition to gross levels of nutrients used for Typha production over the course of a growing season, seasonal patterns of uptake are of interest since applied nutrients can be lost from the system before being taken up by the plant as is the case with nitrogen losses resulting from denitrification. Several measures can be taken to minimize fertilizer losses, such as selecting the proper form of fertilizer and controlling water levels to minimize leaching and aeration. But timing fertilizer application to coincide with the time of maximum uptake by the plant appears to be one of the most promising control measures, and for this, knowledge of seasonal uptake patterns is needed.

Time of harvest is another factor which can affect nutrient loss from the system. Nutrients are mobilized from the aboveground plant parts at some time late in the growing season and transported to the rhizome system for storage over winter (van der Linden, 1980). By timing harvest to occur after nutrients have been translocated to rhizomes, unnecessary nutrient removal can be avoided. Again, a knowledge of seasonal patterns of nutrient uptake and movement within the plant is needed. A few studies have observed seasonal patterns of nutrient movement in natural stands. Boyd (1970b) studied a Typha latifolia stand in South Carolina in which shoot growth began in March, peaked in mid-June, and had declined by mid-July soon after the completion of flowering. Penfound (1956) found a similar pattern in Oklahoma. Boyd (1970) also followed nutrient movement and found that nutrient uptake (measured as g nutrient/$m^2$) followed the same pattern as biomass increase. In a similar study looking at five natural stands, Boyd (1971) confirmed the same patterns of nutrient uptake and dry weight gain. Klopatek (1975) observed similar patterns of biomass and nutrient accumulation in a Wisconsin Typha stand, although the entire process was shifted later in the season with growth beginning in mid-May. Van der Linden (1980) observed similar patterns in another emergent aquatic species, Phragmites communis. To determine if similar patterns would be found in managed Typha stands in Minnesota, a two year experiment was established in the northeastern part of the state near Zim. The results are discussed in section 6.4 of this report.

## 6.2 NUTRIENT YIELD COMPARISONS

A comparison of density, yield and concentration of nitrogen, phosphorus and potassium in plant tissue from several studies is presented in Table 6-1. Levels of micro- and other macronutrients in plant tissue from the same locations, where available, are presented in Table 6-2. These values can serve to illustrate the range of nutrient concentrations found in Typha plants grown in various locations, and may be used for comparison with other investigations as an indicator of relative plant nutrient status. It is interesting to note that sodium occurs in unusually high concentrations in Typha tissue. The significance of this is not known since sodium is not generally considered to be an essential plant nutrient, although it has been shown to increase yield in certain crops (Salisbury & Ross, 1978). Iron is also found in unusually high concentrations in belowground Typha tissue, but not in aboveground tissue. Again, the significance of this is not known. High levels of sodium and iron were observed in these same experiments during the establishment season (Pratt et al., 1982).

In addition to providing baseline numbers, values in Tables 6-1 and 6-2 can be used evaluate the relationship of tissue nutrient concentration to plant productivity. Comparing nutrient status with productivity over a wide range of conditions, regression analysis, using mean values for all Minnesota experiments, showed no significant relationship between aboveground dry weight and tissue nutrient concentration except for sodium, which had an $r^2$ value of 0.77. It is not known what, if any, cause and effect relationsnip this correlation represents. Values from Boyd's work were not included in this analysis since sampling occurred at a different time, and there is significant evidence that nutrient concentrations change throughout the season (Bonnewell, 1981; Boyd, 1970; Kvet, 1975).

Within one study, Boyd and Hess (1970) did analyze for a relationship between yield and plant nutrient levels. He found a strong correlation between nutrient standing crop (grams nutrient per square meter) and yield. This is not surprising since productivity is a component of the nutrient standing crop measurement. Boyd and Hess did not present correlation data between nutrient concentration and yield, but did state that nutrient concentrations were higher in the most productive stands and lower in the least productive, although the relationship did not hold in between.

Other studies have also compared tissue nutrient concentration and productivity. Bonnewell (1981) found low correlations for all nutrients studied, with phosphorus being most highly correlated with shoot biomass ($r^2 = 0.25$). Current research discussed in the following sub-section of this report also revealed no significant relationship between tissue nutrient concentration and Typha productivity.

Values in Tables 6-1 and 6-2 can also be used to explore the relationship between plant nutrient status and shoot density. Regression analysis, using mean values for Minnesota experiments, showed no significant relationship between density and tissue nutrient concentration. Sodium concentration showed the best correlation with density ($r^2 = 0.62$), as it did with biomass yield. Any effect of nutrient status on density is of interest since there is some indication that high density is associated with increased biomass yields (Bonnewell & Pratt, 1978; Ondok, 1971; Pratt et al., 1982), although there are conflicting reports on the relationship of density and yield (Boyd, 1971; Klopatek & Sterans, 1978).

Table 6-3 presents soil nutrient data for the Minnesota Typha stands shown in Tables 6-1 and 6-2, and for Wisconsin marshes containing Typha vegetation. Soil nutrient levels were not reported in Boyd's studies which were included in Tables 6-1 and 6-2. The

Table 6-1. BIOMASS YIELD AND TISSUE NUTRIENT CONCENTRATION IN NATURAL AND MANAGED *TYPHA* STANDS

| Location (experiment) | Time of Sampling | Density (shoots/ m2) | Mean Dry Weight (g/m2) | | Mean % Nitrogen | | Mean % Phosphorus | | Mean % Potassium | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | AG | BG | AG | BG | AG | BG | AG | BG | |
| S.E. United States[a] | Mid June | --- | 300-2300 | --- | 0.75-2.25 | --- | 0.05-0.40 | --- | 0.50-4.[illegible] | --- | Boyd & Hess 1970 |
| South Carolina | Mid July | --- | 625 | --- | 0.51 | --- | 0.09 | --- | 1.60 | --- | Boyd 1970 |
| South Carolina[b] | Mid July | 22-32 | 530-1132 | --- | 0.9-1.1 | --- | 0.13-0.24 | --- | 1.2-2.0 | --- | Boyd 1971 |
| St. Paul, MN | Late Sept | 51 | 885 | --- | 0.68 | --- | 0.11 | --- | 1.42 | --- | Pratt *et al.* 1982 |
| Aitkin, MN[c] (fertilization study) | Late Sept | 41 | 806 | --- | 0.92 | --- | 0.16 | --- | 0.71 | --- | Current research |
| Aitkin, MN[c] (seeding establishment) | Late Sept | 111 | 1385 | 764 | 1.02 | 2.05 | 0.17 | 0.38 | 1.94 | 1.67 | Current research |
| Zim, MN[c] (excavation study) | Late Sept | 47 | 576 | 554 | 0.93 | 0.71 | 0.15 | 0.23 | 1.02 | 1.28 | Current research |
| Zim, MN[c] (uptake study) | Late Sept | 42 | 694 | 501 | 1.56 | 1.15 | 0.31 | 0.43 | 1.80 | 1.36 | Current research |
| Minnesota (natural stands) | Mid Sept | 51 | 1395 | --- | 1.13 | --- | 0.22 | --- | 1.84 | --- | Pratt *et al.* 1982 |

[a]Survey of 30 natural stands. Range represents mean values for most and least productive stands.
[b]Survey of 5 natural stands. Range represents mean values for most and least productive stands.
[c]Two year old managed stands.

Table 6-2. TISSUE NUTRIENT CONCENTRATION IN NATURAL AND MANAGED *TYPHA* STANDS

| Location (experiment) | % of Dry Weight: Calcium AG | Calcium BG | Magnesium AG | Magnesium BG | Sodium AG | Sodium BG | Parts per Million: Iron AG | Iron BG | Manganese AG | Manganese BG | Copper AG | Copper BG | Boron AG | Boron BG | Zinc AG | Zinc BG | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S.E. United States[a] | 0.25–1.75 | --- | 0.05–0.35 | --- | 0–1.20 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | Boyd & Hess 1970 |
| South Carolina | 0.53 | --- | 0.10 | --- | 0.19 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | Boyd 1970 |
| St. Paul, MN | 1.24 | --- | 0.14 | --- | 0.17 | --- | 141 | --- | 500 | --- | 2 | --- | 12 | --- | ---- | --- | Pratt *et al.* 1982 |
| Aitkin, MN (fertilization study) | 1110 | --- | 0.18 | --- | 0.24 | --- | 106 | --- | 521 | --- | 5 | --- | 13 | --- | 15 | --- | Current research |
| Aitkin, MN (seeding establishment) | 1.00 | 0.46 | 0.25 | 0.20 | 0.49 | 0.21 | 145 | 1710 | 368 | 106 | 2 | 3 | 12 | 6 | 13 | 37 | Current research |
| Zim, MN (excavation study) | 1.05 | 0.58 | 0.27 | 0.24 | 0.24 | 0.27 | 111 | 1665 | 285 | 186 | 26 | 25 | 15 | 12 | 25 | 31 | Current research |
| Zim, MN (uptake study) | 1.35 | 0.72 | 0.33 | 0.24 | 0.19 | 0.35 | 119 | 1860 | 335 | 117 | 3 | 5 | 18 | 15 | 15 | 35 | Current research |
| Minnesota (natural stands) | 1.19 | --- | 0.31 | --- | 0.41 | --- | 54 | --- | 423 | --- | 2 | --- | 25 | --- | --- | --- | Pratt *et al.* 1982 |

[a]Survey of 30 natural stands. Range represents mean values for most and least productive stands.

Table 6-3. AVAILABLE SOIL NUTRIENTS IN NATURAL AND MANAGED *TYPHA* STANDS

| Location (experiment) | %Organic Matter | pH | ppm $NO_3$- and $NH_4$+-N | available P (ppm) | available K (ppm) | Total ppm Ca | Mg | Na | Fe | Mn | Zn | Cu | B | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wisconsin | 40.4-43.4 | 6.4-6.5 | --- | 50-203 | 133-230 | 5270-[a] 12,730 | 1219-[a] 2318 | --- | --- | --- | --- | --- | --- | Klopatek & Stearns 1978 |
| Wisconsin | 42.6 | 6.4 | --- | 164 | 222 | 9713[a] | 2060[a] | --- | --- | --- | --- | --- | --- | Klopatek 1975 |
| St. Paul, MN | 45 | 6.1 | --- | 52 | 45 | --- | --- | --- | --- | --- | --- | --- | --- | Pratt *et al.* 1982 |
| Aitkin, MN (fertilization study) | 42 | 5.4[b] | 38 | 22 | 92 | 16,600 | 3,380 | 257 | 17,300 | 661 | 56 | 23 | 21 | Current research |
| Aitkin, MN (seeding establishment) | 6 | 5.4[b] | 16 | 40 | 46 | --- | --- | --- | --- | --- | --- | --- | --- | Current research |
| Zim, MN (excavation study) | 83 | 5.1[b] | 15 | 17 | 134 | 15,000 | 2363 | 90 | 7540 | 381 | 37 | 27 | 0 | Current research |
| Zim, MN (uptake study) | 85 | 5.3[b] | 37 | 24 | 116 | --- | --- | --- | --- | --- | --- | --- | --- | Current research |
| Zim, MN | 87 | 5.3 | --- | 19 | --- | 11,500 | 1450 | 45 | --- | 265 | 31 | 2 | 2 | Andrews *et al.* 1981 |

[a]Exchangeable, not total parts per million calcium and magnesium.
[b]pH measured in 0.01 M $CaCl_2$. All other pH measured in water.

values presented in Table 6-3 can serve as a starting point to illustrate the range of soil nutrient conditions under which Typha spp. have been known to grow.

The relationship of substrate fertility to Typha productivity can also be studied using these baseline numbers. Comparing soil nutrient values from Table 6-3 with yield values given in Table 6-1 for Minnesota experiments shows that there is no significant positive correlation between soil nutrient levels and productivity. In fact, for potassium there is a negative correlation with the most productive stand (Aitkin seeding establishment experiment) growing on a soil with one of the lowest available potassium levels. There was a weak positive correlation between soil phosphorus and productivity ($r^2$ = 0.36). Other studies also found little relationship between substrate nutrient levels and productivity. Klopatek and Stearns (1978) concluded that the marsh soils he studied supplied more than an adequate amount of nutrients to marsh plants and that other environmental factors were limiting to growth. Boyd and Hess (1970) found little correlation between soil nutrient concentrations and yield, with phosphorus giving the strongest positive correlation ($r^2$ = 0.50). Bonnewell (1981) observed similar relationships, again with phosphorus providing the strongest positive correlation ($r^2$ = 0.25). In all these studies it was concluded that no clear relationship between environmental nutrient levels and Typha productivity existed.

The effect of substrate fertility on plant nutrient removal is of interest, especially since increased soil fertility under some field conditions in natural and managed stands does not seem to increase yield (Bonnewell, 1981; Boyd & Hess, 1970; Klopatek & Stearns, 1978; Section 6.3 of this report). Increased nutrient removal without an associated biomass increase would not be desirable from a production standpoint. No significant correlation was seen between soil nutrient levels and plant tissue nutrient concentration for nitrogen, phosphorus, and potassium at various sites in Minnesota (Tables 6-1 and 6-3). Bonnewell (1981) also found a low correlation between Typha tissue element concentration and the same element's concentration in the substrate. Klopatek (1975) found a strong positive correlation between nutrient standing crop and soil nitrogen (total) and phosphorus (available), but he did not report correlations for tissue nutrient concentration. Despite the fact that some greenhouse studies have shown a positive effect of substrate nutrient availability on Typha tissue nutrient concentration (Bonnewell & Pratt, 1978; Boyd, 1971) it appears that other factors may limit uptake in the field.

Several conclusions can be drawn from this overview of nutrient relations in Typha spp.

- Results presented in Tables 6-1 through 6-3 begin to provide some baseline numbers which can be used for comparative purposes in future experiments.

- No clear relationship between tissue nutrient concentration and Typha productivity has been established based on several studies. If such a relationship could be established, it could serve as a valuable diagnostic tool for fertilization requirements in managed Typha paddies.

- No clear relationship exists between substrate fertility and tissue nutrient levels or yield based on several studies. This may indicate that under the wetland conditions investigated, some factors other than soil fertility were limiting to growth.

- Nutrient relations in a Typha marsh represent a complex system. More investigation is needed to elucidate that system so that management practices may be developed which minimize nutrient inputs while optimizing productivity.

## 6.3 EFFECT OF NITROGEN, PHOSPHORUS AND POTASSIUM ON *TYPHA* PRODUCTIVITY OVER TWO YEARS

It is evident from the review of *Typha* fertilization experiments presented in Section 7.0 that conflicting results have been obtained for the response of *Typha* to fertilization under the experimental conditions considered. In addition, none of the experiments were conducted under field conditions, and none looked at the interactions of different levels of the three macronutrients nitrogen, phosphorus and potassium. For this reason a blocked complete factorial experiment with three levels of nitrogen (0, 75 and 150 kg/ha), two levels of phosphorus (0 and 150 kg/ha), and two levels of potassium (0 and 300 kg/ha) was established at a field site near Aitkin in central Minnesota during 1981 (see appendix A for details of experimental methods). The experiment was established with several objectives in mind:

- To determine the effect of different combinations of nitrogen, phosphorus, and potassium on first and second season yields, and the partitioning of biomass into above- and belowground components.
- To determine the effect of different combinations of nitrogen, phosphorus and potassium on factors affecting yield including density, competitors, soil fertility and tissue nutrient concentration.
- To gather information on *Typha* spp. nutrient requirements other than nitrogen, phosphorus and potassium

### 6.3.1 Establishment Season Results

Table 6-4 shows the mean yield and density at the end of two growing seasons for plots receiving different levels of nitrogen, phosphorus and potassium. Although there is a trend toward increasing yields in the first season with increasing rates of fertilization, these increases are not significant according to analysis of variance, with the exception of the effect of potassium fertilization on belowground biomass. An increase in belowground biomass with potassium fertilization was also observed in Krolikowska's experiment (1982). It is not possible to compare annual *Typha* productivity at different fertilization levels in this experiment with the results of other fertilization experiments (Bonnewell & Pratt, 1978; Boyd, 1971; Krolikowska, 1982; Szczepanska & Szczepanski, 1976) since productivity was not expressed on a unit area basis in these papers.

A significant increase in shoot density in the first season of this experiment was seen with phosphorus and potassium fertilization, similar to the results of Boyd (1971), but unlike the results of Krolikowska (1982) and Szczepanska and Szczepanski (1976). The fact that shoot density is strongly correlated with yield in this experiment could possibly account for the higher belowground yield seen with potassium fertilization. However, it does not appear that the density increase resulted in significantly higher aboveground yields in potassium fertilized plots, or above- and belowground yields in phosphorus fertilized plots.

Partitioning of biomass into above- and belowground portions of the plant was unaffected by fertilizer treatment in the first season when the percent of total dry weight found in the aboveground portion averaged 47% overall. Boyd (1971), Bonnewell and Pratt (1978), and Krolikowska (1982) all found an increase in the above- to belowground biomass ratio with increasing nitrogen, phosphorus, and, in some cases, potassium

Table 6-4. TYPHA FERTILIZATION STUDY ANALYSIS OF VARIANCE SUMMARY

| Fertilizer Rate (kg/ha) | Establishment Season: Mean Density (shoots/$m^2$) | Establishment Season: Mean Dry Wt. (tonnes/ha) AG | Establishment Season: Mean Dry Wt. (tonnes/ha) BG | Second Season: Mean Density (shoots/$m^2$) | Second Season: Mean Dry Wt. (tonnes/ha) AG* | Second Season: Mean Dry Wt. (tonnes/ha) BG |
|---|---|---|---|---|---|---|
| Nitrogen 0 | 26 | 3.28 | 3.64 | 47 | 7.28 | -- |
| Nitrogen 75 | 28 | 3.69 | 4.24 | 37 | 5.91 | -- |
| Nitrogen 150 | 29 | 4.08 | 4.31 | 40 | 6.97 | -- |
| Phosphorus 0 | 25 | 3.54 | 3.78 | 43 | 6.68 | -- |
| Phosphorus 150 | 30 | 3.83 | 4.34 | 39 | 6.67 | -- |
| Potassium 0 | 26 | 3.39 | 3.73 | 42 | 6.66 | -- |
| Potassium 300 | 30 | 3.98 | 4.40 | 41 | 6.78 | -- |
| Combined 150-150-300 | 32 | 3.99 | 4.64 | 32 | 6.67 | -- |
| Unfertilized 0-0-0 | 22 | 2.70 | 3.19 | 45 | 7.05 | -- |

* Aboveground tissue samples in the second season do not include the lower 15 cm of plant shoots. These lower shoots were left intact to provide aeration of the rhizome system and ensure stand survival.

concentration in the growth medium. No information on biomass partitioning in the second season of this experiment is available since belowground material was not sampled.

The phosphorus and potassium fertilizer treatments were effective in significantly increasing tissue nutrient concentration during the establishment season as shown in Fig. 6-1, and available soil nutrients as shown in Fig. 6-2 according to analysis of variance. Nitrogen fertilization resulted in higher nitrogen concentration in the plant tissue, although the relationship was not significant. Increased nutrient levels indicate that applied nutrients did not move appreciably in the soil, and support the conclusion made previously (Pratt et al., 1982) that some factors other than nitrogen, phosophorus, and potassium were limiting to growth. Higher concentration of nutrients in plant tissue without an associated increase in biomass indicates luxury consumption of these nutrients.

### 6.3.2 Second Season Results

It was believed that the treatment related increase in soil and belowground tissue nutrients in the first season might carry over into the second season and have an effect on yield and density. Examination of second season results have not supported this hypothesis. While aboveground yields more than doubled in the second season, on the average, regression analysis indicates that higher carry over of nutrients in belowground tissue and soil in some plots did not cause an associated higher yield increase. Analysis of variance for the second season also shows no effect of fertilizer treatment on aboveground productivity and, in fact, treatment effects in density seen in the first season had disappeared in the second year (Table 6-4).

Analysis of variance did indicate a significant relationship between tissue nutrient concentration in the second season and initial fertilizer treatment for all nutrients (Fig. 6-1). The fact that there was a significant relationship between tissue nitrogen concentration and treatment in the second year when the relationship was not significant in the first year supports the hypothesis that there was luxury consumption of this nutrient in the establishment season. Since availability of nitrogen decreased across all treatments in the second year (Fig. 6-2), saturation of plant nitrogen uptake may not have occurred at the lower nitrogen treatment levels in the second season, perhaps explaining why treatment differences were seen in tissue nitrogen concentration (Fig. 6-1). While overall concentrations of nutrients in the soil were lower in the second season than the first, significantly higher concentrations were still seen in plots receiving potassium and phosphorus fertilizer (Fig. 6-2). This carryover of nutrient differences in tissue and soil into the second season indicates the continued long term effect of the fertilizer treatment, and supports the conclusion that some factors other than nitrogen, potassium and phosphorus were limiting to growth.

### 6.3.3 Effect of Non-Nutrient Factors on Productivity

Since the yield and nutrient data at the end of two field seasons suggest that nitrogen, phosphorus and potassium did not limit *Typha* biomass production at this site, some investigation of what factors may have been limiting is needed. A full discussion of several factors which may have affected initial establishment and subsequent first season productivity can be found in a previous analysis of this experiment (Pratt et al., 1982). These factors included initial survival of planting material (measured as early season densities) competitor cover, micronutrient levels (micronutrients were applied at this site), and water depth. Results of statistical analysis indicated that water depth, tissue micronutrient levels, and competitor cover had little effect on final

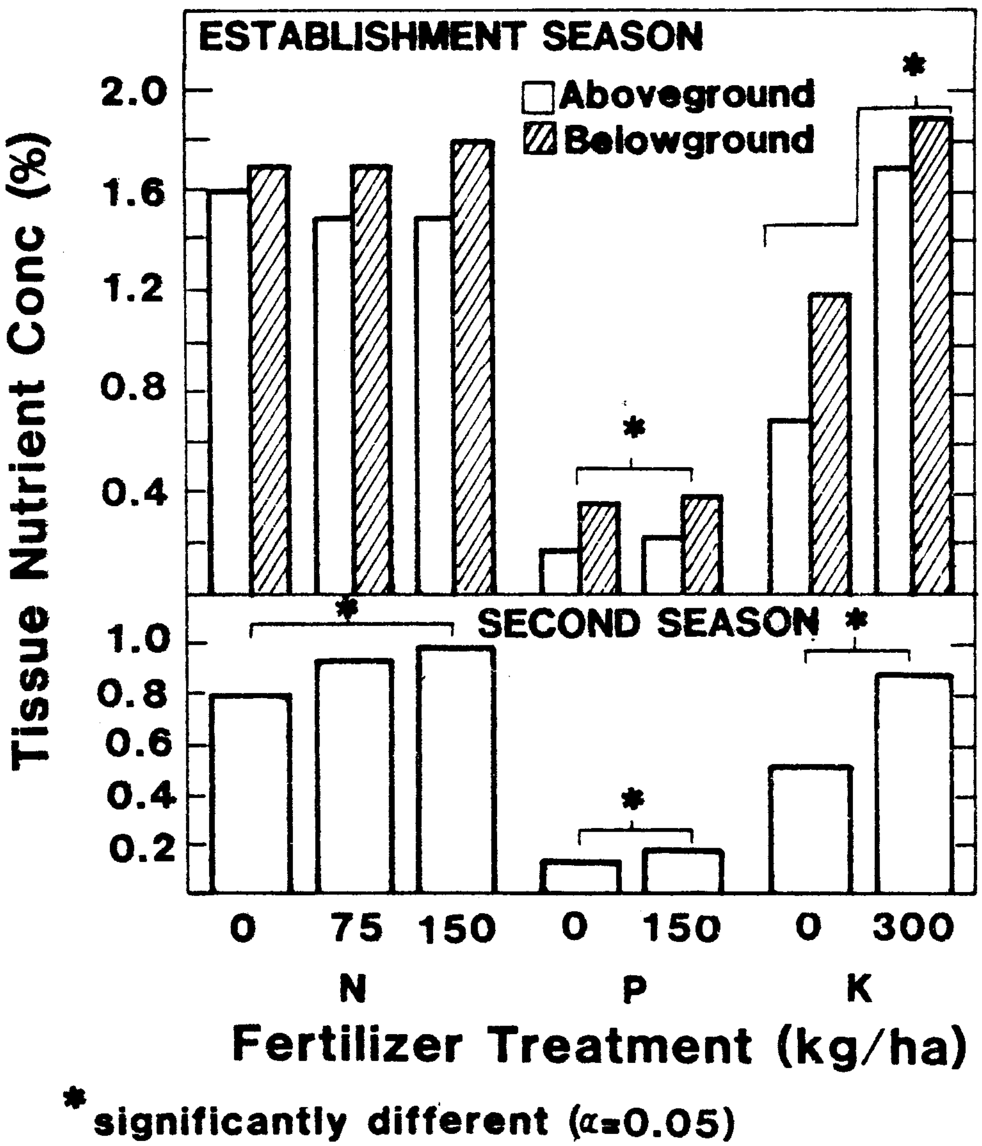


Figure 6-1. CONCENTRATION OF NUTRIENTS IN PLANT TISSUE BY TREATMENT, WITH ANALYSIS OF VARIANCE SUMMARY

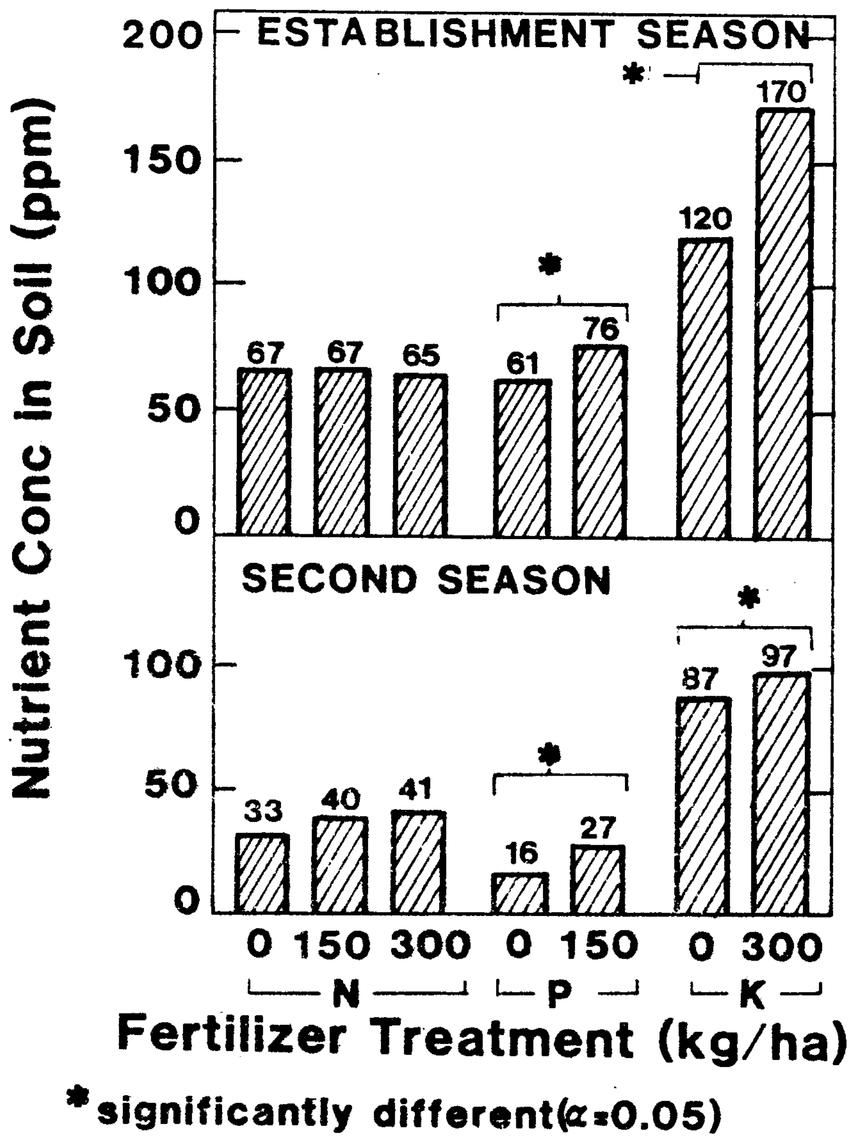


Figure 6-2. MEAN AVAILABLE SOIL NUTRIENT CONCENTRATIONS BY TREATMENT, WITH ANALYSIS OF VARIANCE SUMMARY. (AVAILABLE NUTRIENTS INCLUDE WATER SOLUBLE P, WATER SOLUBLE AND EXCHANGEABLE K, AND $NH_{4+}$ AND $NO_{3-}$ NITROGEN. SEE APPENDIX A FOR DETAILS OF METHODS.)

yield. A strong correlation did exist between survival of planting material and final yield. The survival rate was quite variable and was not affected by fertilizer treatment, suggesting that differences in viability of the planting stock under the existing site conditions, rather than differences in fertilization regime, accounted for the variation in productivity at the end of the season. This conforms to observations made when planting the experimental plots that the commercially obtained stock was highly variable in terms of size and number of buds and shoots.

Initial soil fertility at the experimental site is another factor which may have contributed to the lack of treatment effect on yield. Relative to other field sites where Typha stands have been established, mean available nitrogen, phosphorus and potassium levels were average to high at this site (Table 6-3), suggesting that the field may not have been depleted of nutrients enough to effect a fertilizer response. Since it was not possible to remove all aboveground material on this site due to equipment limitations, many of the nutrients were recycled, and high fertility levels were maintained into the second year. Nutrient levels throughout the field were also quite variable, with nitrogen ranging from 41 to 155 ppm, phosphorus from 0 to 37 ppm, and potassium from 82 to 211 ppm, and it was thought that initial fertility differences may have confounded treatment effects. The data did suggest that initial fertility, rather than treatment, may have caused yield differences, with one area of the field (block 2) having higher nitrogen, phosphorus and potassium levels before fertilization and a significantly higher yield at the end of the first season. However, regression analysis did not support a statistically significant relationship between initial fertility differences and first season yields.

Several conclusions can be drawn from this two year field experiment examining the effects of nitrogen, phosphorus and potassium fertilizer on Typha productivity:

- Phosphorus and potassium applications resulted in increased density and potassium application resulted in increased belowground dry weight in the establishment season. These treatment effects were not seen in the second season.

- Fertilizer treatments were effective in significantly increasing tissue nutrient concentration and soil fertility for phosphorus, potassium, and in some cases, nitrogen, indicating that applied fertilizer did not move appreciably in the soil and was available to the plants.

- Expected differences in second season productivity due to increased soil and tissue nutrient levels caused by treatment were not seen.

- Lack of treatment effect on productivity in the first and second seasons suggest that some factors other than nitrogen, phosphorus and potassium were limiting to growth. Statistical analysis and field observation suggest that variability in planting stock quality may have been the factor which accounts for much of the difference in productivity.

- In order to avoid confounding results of future fertilization experiments with high soil fertility levels, a field depleted of nutrients through previous cultivation and harvest should be used, and, for a multi-year experiment, means of removing aboveground material should be obtained.

## 6.4 NUTRIENT UPTAKE PATTERNS

Two experiments were established on fields near Zim in northeastern Minnesota in 1982. Mechanically transplanted seedlings of Typha latifolia were used to establish plots on a 0.4 ha field, and mechanically transplanted rhizomes of various Typha genotypes were used to establish plots on a 0.2 ha field. (See appendix A for full details of methods.) The primary objective of both experiments was to determine the patterns of nutrient uptake and biomass accumulation over the course of two growing seasons. This information will be used to develop a fertilization schedule which minimizes nutrient losses, and a harvesting schedule which minimizes nutrient removal and maximizes biomass production.

Figs. 6-3 and 6-4 illustrate patterns of accrual and partitioning of biomass and nitrogen, phosphorus and potassium during the first and second seasons, respectively. Fields were planted on June 9 and sampled every 28 days until October 27 during 1982. During 1983, plots were sampled every 28 days beginning on May 12, when aboveground growth was just beginning, and ending on October 27. During the establishment season, growth was in a lag phase until early August, and maximum biomass accrual occured between the sampling dates of August 4 and September 2. Fifty-two percent of the season's total biomass was produced during this period in seedling planted plots, and 37% in rhizome planted plots. The maximum amount of each nutrient ($g/m^2$) was also taken up during this same period, with 48% of the season's total nitrogen accrued for seedling and rhizome planted plots, 50% and 57% phosphorus and potassium, respectively, in seedling planted plots, and 40% and 36% P and K in rhizome planted plots. After this period, total biomass and nutrient accrual continued up until the last sampling date, but at a much slower rate. (The first killing frost was on October 5, with a low of 18°F.) Also during the last two months of sampling, changes in partitioning of biomass and nutrients between above- and belowground plant portions occured. Since total nutrients and biomass were still increasing, indicating continued nutrient uptake and photosynthesis, it is likely that partitioning changes were due largely to translocation from above- to belowground tissue rather than to other suggested mechanisms such as leaching losses (Boyd, 1970).

Although the general shape of the curves were similar, some different patterns of biomass and nutrient accrual emerged during the second season (Fig. 6-4). The first obvious difference is in early season patterns, which is to be expected since the first season began from transplanted seedlings and rhizomes. Seedling planted plots began the second season with 55%, 43%, and 49% of the total second year's final standing crop of N, P, and K already stored in belowground tissue. For rhizome planted plots, the values were 32%, 27% and 48% N, P, and K, respectively. Second season changes began with a decrease in belowground biomass and nutrients, probably as they were used to support new shoot growth.

The period of maximum biomass production during the second year occured at the same time as in the first year in terms of shoot age, i.e., between 56 and 84 days after plant growth began, but this period was reached one month earlier during the second season (July 7 to August 4). This suggests that growth phases may be more closely associated with plant maturity than environmental factors such as photoperiod or temperature. Although the period of maximum biomass accumulation occurred during the third month of growth in both seasons, the biomass production curve showed a less distinct increase in the third month during the second season, with high rates of production occurring in successive months. Another difference observed during the second season is that, rather than accompanying maximum biomass production, periods of maximum nutrient uptake preceded it in some cases. This was true for potassium

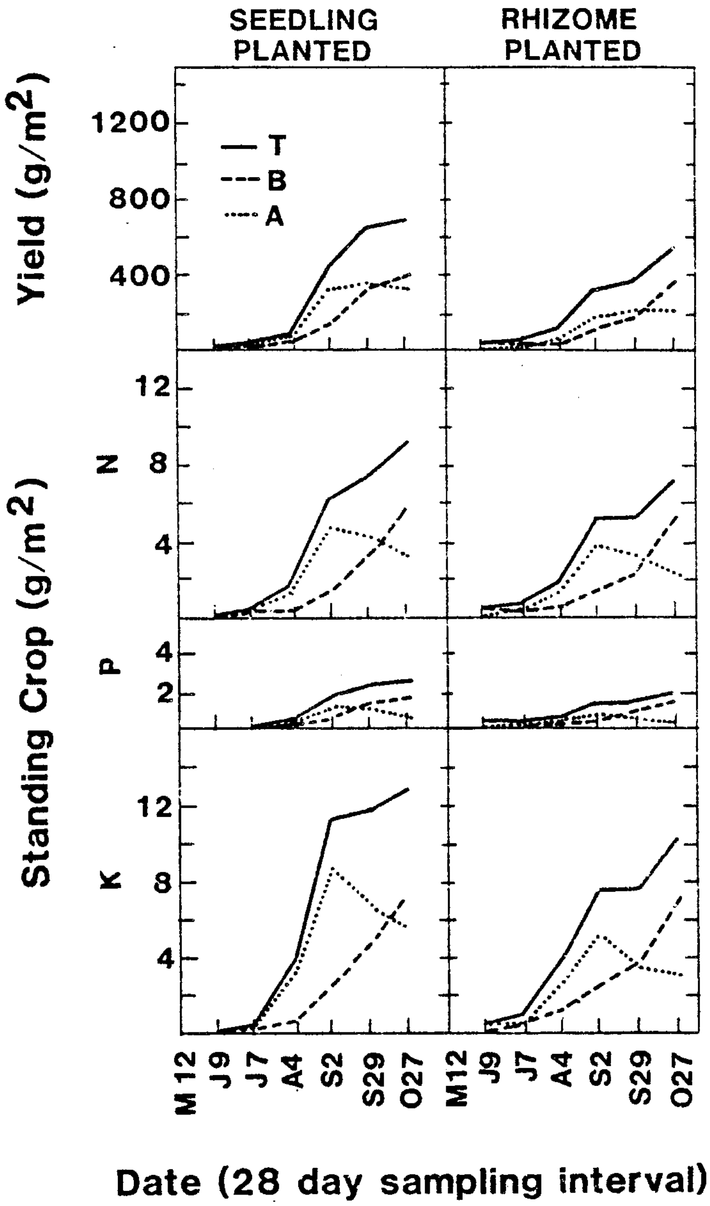


Figure 6-3. BIOMASS AND NUTRIENT ACCRUAL OVER THE COURSE OF THE ESTABLISHMENT SEASON FOR SEEDLING AND RHIZOME PLANTED STANDS

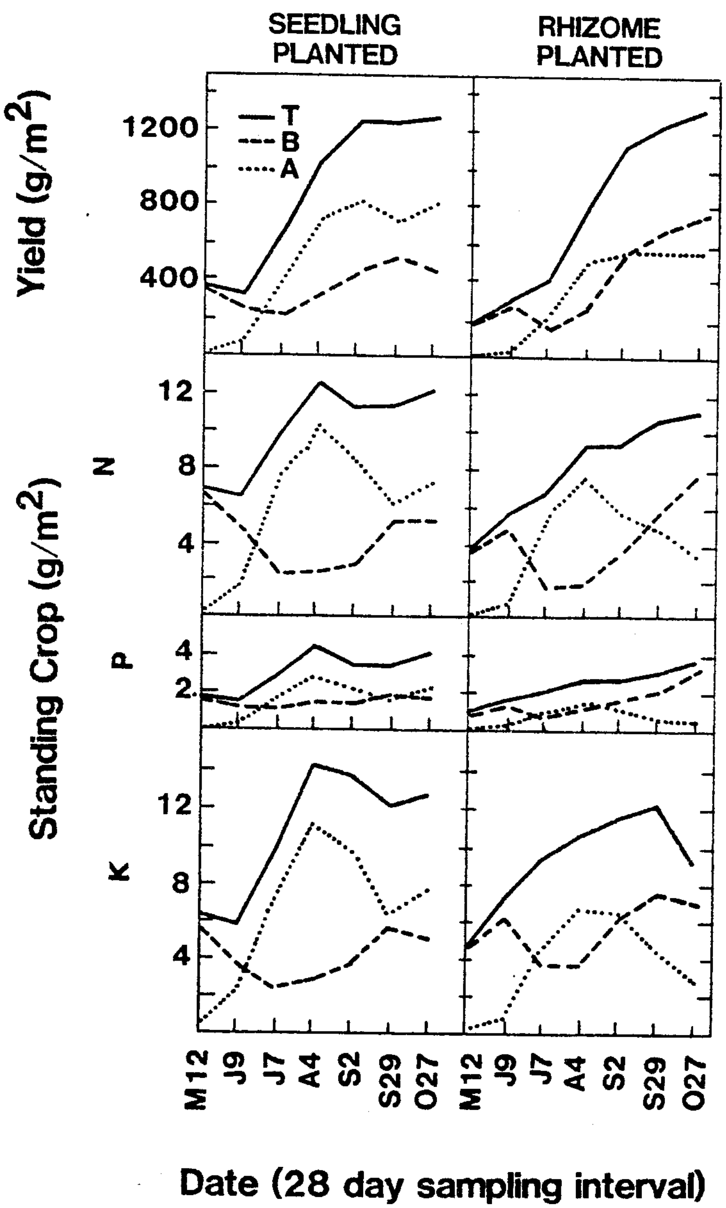


Figure 6-4. BIOMASS AND NUTRIENT ACCRUAL OVER THE COURSE OF THE SECOND SEASON FOR SEEDLING AND RHIZOME PLANTED STAND

uptake in rhizome planted plots, and to a lesser extent, nitrogen and phosphorus uptake in seedling planted plots. Boyd (1970) and Klopatek (1975) have observed both cases in natural stands with the period of maximum nutrient uptake coinciding with and preceding the period of maximum biomass production.

Patterns of biomass and nutrient accrual and partitioning toward the end of the season were also somewhat different in the second year. Total biomass accumulation again continued at a lowered rate until the last sampling date, even though the first killing frost (25°F) was on September 26. A decrease in biomass and nutrients in aboveground tissue, accompanied by an increase in nutrients and biomass in belowground tissue began after the period of maximum biomass production just as it had during the first year. However, for seedling planted plots, the trend reversed between September 29 and October 27. The significance of this is not known. The rhizome planted plots did not reverse the pattern during the month of October, but evidently continued to translocate material to the rhizome system. The potassium standing crop in rhizome planted plots followed the same translocation pattern, but overall, there was a large decrease in total potassium during the last month of sampling. The cause of the potassium loss is not known, but it could be due to leaching from above- and belowground tissue. Leaching has been suggested as a fate of some nutrients, especially potassium in emergent aquatic ecosystems (Boyd & Hess, 1970; Klopatek, 1975).

Although the total amount of nutrients accumulated increases throughout the growing season, the concentration of nutrients in plant tissue decreases throughout the season in most cases. During both years of this experiment, concentration of all nutrients measured increased in aboveground tissue during the first month of growth, then declined throughout the rest of the season. This same trend in aboveground Typha tissue was observed by Boyd (1970). In belowground tissue, the trend began the same for nitrogen and potassium, but changed during the last two months of growth when concentration increased, probably due to translocation of these nutrients from the aboveground tissue. Klopatek (1975) observed similar patterns in Typha. Phosphorus concentration in the belowground tissue remained fairly constant throughout the growing season.

The nutrient accumulation and partitioning patterns observed during the two years of this experiment are fairly well described by the nutrient cycle phases established by Klopatek (1975) for emergent aquatic vegetation. The first is a lag growth phase when plant tissue contains its highest nutrient concentration. The second phase is the period of peak nutrient uptake and, in some cases, peak dry matter production. Phase 3 is the period of translocation of nutrients to belowground structures from the shoots, and the fourth is the leveling off of tissue nutrient changes just prior to the onset of dormancy. Although the general pattern described by these phases has been observed in this work and the work of Boyd (1970) and Klopatek (1975), the dates at which changes take place vary considerably. Boyd found the period of maximum biomass accumulation in a South Carolina Typha stand that began to grow in early March to be between May 16 and May 29, during the time when flowers were emerging. Klopatek (1975) monitored a Wisconsin stand which began to grow in mid-May, and found the period of peak biomass production to be during the month of July. This is similar to the time of growth initiation and peak biomass production found during the second season of our experiment. Like Boyd (1970), we found that the time of early flowering coincided with the period of maximum biomass production (July 7 to August 4 during the second season). During the first season of this experiment, planting occuRred on June 9, and the period of maximum biomass production occurred between August 4 and September 2. It is interesting to note that despite differences in time of year, all Typha stands observed in these experiments reached the period of maximum biomass production during the third month of growth.

The patterns of nutrient and biomass accrual observed in this experiment can serve as a starting point for planning Typha stand management options such as time of fertilization and harvesting. If fertilizer, particularly nitrogen, had been applied to these plots at the first of the growing season, much may have become unavailable through physical and biological processes before it could be used by Typha. It is not clear if fertilization should be timed to coincide with a particular time of year, or with stand age, although it appears that the latter is a better indicator of the period of maximum nutrient uptake and biomass production. This study also suggests that harvest of aboveground material could take place as late as the end of September without much sacrifice in aboveground biomass, and that fewer nutrients will be removed from the system at this time. In all cases but seedling planted plots in the second season, aboveground dry weight did not decrease during September, but nutrient standing crop did. Another potentially positive factor of a late harvest is that the biomass may be drier by the end of September. For these experiments, moisture percent had dropped from a mean of 76% in early September to 72% in late September. These values may be more or less, depending on weather conditions. Although total plant biomass increased throughout October, aboveground biomass decreased, and plants lodged, making harvest difficult.

Several conclusions can be drawn from this two year nutrient uptake experiment.

- The period of maximum biomass production in this experiment and others occurred during the third month of growth. The period of maximum nutrient uptake frequently accompanied, but in some cases preceded, maximum dry weight increase. This suggests that fertilization might best occur during the second month of growth.

- There is some evidence that the period of maximum biomass accumulation coincides with the onset of flowering. It is not known if this is because flowering has a determinant effect on growth, or if some other relationship exists. Investigations of the effect of flowering on final biomass yield are needed.

- Following the period of maximum biomass accrual, translocation of nutrients and dry weight components to the belowground tissue occurred. Harvesting at the end of September in Minnesota Typha stands would probably maximize aboveground biomass while minimizng nutrient removal.

## SECTION 7.0

## WEED CONTROL

### 7.1 INTRODUCTION

Competition for nutrients, water, and canopy area from weed species in the establishment of new stands of Typha is a potential problem. This can be particularly true in land that has been previously untilled or lain fallow for a number of years and has a well established seed bank. Land preparation methods and cultural practices have been shown to have an influence on competitor population (Andrews et al., 1981). There is also a potential for herbicide control under certain conditions. Identification of potential weed species is an important first step in deciding what land preparation and cultural practices should be used.

### 7.2 IDENTIFICATION OF WEED SPECIES

In a 1980 floristic study of the native population at a study site near Zim in northeastern Minnesota, 41 species of plants were identified (Andrews et al., 1981). Of these, 11 species were classified as abundant or very abundant. They fall into two categories:

- Perennial Monocots:
  - Calamagrostis canadensis (Blue joint)
  - Agrostis hyemalis (hairgrass)
  - Carex crawfordii (sedge)
  - Eleocharis ovata (spike rush)
- Herbaceous Dicots:
  - Polygonum hyemalis and P. lapathifolium (smartweed - both annuals)
  - Cerastium sp. (mouse-eared chickweed - perennial)
  - Bidens cernua (beggartick - annual)
  - Cicuta bulbifera (water hemlock - biennial)
  - Lycopus americanus (mint - perennial)
  - Hypericum majus (St. Johnswort - perennial)

These plants were present before Typha stands were established on the site, and may or may not represent a weed problem under cultivated Typha paddy conditions. At a different study area near Zim, Glyceria grandis (reed meadowgrass - perennial), Polygonum spp., and Carex spp. represented the predominant weed species in cultivated Typha paddies during two field seasons. Minor infestations of Bidens cenura and Eleocharis ovata were also noted, particularly in the drier areas near the dikes. A complete floristic survey was not conducted at this site.

A complete floristic survey for another research area near Aitkin, in central Minnesota, was not attempted. However, several weed species appear to predominate. Phalaris arundinacea (reed canarygrass - perennial) and Glyceria grandis account for the majority of the monocot problem, with minor infestations of Carex sp., Eleocharis sp., and Scirpus validus (soft-stemmed bullrush). Broadleaf competition was minor, with Alisma triviale (water plantain) almost exclusively predominant.

Echinochloa crusgalli (barnyard grass - annual) was an abundant weed in the Aitkin mineral soil plots during the first growing season. This species, however, has failed to reappear in the following seasons.

## 7.3 EFFECTS OF LAND PREPARATION

As previously stated, land preparation can exert a strong influence upon the competitor community. In a 1980 study near Zim, in northeastern Minnesota, substrate preparation by rotovation reduced the mean competitor standing crop by 40%, while excavation of the surface layer (20 cm) reduced competitor standing crop by 96% (Andrews et al., 1981).

Another peatland excavation study was carried out near Zim to investigate the value of Typha spp. as a reclamation tool if peat mining were to occur. This experiment dramatically demonstrated that the removal of the existing seed bank and perennial root systems by excavation virtually eliminates any weed problems for several growing seasons as long as the soil remains flooded. At excavation depths of 0.0, 0.6 and 1.5 meters, mean competitor standing crops were an equivalent of 3.5, 0.0, and 0.1 tonnes/ha (dry wt), respectively, at the end of the establishment season (Pratt et al., 1982). Excavation would prove too costly as a means of weed control. However, a decrease in the competitor population represents a side effect of peat mining which would be advantageous for utilizing biomass crops as a reclamation tool if peat mining were to occur. Mined areas should, however, be planted with the crop species and flooded soon after excavation to prevent the reestablishment of perennials by seed.

## 7.4 EFFECTS OF WATER LEVEL

Water depth and timing of initial flooding appear to have an effect on initial infestation and establishment of competitor species. In field observations it has been noted that areas with significant standing water (10 cm or greater) have far fewer competitors, particularly dicots, than mudflat or drier areas. In areas where water levels are brought up early in the growing season (before seed germination) and maintained throughout, perennial grasses and sedges show less ability to become established. Contrary to this, if these grasses and sedges are already established, raising the water level provides no significant control.

This control may be due to the prevention of seed germination by standing water. In a small growth chamber test, soil from the 1982-83 nutrient uptake experiment area near Zim was placed in several plastic horticultural trays. Half of the trays were flooded to a depth of 4 cm; the remaining half were saturated, but only to the soil surface. After 4 days, germination was noted in the unflooded trays, but not in the flooded trays. After 20 days, seedlings in the unflooded trays were dense. Polygonum, Carex, and Potentilla predominated with over 300 individuals each per flat (2300 per $m^2$). Germination in the flooded trays was limited to 5 individuals of Carex. These conditions remained until the test was terminated after 70 days.

One problem has been experienced with raising water levels on peat soils, particularly in the 1982-83 nutrient uptake experiment. Peat with a bulk density of 0.14-0.54 g/m$^2$ (Garver et al., 1983) has a tendency to float, and wherever the floating peat reached the surface, large infestations of Polygonum sp. occurred. These floating mats could also provide a means of establishment for perennial grasses and sedges.

## 7.5 POSSIBLE CONTROL WITH HERBICIDES

Much literature is available concerning herbicides that can be used to control Typha sp., but very little exists suggesting herbicides that possibly could be used to control potential Typha competitors with little or no yield reduction to Typha. The common herbicide 2,4-D has potential for the control of broadleaf weeds. 2,4-D in either the amine or ester form applied at a rate of 6.7 kg/ha has no effect on Typha (Lee & Timmons, 1954), while broadleaves can be controlled at a rate between 0.28 and 2.24 kg/ha (Herbicide Handbook, 1979). Because these levels are fairly well documented, and broadleaves do not provide a major competitor problem, 2,4-D was not investigated further.

Control of perennial grasses is much more difficult than control of broadleaf weeds. However, three herbicides were identified as potentially valuable for perennial grass control in Typha stands. Amitrol-T (3-amino-s-triazole) was reported to be non-effective against cattails at a rate of 11.2 kg/ha when applied early in the season (Timmons et al., 1958). The usual rate for this herbicide is 2.24 to 11.2 kg/ha (Herbicide Handbook, 1979) and is usually effective against perennial grasses in this range.

Roundup (glyphosate), a very effective non-selective herbicide, was used extensively for weed control in areas around the experimental plots. During several of these sprayings, it was noted that volunteer Typha was often unaffected by the herbicide, even when the spray concentration was quite strong (3%). Additionally, flooded conditions appeared to further mitigate any herbicide damage.

A relatively new chemical, Poast (BASF Wyandotte Corp. BAS-90520H) was also selected for trial. Poast is effective for controlling grasses at rates ranging from 1.2 to 2.9 l/ha. Species of monocots, such as Typha, with a thick, waxy cuticle have shown good resistance to Poast (Andersen, personal communication) and it was on this basis that Poast was selected.

A field trial was designed using the fertilization study area near Aitkin, Minnesota. The test consisted of 9 treatments and a control. The treatments were: Amitrol-T at 2.2, 5.6, and 11.2 kg/ha, Roundup at 2.3, 4.7, and 7.0 l/ha, and Poast at 1.2, 2.1, and 2.9 l/ha. Details of experimental methods can be found in Appendix A. Treatments were applied June 1, 1983 (Typha, Phalaris, and Glyceria were all vigorously growing and still vegetative), and evaluated June 22, 1983. Evaluation was qualitative; damage levels for Typha Phalaris and Glyceria were assigned a number value between 1 and 5, with 1 = no damage and 5 = shoot death.

Results of this field trial are presented in Table 7-1. Fairly even control of the weed species Phalaris and Glyceria was acheived with all herbicide treatments. Amitrol-T appeared to exhibit a selectivity by species for Typha. T. latifolia was generally chlorotic and stunted, while T. angustifolia exhibited only minor damage to the leaf tips. Other than the effect of Amitrol-T on T. latifolia, little damage to Typha spp. was observed for any herbicide treatment. A second evaluation was performed on July 26, 1983. No further damage was noted except that all trace of Typha latifolia was

Table 7-1. QUALITATIVE ASSESSMENT OF DAMAGE TO TARGET SPECIES IN AITKIN FIELD TRIAL

| Treatment | Damage Level | | | |
|---|---|---|---|---|
| | Typha latifolia | Typha angustifolia | Phalaris arundinacea | Glyceria grandis |
| Amitrol-T 2.2 kg/ha | 4 | 2 | 4 | 4 |
| Amitrol-T 5.6 kg/ha | 4 | 2 | 5 | 4 |
| Amitrol-T 11.2 kg/ha | 4 | 2 | 5 | 5 |
| Roundup 2.3 l/ha | 1 | 1 | 4 | 4 |
| Roundup 4.7 l/ha | 2 | 2 | 5 | 5 |
| Roundup 7.0 l/ha | 1 | 1 | 5 | 5 |
| Poast 1.2 l/ha | 1 | 1 | 3 | 4 |
| Poast 2.1 l/ha | 1 | 1 | 4 | 4 |
| Poast 2.9 l/ha | 1 | 1 | 4 | 4 |
| Control | 1 | 1 | 1 | 1 |

missing in the Amitrol treated plots. Grasses were growing into the plots from the surrounding alleys; consequently, regrowth of the sprayed grasses was impossible to evaluate.

Roundup and Poast were tested further in a controlled greenhouse experiment. Amitrol-T was not tested since it had damaged Typha in the previous experiment. Treatment parameters in this factorial experiment included application rate of the herbicide, species (T. latifolia versus T. angustifolia), and water level (flooded versus saturated). The test plants were 4 month old seedlings. Application rates were: Roundup at 2.3 and 4.7 l/ha, Poast at 2.3 l/ha, and a water control, all applied in a solution volume equivalent to 18 l/ha. Details of experimental methods can be found in Appendix A. The treatments were applied August 13, 1983 and evaluated 45 days later.

Treatment evaluation consisted of estimating damage to above- and belowground plant portions on a qualitative scale from 1 (no damage) to 5 (death). Above- and belowground dry weights were also measured to monitor any yield reducing effect an herbicide treatment may have. Mean values by treatment for estimated damage to above- and belowground tissue are given in Table 7-2. Table 7-3 illustrates the mean aboveground, belowground, and total dry weights over the various treatments.

The data summarized in Tables 7-2 and 7-3 suggest that Poast did not significantly change growth patterns of Typha angustifolia from that seen in control plants as measured by dry weight and qualitative damage estimates in either mudflat or flooded conditions. Although Poast did not result in perceptible damage to Typha latifolia as reported in Table 7-2, there did appear to be a reduction in the yield of T. latifolia plants receiving Poast treatment as compared to control plants. The yield reduction can be seen in Table 7-3 for both above- and belowground plant portions under both flooded and mudflat conditions.

Table 7-2. QUALITATIVE ESTIMATE* OF DAMAGE TO ABOVE- AND BELOWGROUND ORGANS OF TYPHA SPP. WITH DIFFERENT HERBICIDE TREATMENTS

| Herbicide Treatment | T. angustifolia Flooded | T. angustifolia Unflooded | T. latifolia Flooded | T. latifolia Unflooded |
|---|---|---|---|---|
| ABOVEGROUND: | | | | |
| Roundup, 2.3 l/ha | 5 | 5 | 2 | 2 |
| Roundup, 4.7 l/ha | 5 | 5 | 4 | 5 |
| Poast, 2.3 l/ha | 1 | 1 | 1 | 1 |
| Control | 1 | 1 | 1 | 1 |
| BELOWGROUND: | | | | |
| Roundup, 2.3 l/ha | 5 | 4 | 1 | 1 |
| Roundup, 4.7 l/ha | 5 | 5 | 2 | 2 |
| Poast, 2.3 l/ha | 1 | 1 | 1 | 1 |
| Control | 1 | 1 | 1 | 1 |

* Estimated on a scale of 1 to 5 with 1 being no damage and 5 being death.

Roundup caused much more damage to Typha spp. than Poast did, as can be seen in Tables 7-2 and 7-3. The higher rate of Roundup resulted in higher damage estimates and lower yields than found in control plants for both Typha angustifolia and T. latifolia. The same pattern held for the lower rate of Roundup, although the damage was less severe.

Differences in response to the herbicide between the two species must be viewed on the basis of the qualitative damage estimates in Table 7-2, because inherent species differences in productivity may confound yield data as a measure of herbicide response. Poast did not display any selectivity between species under either water condition, and was never different from the control. Roundup, on the other hand, did show a selectivity. T. angustifolia was severely damaged by Roundup under all conditions. T. latifolia, however, displayed some resistance to Roundup, particularly at the lower rate of application. Damage to T. latifolia from low levels of Roundup was somewhat variable among individual pots, but consisted mostly of partial chlorosis of the outer leaves.

The effect of water level on Typha spp. response to herbicide treatments appears to be nonexistent. However, technical problems were encountered in consistently maintaining flooded conditions for some treatments, so the response of herbicide treatments to the water depth factor in this experiment is inconclusive. It is interesting

Table 7-3. ABOVEGROUND, BELOWGROUND, AND TOTAL PRODUCTIVITY IN *TYPHA* SPP. RECEIVING DIFFERENT HERBICIDE TREATMENTS (grams)

| | *T. angustifolia* | | *T. latifolia* | |
|---|---|---|---|---|
| Herbicide Treatment | Flooded | Unflooded | Flooded | Unflooded |
| ABOVEGROUND: | | | | |
| Roundup, 2.3 l/ha | 6.25 | 9.00 | 20.00 | 18.25 |
| Roundup, 4.7 l/ha | 7.00 | 6.75 | 14.25 | 11.00 |
| Poast, 2.3 l/ha | 36.50 | 48.50 | 24.75 | 33.50 |
| Control | 34.50 | 50.50 | 46.00 | 42.25 |
| BELOWGROUND: | | | | |
| Roundup, 2.3 l/ha | 2.38 | 3.00 | 19.75 | 13.50 |
| Roundup, 4.7 l/ha | 5.75 | 2.83 | 13.50 | 9.00 |
| Poast, 2.3 l/ha | 21.50 | 38.50 | 16.00 | 19.75 |
| Control | 17.25 | 30.25 | 26.00 | 21.75 |
| TOTAL: | | | | |
| Roundup, 2.3 l/ha | 8.63 | 12.00 | 39.75 | 31.75 |
| Roundup, 4.7 l/ha | 12.75 | 9.58 | 27.75 | 20.00 |
| Poast, 2.3 l/ha | 58.00 | 87.00 | 40.75 | 53.25 |
| Control | 51.75 | 80.75 | 72.00 | 64.00 |

to note that flooding appeared to reduce productivity of _Typha angustifolia_ in all surviving plants. Water depth should be considered again in future experiments.

## 7.6 CONCLUSIONS

Several conclusions can be drawn from the _Typha_ weed species studies discussed here.

- _Phalaris arundinacea_ and _Glyceria grandis_ appear to represent the most severe competitor problem in cultivated _Typha_ paddies. Both are tall perennial grasses and, as such, are persistent from season to season and grow up into the _Typha_ canopy, probably competing for sunlight as well as nutrients. Most other potential weed species which have been identified, either annuals or perennials, do not grow as tall or as densely, and do not appear to present as much of a competitor problem.

- Land preparation can affect the occurrence of competitor species. It appears that at least some form of cultivation will be required before _Typha_ stands are established on a wetland site. Removal or elimination of the seed and rhizome bank contained in surface soil provides the most complete initial weed control.

- Control of water level can affect the occurrence of competitor species. Far fewer and less diverse populations of weeds occur on flooded soils. The value of maintaining a flooded paddy for weed control must be weighed against the cost of irrigation, and the water level requirements of _Typha_ at a given stage of growth (e.g., paddies can not be flooded directly after seeding or transplanting rhizome pieces).

- Poast appears to be a promising chemical control for the target weed species _Phalaris arundinacea_ and _Glyceria grandis_ in _Typha_ stands. Although Poast does not appear to damage _Typha_, more experimentation is needed to evaluate the toxicity of this chemical to both species of _Typha_ at various growth stages and under varying water conditions. A large scale field test is also in order, along with a more controlled evaluation of the effectiveness of Poast against the target species under varying environmental conditions.

- An attempt should be made to ascertain the cause of _Typha_'s resistance to certain herbicides. Specifically, is the resistance due to physical barriers to uptake such as a thick waxy leaf cuticle or is it the result of physiological differences between _Typha_ and other perennial grasses. This information would be useful when developing application methods.

## SECTION 8.0

## RHIZOME HARVESTING POSSIBILITIES

### 8.1 INTRODUCTION

The attractiveness of rhizomes for bio-energy use is based on both their high biomass yield and chemical composition. Belowground yields of 3000 dry g/m$^2$ have been reported (Andrews et al., 1978; Bray, 1962) and, as noted in the introduction to this report, up to 40% of rhizome dry weight consists of readily fermentable starch and sugars at the end of the growing season (Pratt et al., 1981). At other times of the season, approximately 20% of the rhizome dry weight is composed of fermentable material. Maximum belowground biomass accumulation occurs in the fall, and most of the present season's rhizome biomass remains by the following spring (see Section 6.0) where it contributes to early season growth of new shoots and rhizomes before dying at the end of the second season.

Rhizomes grow parallel to the soil surface with a length ranging from 2-61 cm and a diameter of 1-2 cm (Linde et al., 1976). The rhizomes and associated shoot bases are primarily located 0-30 cm below the soil surface and have a moisture content of approximately 90% of total wet weight. When dry, the belowground portion of *Typha* has an energy content ranging from 3950-4100 cal/g (7100-7400 BTU/lb), approximately 10% lower than the aboveground tissue (see Section 5.3).

Field conditions, as well as plant characteristics, will determine the harvesting options available for rhizome biomass. Those being considered for *Typha* production range from organic soils with dry bulk densities as low as 0.14 g/cm$^3$ to mineral soils with densities around 1.6 g/cm$^3$ (Garver et al., 1983). Depending on irrigation practices, soil type, weather, and ability to control water level, soil moisture will generally range between 50 and 90% of total wet weight (experimental observations).

One of the field conditions most likely to restrict the type of equipment used for rhizome harvesting is the soil's support capacity. Completely accurate measurements of support capacity have not been possible because of the large number of variables affecting it. Some of these variables include physical soil properties, soil moisture concentration, and duration, frequency, and type of soil loading (Gill & Van den Berg, 1965). An approximation of support capacity is often obtained using a cone penetrometer (American Society of Agricultural Engineers: Standard S313.1) to measure a soil's penetration resistance in the 0-15 cm depth range. The larger the resistance, the greater the soil's support capacity will be. Several studies have sought to use the cone penetrometer to examine soil trafficability as a function of soil type and moisture concentration (Bornstein & Hedstrom, 1981; Paul & DeVries, 1979a,b; Schertz et al., 1982). These studies found that at complete saturation (0 bar soil water tension), organic muck soils had a penetration resistance of 0.5 kg/cm$^2$ compared with 2.2-4.1 kg/cm$^2$ for silty clay loam soils. At field capacity (approximately 0.33 bar soil water tension), this resistance had increaed to 1.8 kg/cm$^2$ for muck soils and 5.2-11 kg/cm$^2$ for silty clay loams. As soils became drier, this penetration resistance continued to increase for both soil types, although muck soils continued to have lower resistances than silty clay loams. Using 20% wheel slip as a critical value for trafficability of small, conventional agricultural equipment, Paul & DeVries (1979) found minimum soil strength values of 2.6 and 5.5 kg/cm$^2$ for organic muck and silty clay loam soils, respectively. To obtain these values, muck soils would need to be considerably drier than field capacity, and silty clay laoms would need to be at or drier than field capacity.

With approximately half of the total plant biomass for Typha spp. located in the belowground rhizome system, it is necessary to consider methods and consequences of harvesting this resource. Although several analogous harvesting operations exist in traditional agriculture, the special problems, such as trafficability, associated with operating equipment in wetlands have limited the direct application of existing agricultural equipment to Typha rhizome harvesting. Two attempts to adapt agricultural equipment to meet the requirements of rhizome harvesting are discussed in this section along with several ideas that may warrant further research.

## 8.2 MODIFICATIONS OF A POTATO HARVESTER (Schertz et al., 1982)

This continuing project, being conducted at the University of Minnesota, is attempting to develop a rhizome harvester by modifying the closely related harvesting system of a potato harvester. Although functionally quite similar, a rhizome harvester would probably have to operate under conditions of low soil support capacity associated with wetlands. Additionally, the physical structure of the rhizome system differs substantially from that of a potato, resulting in unique separation characteristics. Because of these operational dissimilarities, the direct application of a potato harvester to rhizome harvesting is not possible and has resulted in the following engineering research aimed at modifying operational components of a potato harvester.

Initial tests of the modified potato harvester concept were conducted using a small, tractor-pulled potato harvester with a 0.66 m cutting width and a 1.5 m long carrier/separation chain. Modifications to this machine included: addition of two rolling coulters for making vertical cuts, addition of clearance above carrier chain to allow soil and rhizomes to pass freely through the machine, and extension of frame to allow attachment of different cutting devices.

Field tests of this modified harvester in a wet peat soil proved successful at cutting and lifting the rhizome-soil material. Although the carrier/separation chain was too short to effectively separate rhizomes from soil, the ease of separation of the rhizomes from the soil was found to be dependent on the integrity of the soil. While the potato harvester concept appeared to be a sound one, it was evident that traction and flotation of a larger scale harvester would be limiting. It was also evident that wet soil conditions would present special separation problems.

To address the problems of traction and flotation, a system was developed wherein the harvester's flotation was independent of the tow machine. Draft force and hydraulic power for the harvester were provided by a Seiga Amphibious Transporter equipped with an auxiliary power source. In addition to reducing traction and flotation problems, the arrangement allowed for measurement of required draft forces as different modifications were made to the harvester. In the final configuration shown in Fig. 8-1, controlled depth adjustment of the cutting blade and collection of the rhizome-soil material for further processing are possible.

Field tests of the harvester-transporter system in two natural stands of Typha were judged to be successful. The system was capable of cutting, lifting, collecting, and transporting the rhizome-material. Soil conditions in one stand consisted of a sandy loam, while the other stand was a silty clay loam. Soil moisture conditions varied from saturated to damp, with little to no standing water being present.

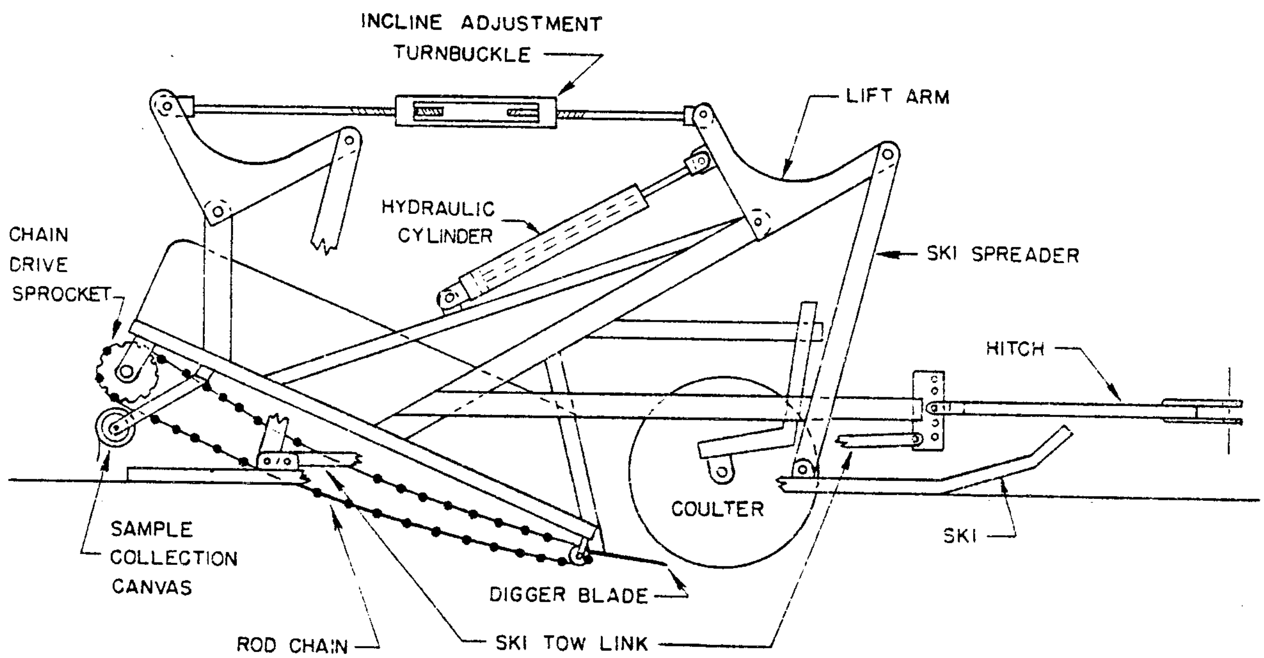


Figure 8-1. SCHEMATIC DIAGRAM OF FINAL CONFIGURATION OF RHIZOME HARVESTER BASED ON POTATO HARVESTER CONCEPT. (FROM SCHERTZ ET AL., 1982)

No separation of rhizomes from soil was attempted in the field since this function is being dealt with separately. The experimental harvester will be used to transport rhizome-soil material to the side of the field where it will be run through experimental separation devices. These devices, presently conceptual in design, include:

- a rotating tapered drum with wall screens allowing soil to pass through either by gravity or by using water jets,
- a water spray and flush system to wash the soil from the rhizomes using high pressure nozzles,
- a vibrating screen to shake soil from the rhizomes,
- a modified pea combine using its rotating screen, and
- combination of these devices.

It is anticipated that the device that proves functionally superior in terms of separation will then be integrated with the experimental harvester to form a complete rhizome harvesting machine.

In addition to qualitative observations of harvester performance, an assessment of required draft forces and power requirements for the configuration shown in Fig. 8-1 was also obtained. At a speed of approximately 1 km/h and a cutting depth of 25 cm, a unit draft of 8.6 $N/cm^2$ was observed. Additionally, the maximum hydraulic power input required for the rod-chain conveyor was approximately 7.5 kW. These figures for draft force and power requirements may change with future modifications such as rotating cutting blades, powered coulters, and vibrating digger blades. These modifications would reduce required draft force by transferring more of the necessary power through the hydraulic system. Reducing draft force may be an important consideration depending on field characteristics such as trafficability.

As a starting point for development of a cattail rhizome harvester, the modified potato harvester concept appears to be a sound one. While equipment development did not lead to modification of a commercial potato harvester, the project was able to develop a versatile system for evaluating the requirements of a commercial machine. Further studies involving optimization of components and solutions to traction, flotation, and separation problems appear warranted, as do further studies of field conditions and management options for improving trafficability.

## 8.3 SUBMERGED RHIZOME HARVESTING

Another option which has been considered and tried for rhizome harvesting involves uprooting submerged rhizomes using a soil cultivation apparatus mounted on a floating platform (Ladenburg, personal communication). The soil cultivation apparatus was based on the patented invention (Hood et al., 1979, Patent No. 4,171,723) shown in Fig. 8-2. A rotating 3 m wide bar, mounted transverse to the direction of movement of the floating platform, was pushed along beneath the soil surface. As the bar rotated opposite the direction of travel, it uprooted the rhizome system. The bar was mounted in a manner that allowed for height adjustment to compensate for varying water levels in the marsh.

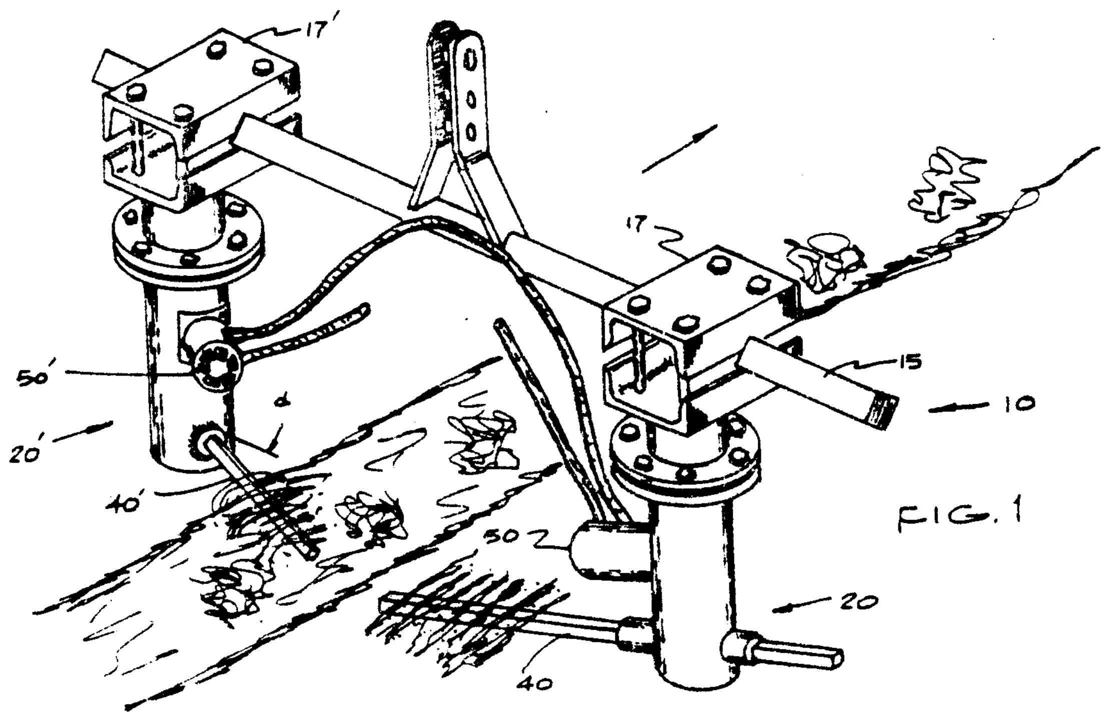


Figure 8-2. CROP UPROOTING AND SOIL CULTIVATING APPARATUS AS PATENTED BY HOOD ET AL., 1979 (PATENT #4,171,723)

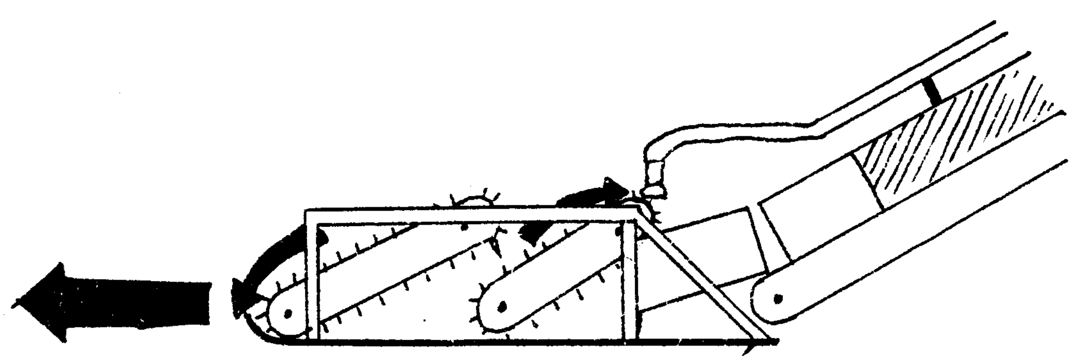

Figure 8-3. MECHANICAL OYSTER HARVESTER AS DESIGNED AND PRESENTED BY J.A. COLLIER, CLEMSON UNIVERSITY (COLLIER, 1981)

By harvesting rhizomes from a floating platform, a number of advantages over terrestrial harvesting systems can be realized. Soil support capacity and equipment flotation are no longer important considerations assuming water depth is sufficient to totally support the platform. Also, water is available for separating and cleaning rhizomes. Finally, since rhizomes contain large amounts of aerenchyma tissue (specialized plant tissue involved in gas exchange), they float, thus making collection by skimming a possibility. Alternatively, Ladenburg has suggested using a modified oyster harvester for collection. This idea is based on a design by Collier (1981) shown in Fig. 8-3.

Several disadvantages to this submerged harvesting system are also apparent. While flotation problems are greatly reduced, problems associated with traction and generation of draft force are increased. Whether or not these problems are serious will depend on measurements of required draft force and quantitative evaluation of harvester performance. These apparantly were not done by Ladenburg. Additionally, the necessity of maintaining significant amounts of water on the field during harvest will be expensive at best (assuming irrigated paddies) and impossible at worst (assuming possible drought conditions).

## 8.4 MISCELLANEOUS CONCEPTUAL IDEAS

In the course of discussions with equipment manufacturers, agricultural engineers, and rice farmers, several interesting ideas relating to rhizome harvesting were suggested. Although untried, many of the ideas may warrant future research and are thus mentioned here as a possible starting point for additional research.

To solve problems associated with traction and flotation, several amphibious vehicles have been suggested. These include the Seiga Amphibious Transporter made in Denmark, a tracked marsh vehicle manufactured by Quality Marsh Equipment, and an augered pontoon vehicle made and used by Godward Wild Rice Company, Aitkin, Minn. The Seiga vehicle consists of four to six large rubber tires capable of supporting the vehicle under flooded conditions. The vehicle has been successfully used for many wetland uses including wetland tillage and planting and aboveground harvest of emergent aquatic plants. The Quality Marsh Equipment device consists of two pontoons, each 1.2 m wide, 1.2 m high, and 12.2 m long. Each pontoon has an aluminum alloy track circumscribing it as viewed from the side. The device was successfully used to carry a rotary trencher through a wetland. In addition to amphibious devices, floating platforms such as those used for aquatic weed harvesters (Aquamarine Corp., Mariner Corp., and others) have been suggested for paddies capable of being flooded during harvest.

To address problems associated with removing rhizomes from the ground, ideas ranging from an air injection system to rotating tiller blades have been suggested. Collection methods similar to cranberry harvesting and aquatic weed harvesting have also been considered.

## 8.5 CONCLUSIONS

- Field conditions likely to be encountered during rhizome harvesting need to be specifically defined so that specialized equipment can be developed to meet operational requirements. This will involve:

- field measurements such as soil type, moisture levels, and penetrometer indexes, and

- evaluations of optimum harvest times based on desired end biomass project and constraints such as water availability and ability to regulate water levels.

- Regardless of whether a terrestrial or floating harvesting system is used, attempts to design equipment that reduces required draft forces, power requirements, and/or weight will likely result in reduced operational problems and harvesting costs.

- The modified potato havester concept provides a promising basis for further development because of its demonstrated performance. Extrapolation of results from small scale tests to commercial size machines should be attempted to identify limiting factors.

- Research is needed to identify and test various methods of separating rhizomes from soil, and to evaluate methods of field transport, handling, and processing of the heavy, bulky rhizome material.

- Research is needed to identify the effects of rhizome harvesting on subsequent year's productivity of both above- and belowground biomass.

## SECTION 9.0

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# APPENDIX A

## ANALYTICAL METHODS

The following methods are used for analysis of plant tissue macronutrients.

- Nitrogen: a micro Kjeldahl technique is used for determination of total nitrogen. Following digestion, ammonia levels are measured with a $NH_3$ specific-ion electrode. (Bremmer, 1965; Cereal Lab Methods, 1962; McKeague, 1978).
- Phosphorus: tissue is dry ashed at 500 C for 12 hours and phosphorus is then extracted with HCl solution. Concentration is determined by spectrophotometry at 882 nm using an ascorbic acid-molybdate blue assay. (John, 1970; Teras, 1971).
- Potassium: tissue is dry ashed and potassium is extracted using same methods as for phosphorus. Concentration is determined by atomic absorption spectroscopy at 766 nm. (Buck Scientific; Perkin-Elmer, 1976; Van Loon, 1980).

Available soil macronutrients and pH are determined using the following methods.

- Nitrogen: since both $NO_3^-$ and $NH_4^+$ levels are of interest, two methods are used. Nitrate levels are determined using a cadmium column (EPA, 1979; Jackson, 1980) to reduce water extracted nitrate to nitrite, reacting the nitrite with a red azo dye complex, and measuring absorbance of solution at 540 nm with a spectrophotometer (Huffman, 1981; Taras, 1971). $NH_4^+$ is determined from a KCl soil extract using an $NH_3$ specific-ion electrode. (Bonwart, 1972; Bremer & Keeney, 1966; Mertens, 1975; Sakrawat, 1979; Siegel, 1980).
- Phosphorus and Potassium: Mehlich's extract is used for determination of available P and K (Mehlich, 1978). Following extraction, concentrations are determined using the same procedures described after ashing P and K above. (Buck Scientific; John, 1970; Perkin-Elmer, 1976; Taras, 1971).
- Soil pH: measured as both water pH and $CaCl_2$ pH, the latter being a closer approximation of the soil solution pH under actual field conditions. $CaCl_2$ pH is also less subject to variability from different soil:solution ratios (Peech, 1965).

## EXPERIMENTAL DESIGN

### FIELD TRIALS - AITKIN, MINNESOTA

<u>Fertilization Study</u>

Objectives:

- Determine the effect of different combinations of fertilizer on the amount of above and belowground biomass produced after one and two years on a previously uncultivated peat soil.
- Determine the nutrient standing crop after one and two years.
- Determine the effect of different combinations of fertilizer on density increase and shoot height over the course of two growing seasons.

- Determine the effect of different combinations of fertilizer on soil fertility after one and two years.
- Provide a source of aboveground biomass for experiments involving handling of biomass.

Materials and Methods.

The peat research site consists of a 0.5 ha area surrounded on three sides by the Little Willow River and a wild rice paddy on the fourth side. Prior to use by this project, the land was uncultivated.

Field preparation. Field was leveled to $\pm$8 cm and disced and dragged six times prior to fertilizer application. Using a 10-foot Gandy Spreader, 70 kg/ha of Peters Fritted Trace Elements and 20 kg/ha of $CuSo_4$ were applied and incorporated with a disc to a depth of approximately 15 cm. Nitrogen, phosphorus, and potassium were applied to appropriate plots using the 10-foot Gandy Spreader and incorporated with a Howard rotovator.

Design.

- Blocked complete factorial (3x2x2)
- Factors: Nitrogen (3 levels), Phosphorus (2 levels), Potassium (2 levels)
- Levels: a) Nitrogen - 0, 75, nad 150 kg (elemental form)
  b) Phosphorus - 0, 150 kg/ha (oxide form)
  c) Potassium - 0,300 kg/ha (oxide form)
- Treatments per block: 12
- Blocks: 4
- Total plots: 48
- Size of plots: 3 m x 5 m
- Planting density: 9 rhizomes/$m^2$

Observations and sampling.

- Density
- Height
- Insect damage
- Competitors
- Soil samples for nutrient analysis
- Above and belowground plant samples for biomass and nutrient standing crop determination at the end of two growing seasons (1981-82).

Stand Establishment Trial

Objectives.

- Provide large solid stands of cattails for use as a cutting orchard for future planting stock.

- Test the feasibility of using a mechanical transplanter to plant cattail seedlings which were started in a greenhouse.
- Establish large stand of Typha angustifolia from seed.

Materials and Methods.

This site consists of a 0.21 ha area with a sandy loam soil. Prior to use by this project the land had been tilled but not fertilized or planted. Planting was completed on June 16, 1981.

Field preparation. Field was leveled to $\pm 8$ cm with a land plane and then disced and dragged. 1250 kg/ha of Howe's 6-12-24 fertilizer (nitrogen in ammoniated form) was applied with a centrifugal spreader and incorporated to a depth of 10 cm with a Howard rotovator. Field is ditched on four sides for water level control.

Design.

- Area size: 10 m x 55 m
- Number of areas: 2
- Planting density: 9 rhizomes/$m^2$
- Planting material:
  - Area 1: 3 month old Typha latifolia seedlings
  - Area 2: Typha angustifolia seed
- Planting density: 4 seedlings/$m^2$ and 700 seeds/$m^2$

Observations and sampling.

- Density
- Height
- Tissue and soil nutrient content
- Biomass yield
- Insect damage
- Competitors

Comparison of Seedling Stand Establishment: Typha latifolia and Typha angustifolia

Objectives.

- Compare first and second year productivity in stands established from Typha latifolia and Typha angustifolia seedlings.
- Compare first and second year density, height, and nutrient usage in stands established from Typha latifolia and Typha angustifolia seedlings.

Materials and methods.

This experiment will be established on the 0.21 ha site in Aitkin where experiment G8107 is located. The soil is a sandy loam. The area was originally prepared in 1981 as described in materials and methods for experiment G8107. Urea will be applied to the area at a rate of 75 kg N/ha prior to planting.

Design. Completely randomized block.

- Treatments: 2
  - Typha latifolia seedlings
  - Typha angustifolia seedlings
- Replications: 2 within each block
- Blocks: 3
- Plot size: 5 m x 8 m
- Number of plots: 12
- Density of planting material: 5 per $m^2$

Observations and sampling.

- Density
- Soil nutrient analysis
- Plant nutrient analysis
- Total biomass yield at the end of one and two years (1983, 1984)
- Percent flowering shoots in second year

Herbicide Trial

Objectives

- Determine the effectiveness of various levels of Poast, Roundup and Amitrol T herbicides against Phalaris arundinacea (reed canary grass) and Glyceria grandis (reed meadow grass).
- Determine possible detrimental affects of the same herbicides on Typha.

Materials and methods.

Extant plots from the Fertilization Study will be used. See description of that experiment for details of previous treatment of plots.

Design.

- Randomized complete block.
- Treatments
  - Glyphosate (Roundup) at 1.2 l/ha
  - Glyphosate (Roundup) at 2.3 l/ha
  - Glyphosate (Roundup) at 3.5 l/ha
  - BAS90520H (Poast) at 1.2 l/ha
  - BAS90520H (Poast) at 2.1 l/ha
  - BAS90520H (Poast) at 2.9 l/ha
  - Amitrole (Amitrol T) at 1.1 kg/ha
  - Amitrole (Amitrol T) at 3.4 kg/ha

- Amitrole (Amitrol T) at 5.6 kg/ha
- Hand weeded control
- Control - no treatment

- Treatments per block: 11
- Blocks: 4
- Total plots: 44

Observations and sampling. Two weeks and one month after treatment application, plots will be scored on a scale of 1 to 5 for damage to reed canary, damage to reed meadow grass, and damage to cattails.

## Herbicide Trial, Greenhouse

### Objectives

- To further test the possible detrimental effects of Roundup and Poast on *Typha*.
- To determine possible effects of water depth on herbicide activity.
- To determine possible herbicide selectivity between *T. latifolia* and *T. angustifolia*.

### Materials and methods

Test plants were 4 month old seedlings growing in 10 cm florist's pots in a greenhouse. Herbicides were applied by overhead spray. Treatments were sampled after 60 days. Damage assessment was numeric with 1 = no damage, 5 = total destruction.

### Design.

- Randomized complete factorial (4 x 2 x 2)
- Factors: Herbicide (4 levels), water depth (2 levels), species (2 levels)
- Levels:
  - Herbicide (all rates aplied in water at 187 l/ha)
    - a) Roundup @2.3 l/ha
    - b) Roundup @ 4.7 l/ha
    - c) Poast @ 2.3 l/ha
    - d) Control
  - Water Depth
    - a) Mudflat
    - b) Flooded
  - Species
    - a) *T. latifolia*
    - b) *T. angustifolia*
- Total treatments: 16
- Total plots (containers): 64
- Planting density: 1/container

Observations and sampling.

- Mortality, above- and belowground.
- Biomass, above- and belowground.

FIELD TRIALS - ZIM, MINNESOTA

Peatland Excavation Study - Typha

Objectives

To test the feasibility of growing wetland plants on peatland which has had varying amounts of peat removed. This will be done in an effort to determine potential problems with reclaiming mined peatlands. Variables to be studied include:

- Soil nutrient composition
- Fertilizer requirements
- Water management
- Plant stock (rhizomes vs. seedlings)

Materials and Methods

The research site consists of three areas (each area is 15 x 30 m), each of which has been excavated to a different depth. The three depths are 0 m, 0.6 m, and 1.5 m below surface level. Each area contains four plots plnated with seedlings, and four plots planted with rhizomes.

Field preparation. Unexcavated area was rotovated four times prior to fertilization. In the excavated areas, land was leveled by hand so that maximum elevation difference was 15 cm or less. Plots were laid out and fertilized by hand (alleys were not fertilized). Application rate was 70 kg/ha of Peters Fritted Trace Elements, 20 kg/ha of $CuSO_4$ and 1250 kg/ha of Howe's 6-12-24 fertilizer. In the unexcavated and 0.6 m excavated areas, the fertilizer was incorporated to a depth of 8 cm with a small rototiller. In the 1.5 m excavated area, fertilizer was incorporated to a depth of 8 cm using hand cultivators. Plant material was planted by hand in even spacings.

Design.

- Completely randomized block (each excavation depth will be considered a block; each block will consist of a completely randomized design).
- Treatments: 2 - rhizome planting stock vs. seedling planting stock
- Replications: 4 within each block
- Size of plots: 3 m x 5 m
- Density of planting material: 9 per $m^2$

Observations and sampling.

- Density
- Insect damage
- Competitors
- Water usage
- Soil nutrient analysis
- Plant nutrient analysis
- Total biomass yield at the end of one and two years (1981 - 82)

## Nutrient Uptake Experiment, Seedling Established

### Objectives

- Test the effectiveness of using a modified 2-row mechanical transplanter to establish stand of *Typha* from seedlings.
- Determine the rate of nutrient uptake over the course of two growing seasons in a stand established from seedlings.
- Provide an area for comparing the effects on nutrient uptake and biomass yield of timed fertilization vs. no fertilization in third year stands. The time of fertilization will be based on the first and second year nutrient uptake results.
- Observe differences in growth rate and nutrient uptake between plants started from rhizomes and seedlings (Nutrient Uptake Experiment, Rhizome Established).

### Materials and Methods

The research site consists of a ditched and diked area which has been uncultivated for 10 years. Dams and water gates were constructed to allow for water control over the entire 7.1 ha area. The soil is a reed-sedge peat.

Field preparation. Roundup was applied to the approximately 1/2 ha field at a rate of 1.6 gal/ha to control weeds. The field was then rotovated in September. The field was ditched and diked and water gates installed for water level control. Fertilizer was applied in May using a Gandy Spreader. Application rates were 70 kg/ha of Peters Fritted Trace Elements, 20 kg/ha of $CuSO_4$, and 577 kg/ha of Howe's 0-26-26 fertilizer. Fertilizer was incorporated to a depth of 10 cm using a disc harrow.

Design.

- Randomized complete block
- Treatments
    - Year 1 (1982): Time of sampling for nutrient standing crop (samples taken every four weeks during the growing season).
    - Year 2 (1983): Fertilized vs. not fertilized, and time of sampling for nutrient standing crop.
- Size of sample (plot): 1 $m^2$
- Blocks: 4

- Size of blocks: 12 x 54 m
- Planting material: Three month old Typha latifolia seedlings
- Planting density: 5 seedlings/$m^2$
- Planting method: Two-row modified mechanical transplanter

Observations and sampling.

- Density
- Height
- Aboveground and belowground plant samples for biomass and nutrient content determinations.
- Soil samples for nutrient analysis.

## Nutrient Uptake Experiment, Rhizome Established

### Objectives

- Establish a rhizome stock nursery of the six different genotypes grown in the paddies at St. Paul during 1980-81 (experiment P8101).
- Determine the rate of nutrient uptake over the course of two growing seasons of a stand established from rhizomes.
- Observe differences in growth rate and nutrient uptake between plants started from rhizomes and seedlings (Nutrient Uptake Experiment, Seedling Established).

### Materials and Methods

The research site consists of a ditched and diked area which has been uncultivated for 10 years. Dams and water gates were constructed to allow for water control over the entire 7.1 ha area. The soil is a reed-sedge peat.

Field preparation. Roundup was applied to the approximately 1/4 ha field in August of 1981 at a rate of 1.6 gal/ha to control weeds. The field was then rotovated in September. The field was ditched on two sides and diked on four sides for water level control. Fertilizer was applied in May, 1982 using a Gandy Spreader. Application rates were 70 kg/ha of Petes Fritted Trace Elements, 20 kg/ha of $CuSO_4$, and 577 kg/ha of Howe's 0-26-26 fertilizer. Fertilizer was incorporated to a depth of 10 cm using a disc harrow.

Design.

- Randomized complete block
- Treatments: Time of sampling for nutrient standing crop (samples taken every 4 weeks during two growing seasons, 1982-83, from the four genotypes which demonstrated no significant yield difference in the Typha genotype comparison experiment (Pratt, 1982), Carlos Avery, Fort Snelling, Syre, and Roseau).
- Size of sample (plot): 1 $m^2$

- Blocks: 4 (each of the four genotypes listed above)
- Size of blocks: 6 x 20 m
- Planting material: Identified by source -
  - Carlos Avery Wildlife Management Area
  - Roseau Wildlife Management Area
  - Syre, Minnesota
  - Eagle Lake Wildlife Management Area
  - Fort Snelling State Park
  - Kesters Nursery, Wisconsin
- Planting density: 5 rhizomes/$m^2$
- Planting method: Two-row modified mechanical transplanter

Observations and sampling.

- Density
- Height
- Aboveground and belowground plant samples for biomass and nutrient content determinations.
- Soil samples for nutrient analysis.

PADDY TRIALS - ST. PAUL, MINNESOTA

Comparison of Wetland Species

Objectives

- To compare the productivity of wetland species which have potential as energy crops and/or reclamation species.
- To compare biomass, plant density, and shoot height after one and two years of growth (1981-82).

Materials and Methods

Vegetative planting material was collected or purchased. When possible, material was collected from productive natural stands identified from previous studies. Species being tested include *Phragmites australis* (reed), *Sparganium eurycarpum* (bur reed), *Scirpus fluviatilis* (bulrush), *Spartina pectinata*, and *Carex atherodes*.

Paddy preparation. 1.5 $m^2$ plywood frames, lined with black polyethylene, were filled wtih peat and fertilized with 1250 kg/ha of Howe's 6-12-24 fertilizer (nitrogen in ammoniated form). A watering system was installed.

Design.

- Latin square (6 x 6)

- Factors:

| Species | Source of Planting Material |
|---|---|
| Phragmites australis | Purchased (Wisconsin) |
| Carex atherodes | Fort Snelling State Park |
| Scirpus fluviatilis (I) | Purchased (Wisconsin) |
| Scirpus fluviatilis (II) | Fort Snelling State Park |
| Spartina pectinata | Fort Snelling State Park |
| Sparganium eurycarpum | Carlos Avery Wildlife Management Area |

- Total plots: 36
- Plot size: 1.5 $m^2$
- Planting density: 25/paddy (17/$m^2$)
- Planting date: 5-13-81 (replant 6-11, 12-81)

Observations and sampling.

- Density
- Height
- Biomass yield
- Insect damage

## Phragmites Propagation

### Objective

To determine one or more effective vegetative means of establishing a stand of Phragmites australis (reed).

### Materials and Methods

Vegetative planting material was collected from a natural stand at Carlos Avery Wildlife Management Area. The material was stored for a week in a cold room with the rhizomes and shoot bases packed in moist sphagnum before being planted on May 28, 1982.

Paddy preparation. 1.5 $m^2$ plywood frames, lined with clear polyethylene, were filled with peat from the Forest Lake area and fertilized with 1250 kg/ha of Howe's 6-12-24 fertilizer (nitrogen in ammoniated form). The fertilizer was incorporated by hand to a depth of about 15 cm.

Design.

- Completely randomized design
- Treatments: 4 vegetative planting materials
  - Rhizome pieces with at least one bud
  - Shoot/rhizome (an entire Phragmites shoot varying from 50 to 150 cm n height with attached rhizome material)
  - Cut shoot/rhizome (same as shoot/rhizome above except shoot was excised two nodes above the rhizome/shoot transition. This left a shoot length of between 20 and 40 cm.)

- Cane cutting (shoot tips removed at the first node below the lowest leaf and dipped in Hormadin - a commercial IBA preparation. The average length of the cane cutting was 30-60 cm.)

- Total plots (paddies): 16
- Plot size: 1.5 $m^2$
- Planting density: 16/paddy ($10/m^2$)

Observations and sampling.

- Survival of planting material after one month
- Density
- Height
- Biomass yield

Phragmites Propagation - Greenhouse Trial of Stem Cuttings

Objective

To compare the effects of node maturity, auxin treatment, wounding, and the amount of leaf surface on root and shoot development with *Phragmites* stem cuttings.

Material and Methods

Vegetative planting material was collected from non-flowering shoots in a natural stand in the Zim, Minnesota area on June 24, 1982. Cutting stock was wrapped in plastic and refrigerated until planting the following day.

Planting area preparation. 10 cm plastic florist pots were filled with a mixture of 50 percent sphagnum peat and 50 percent perlite. The pots were placed in a rectangular grid (10 pots x 6 pots) on a greenhouse bench. The area was enclosed in a clear polyethylene tent. All cuttings were watered into their container and sprayed with a commercially available water-soluble PVC antidessicant (Wiltprof).

Design.

- Randomized complete factorial (5 x 2 x 2)
- Factors
  - Rooting stock (5 types)
  - Auxin Treatment (2 levels)
  - Wounding (2 levels)
- Levels:
  - Rooting stock
    a) single node (one node directly below first uncurled leaf), leaves whole
    b) double node (two nodes below first uncurled leaf), leaves whole
    c) single node, leves cut in half
    d) double node, leaves cut in half
    e) two node cane section (two nodes directly below the lowest developed leaf)

- Auxin treatment
    a) 0.8% IBA in talc (basal cut surface moistened and dipped)
    b) talc only
- Wounding
    a) Wounded (shallow, longitudinal cut in the cuticle at the node)
    b) unwounded

- Total treatments: 20
- Total plots (containers): 60
- Planting density: 10/container

Observations and sampling.

- Percent root initiation
- Percent shoot development
- Percent mortality

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APPENDIX B

# A BIBLIOGRAPHY OF THE BIOLOGY, ECOLOGY AND UTILIZATION OF *TYPHA*

by

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# INTRODUCTION

This bibliography is based largely on a thorough search of Biological Abstracts, Volumes 1-74(4), and on many incidental references drawn from various sources. In addition, citations from three journals, The American Journal of Botany (Volumes 1-68), Botanical Reviews (Volumes 1-25), and the Bulletin of the Torrey Botanical Club (Volumes 1-107) are included. Also cited are papers produced by and for the Bio-Energy Coordinating Office, University of Minnesota.

While quite extensive, this bibliography is not an exhaustive summary of the voluminous literature concerning *Typha*. No attempt was made to include much of the early European work which has been reviewed by Kronfeld (327), Graebner (221) and Loew (368). A review of more recent literature by McDonald (396) is quite extensive and has been incorporated into this bibliography. Westlake (663) and Keefe (299) have reviewed literature concerning the productivity of *Typha* and other wetland plants. Brinson *et al* (95) have recently reviewed productivity, decomposition and herbivory in freshwater wetlands. Additional references concerning freshwater wetlands (some relevant to *Typha*) have been compiled by Hall[1].

Both a general and a species index have been prepared. Efforts were made to make the indices as detailed as possible; however, due to an inability to secure copies of all the referenced articles, some materials are indexed strictly from information gleaned from abstracts.

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## General Index

## Species Index

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15. Supplementary Notes

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16. Abstract (Limit: 200 words) The high yield potential and attractive chemical composition of Typha make it a particularly viable energy crop. The Minnesota research effort has demonstrated that total annual biomass yields equivalent to 30 dry tonnes/ha (13 tons/acre) are possible in planted stands. This compares with yields of total plant material between 9 and 16 dry tonnes/ha (4-7 tons/acre) in a typical Minnesota corn field. At least 50% of the Typha plant is comprised of a belowground rhizome system containing 40% starch and sugar. This high level of easily fermentable carbohydrate makes rhizomes an attractive feedstock for alcohol production. The aboveground portion of the plant is largely cellulose, and although it is not easily fermentable, it can be gasified or burned. This report is organized in a manner that focuses on the evaluation of the management options task. Results from stand management research performed at the University of Minnesota during 1982 and 1983 are integrated with findings from an extensive survey of relevant emergent aquatic plant research and utilization. These results and findings are then arranged in sections dealing with key steps and issues that need to be dealt with in the development of a managed emergent aquatic bio-energy system. A brief section evaluating the current status of rhizome harvesting is also included along with an indexed bibliography of the biology, ecology, and utilization of Typha which was completed with support from this SERI subcontract.

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