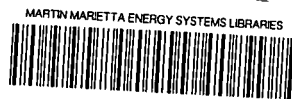


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Cattail (*Typha* Spp.) Biomass Production —Stand Management and Sustainable Yields—

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CATTAIL (*TYPHA* SPP.) BIOMASS PRODUCTION

- Stand Management and Sustainable Yields -

**Final Report
1984 - 1988**

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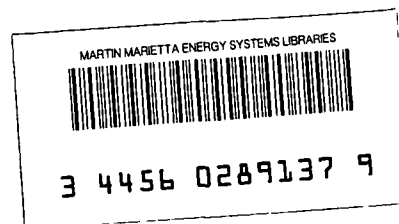
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ABSTRACT

Wetlands in the United States provide a large land base for producing biomass for energy applications. *Typha* species have been identified as a particularly suitable biomass crop for wetlands because of their superior productivity (40+ Mg/ha standing crops), pest resistance, adaptability, and chemical composition. Production methods were evaluated in this report to identify ways of maximizing biomass yields while minimizing costs, leading to a sustainable, economically competitive production system. Harvesting studies found that a single annual harvest of leaf biomass is preferable to a semiannual leaf harvest or an annual leaf harvest coupled with a biennial rhizome harvest. The annual leaf harvest is sustainable, results in the lowest nutrient removal, and yields 80% of the biomass obtained from the combined leaf/rhizome harvest. Semiannual leaf harvests appear to damage *Typha* stands and not be sustainable. Water loss from *Typha* stands, which will influence site selection and possible irrigation requirements, was found to be significantly affected by species selection, water management regimes, biomass yields, and microclimate. Based on equipment considerations, drainage of *Typha* paddies approximately one month prior to harvest is preferable to continuously flooded paddies even though yields appear to be reduced slightly. Studies of substrate pH limitations found that a pH range between 5.5 and 8.0 appears optimal. A flowering study found that while flowering can reduce vegetative shoot propagation and individual shoot standing crop, the frequency of flowering is usually too low to have an impact on overall yields, and, hence, control measures are unnecessary. Finally, an examination of factors affecting aboveground to belowground biomass ratios found that fluctuation in ratios is common following establishment, but stabilizes at approximately one after the third growing season.

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EXECUTIVE SUMMARY

Wetlands dominated by *Typha* (cattails) and other perennial emergent aquatic vegetation are one of the most productive natural systems in the temperate zone. In the north central United States, total wetland plant standing crops have been reported as high as 43 to 51 Mg/ha (19-23 tons/acre), compared with 10-16 Mg/ha for a typical agronomic crop like *Zea mays* (corn). Minnesota, with over 3.4 million hectares (8.4 million acres) of wetlands, appears to have considerable potential for wetland biomass production, and elsewhere in the U.S. an estimated 33 million hectares (81.5 million acres) of wetlands exist (excluding Alaska and Hawaii), some of which could be suitable for wetland biomass production. A challenge faced in utilizing these productive wetland plants and large land base is understanding the technical, physical, and management requirements of undomesticated plant species.

Typha species have been the primary focus of research on wetland biomass crops in Minnesota because of their productivity, adaptability, large sugar and starch rich rhizome system, exceptional pest resistance, and aggressive growth and regeneration characteristics. Research at the University of Minnesota has been involved with characterizing biomass composition and nutrient assimilation patterns, identifying potential pest problems and solutions, developing methods and equipment for establishing and harvesting stands, and exploring possible multiple use situations which would reduce the costs of biomass production. Through this research, potential production practices emerged, each of which involved trade-offs between costs and benefits. To evaluate some of the more important production practices and their implications for commercial production, the studies described in this report were initiated. The ultimate goal is to develop an information base that can be used to develop a biomass energy system that maximizes output while minimizing inputs, resulting in a renewable energy resource that is economically competitive.

The first study examined the sustainability of biomass yields over multiple seasons using different harvesting methods and resulting in different types of biomass products. Harvesting can affect biomass yields, biomass quality, nutrient removal, stand regeneration, and harvesting costs. Harvesting can affect productivity by altering rhizome carbohydrate and nutrient storage needed for early season growth and stand vigor. Leaf harvests alone may affect subsequent biomass yields, since removal of leaf biomass eliminates the litter cover which limits growth of competitors and insulates and shades natural *Typha* stands during winter and early spring. Biomass quality can vary from starch and sugars to cellulose depending on which portion of the plant is harvested. When nutrients are removed with the biomass, they will have to be replaced, usually with expensive fertilization. Finally, direct harvesting costs of capital equipment, mechanical power requirements, and number of passes through a field must be considered.

Sustained yields of *Typha* stands with repeated biomass harvests have never been measured. Natural and cultivated *Typha* stands were therefore studied over a three year period to evaluate the effect of three harvesting scenarios on *Typha* yields and nutrient status. The three harvesting scenarios considered were: 1) harvest of aboveground biomass annually in the fall, 2) harvest of aboveground biomass semiannually in mid-summer and fall, and 3) combined harvest of aboveground biomass annually in the fall and belowground biomass biennially in the fall.

The collective results from six experiments provided the information needed to assess each harvesting scenario. At the present time, an annual aboveground harvest appears to be

the preferred harvesting scenario for *Typha* species. Across all experiments, the annual harvest did the best job of maximizing yield while minimizing cost. Average annual yield was only 20% less than the combined aboveground and belowground harvest and 43-61% more than the semi-annual harvest treatment. Additionally, all experiments indicate that an annual aboveground harvest is sustainable, has no adverse effect on yield, and may actually enhance yield over unharvested stands. Nutrient removal was shown to be less with the annual cutting than with the other two harvest options, thus reducing fertilization costs. Harvesting costs would also be less with the annual aboveground harvest option since only one harvest pass is required per year, compared to two per year for the semi-annual treatment and 3 every 2 years for the combined aboveground and belowground harvest scenario. Additionally, an annual fall or winter harvest can be accomplished using standard forage harvesting equipment, while rhizome harvesting will certainly require special equipment development.

The semi-annual aboveground harvest does not appear to be a viable harvest option for *Typha* grown in northern latitudes. Semiannual treatment plots showed poor shoot regrowth and diminished yields following a full harvest cycle, indicating that midseason harvest is detrimental to stand vigor and long term sustainability. Furthermore, no yield advantage was gained by adjusting the midseason cutting date, and all midseason harvests resulted in a significant decrease in rhizome biomass production.

The combined harvest scenario with 50% rhizome removal is a viable and sustainable option if there is a particular need for the rhizome biomass, which consists of approximately 40% starch and sugars at the end of the growing season. Although the rhizome harvest does depress shoot yield in the subsequent growing season, rhizome standing crop recovers to unharvested levels by the end of the season and shoot yield fully recovers by the end of the second growing season after rhizome harvest. Seventy percent of the yield for the combined harvest was in the form of aboveground biomass. The low amount of rhizome biomass obtained with a 50% harvest biennially makes questionable the value of harvesting rhizomes, especially in light of the increased costs associated with this scenario. These increased costs could only be justifiable if the value of the rhizome biomass as a feedstock were considerably more than the aboveground cellulosic biomass.

The second study examined water requirements of *Typha* plants and the possible need for supplemental irrigation and/or water management regimes. Although wetlands, with water tables at or near the soil surface, will generally be used for biomass production, it is possible that irrigation will be required to maintain an equilibrium balance of water inputs to water losses. Reported evapotranspiration rates for *Typha* are substantially greater than the 51-79 cm annual precipitation range in Minnesota. This gap between water inputs and potential outputs would severely limit the potential of *Typha* as a biomass crop. Because of different climatological sites used in previous studies and questions raised about methodology, additional studies of *Typha* water loss were deemed necessary.

Species selection, water management choices, biomass yields, and microclimate all were found to significantly affect water losses from and, hence, water requirements for *Typha*. In the case of species selection, *Typha latifolia* was slightly more efficient in terms of biomass produced per unit of total water lost than either *T. angustifolia* or *T. x glauca*. However, since *T. latifolia* is generally less productive than the other two species under field conditions, selecting *T. latifolia* on the basis of water use efficiency would sacrifice yield potential in the attempt to minimize irrigation requirements. This would only be advisable in situations where irrigation will be expensive or infeasible. In most wetland situations, optimization of yield should be the determinant of species selection.

Water management options were examined not only to see if water use could be minimized, but also to see if soil moisture conditions conducive to operation of conventional farm

harvesting equipment could be achieved without a sacrifice in biomass yield. A midseason drawdown reduced water loss compared with a continuously flooded regime, but it also reduced yield. The net result was an identical water use efficiency for flooded and drawdown regimes. Trade-offs between inputs and outputs need to be weighed before a recommendation can be made. At present, equipment considerations are probably more important than achieving maximum yields, so a drawdown water management regime is preferable to continuous flooding. It may be possible, depending on soil composition, to draw down at a later date than used in this study and improve yields. Maintaining a continuously saturated field does not seem to offer any advantages.

Microclimate appears to have the most significant effect on water loss from, and irrigation requirements for, *Typha* paddies. The larger, continuous stands of *Typha* which would be encountered in commercial production systems were found to use up to 90% less water for transpiration than some previous estimates and their total water loss does not exceed seasonal precipitation in Minnesota. An interesting finding was that water use efficiency is relatively constant over a wide range of yields under similar microclimatic conditions. For modeling and planning purposes, efficiencies, therefore, appear to have good predictive value.

The third study examined flowering in *Typha* since reports have suggested that extensive flowering may reduce biomass yields. To more closely evaluate the impact of flowering on productivity, and to begin to understand environmental/physiological factors controlling the flowering response, a literature review followed by two experimental studies were conducted. Results suggest that while flowering can have a negative effect on vegetative propagation and size of shoots in an individual ramet, it generally does not appear to reduce overall stand yields. As long as the number of shoots flowering remains less than a typical 10-15% of the total shoots present, there should not be any need to develop methods to inhibit flowering to enhance yield.

The fourth study evaluated the effects of substrate pH on growth patterns and total plant productivity of *Typha latifolia*. Although tolerant of a wide range of substrate pH conditions, *Typha* spp. appear to be somewhat adversely affected by acidic substrates, especially when pH drops below 5.5. When selecting sites for development of commercial *Typha* stands, soil pH should be a consideration, with emphasis on avoiding highly acidic soils. This requirement will be quite important for certain organic wetland soils, which tend to be relatively acidic.

The final study sought to identify factors regulating the distribution of biomass (aboveground leaves vs. belowground rhizomes) within the *Typha* plant so that efforts may be directed at controlling the appropriate factors to achieve desirable yield or chemical characteristics. Using a literature review and analysis of relevant information gathered from prior experimental data, initial planting density, nutrient availability, and water levels were identified as factors which can influence biomass distribution. Although aboveground to belowground biomass ratios fluctuate dramatically in the first few years following stand establishment, the ratio tends to eventually stabilize at approximately one to one in the absence of harvesting. Considering harvest recommendations discussed earlier, aboveground yield may be maximized, at least in young stands, by planting with seed to achieve a relatively high initial density (e.g. 40 plants/m²).

SECTION 1

INTRODUCTION

Wetlands dominated by *Typha* (cattails) and other perennial emergent aquatic vegetation such as *Phragmites* (reeds) and *Scirpus* (rushes) are one of the most productive natural systems in the temperate zone (Westlake, 1965). In the north central United States, total wetland plant standing crops have been reported as high as 43 to 51 Mg/ha (19-23 tons/acre) (Klopatek *et al.*, 1978; Andrews and Pratt, 1978; Bray, 1962). This compares with 10-16 Mg/ha standing crops for a typical agronomic crop like *Zea mays* (corn) (Moss, 1977).

Minnesota, with over 3.4 million hectares (8.4 million acres) of wetlands, appears to have considerable potential for wetland biomass production (Anderson and Craig, 1984). Outside of Minnesota, an estimated 33 million hectares (81.5 million acres) of wetlands exist in the United States (excluding Alaska and Hawaii) (Frayer *et al.*, 1983), some of which could be suitable for wetland biomass production. The challenge faced in utilizing these productive wetland plants and large land base is understanding the technical, physical, and management requirements of undomesticated plant species.

Early screening for potential wetland biomass crops was conducted through literature reviews, natural stand surveys, and yield trials to identify productive species which are adapted to wetland habitats and occur naturally in monoculture or in mixed stands with species of similar harvesting requirements (Pratt *et al.*, 1984; Pratt *et al.*, 1982; Andrews *et al.*, 1981). Of eight native wetland plants tested, *Typha* (cattail) species were identified as the most promising candidates for a wetland biomass production system in Minnesota. In addition to meeting criteria for productivity and adaptability, *Typha* species were chosen for their large, sugar and starch rich rhizome system, exceptional pest resistance, and aggressive growth and regeneration characteristics.

Following the selection of *Typha*, research at the University of Minnesota has focused on characterizing biomass composition (Glass *et al.*, 1980) and nutrient assimilation patterns (Garver *et al.*, 1988) of *Typha*, identifying potential pest problems and solutions (Pratt *et al.*, 1984; Penko, 1986), developing methods and equipment for establishing (Pratt *et al.*, 1986; Bonnewell *et al.*, 1983) and harvesting (Schertz, 1983, 1986) *Typha* stands, and exploring possible multiple use situations which would reduce the costs of biomass production (Dubbe *et al.*, 1989).

Through this research, potential production practices emerged, each of which involved trade-offs between costs and benefits. To evaluate some of the more important production practices and their implications for commercial production, the studies described in this report were initiated. The first study examines the sustainability of biomass yields over multiple seasons using different harvesting methods and resulting in different types of biomass products. The second study examines water requirements of *Typha* plants and the possible need for supplemental irrigation and/or water management regimes. The final three studies further characterize *Typha* production systems in terms of suitable site characteristics, factors affecting the ratio of above- to belowground biomass, and the potential negative influence of flowering on biomass yields. The ultimate goal is to develop an information base that can be used to develop a bioenergy system that maximizes output while minimizing inputs, resulting in a renewable energy resource that is economically competitive.

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SECTION 2

SUSTAINABLE YIELDS AND NUTRIENT REMOVAL

INTRODUCTION

Assessing the commercial potential of *Typha* as an energy resource depends on understanding the trade-offs between productivity and production costs. This information can be used to formulate management systems which will maximize outputs while minimizing inputs. Harvesting is one component of a bio-energy management system that involves trade-offs between biomass yields, biomass quality, nutrient removal, stand regeneration, and harvesting costs.

Harvesting leaf or rhizome biomass from *Typha* stands has the potential to affect long term productivity in various ways. Harvesting can result in reduced or increased nutrient retention in perennial plant tissue, depending on the time of harvest and the type (leaf, rhizome, or both) of biomass harvested. This is based on observed cyclic patterns of nutrient accumulation in leaves and rhizomes of *Typha* (Davis and van der Valk, 1983; Penko, 1985; Garver *et al.* 1988). Nutrients stored in the rhizomes are mobilized early in the growing season for rapid stand growth.

Harvesting can also affect productivity by altering rhizome carbohydrate storage needed for early season growth and stand vigor (Linde, 1976). Multiple leaf cuttings during a growing season may prevent adequate carbohydrate translocation from leaves to rhizomes while resulting in little additional leaf biomass production (Shekov, 1974; Weller, 1975; Sharma, 1978; Sale and Wetzal, 1983). Rhizome harvesting removes carbohydrates required for the stand to fill in and become productive again (Pratt *et al.* 1983).

Finally, leaf harvests alone may affect subsequent biomass yields, since removal of leaf biomass eliminates the litter cover which limits growth of competitors and insulates and shades natural *Typha* stands during winter and early spring (Sharma and Gopal, 1977; Sharma, 1978; Dubbe and Pratt, 1986).

In addition to effects on yield alone, consideration must be given to the input costs of harvesting. When nutrients are removed with the biomass, they will have to be replaced, usually with expensive fertilization. Harvesting systems that minimize nutrient removal would be preferred. Biomass quality, in the case of *Typha* spp., can vary from starch and sugars to cellulose (Glass, 1980) depending on which portion of the plant is harvested. Finally, direct harvesting costs of capital equipment, mechanical power requirements, and number of passes through a field must be considered.

Previous studies have determined standing crop yields for *Typha* spp. in natural stands and in first, second, and third year cultivated paddies (Andrews *et al.* 1981; Pratt *et al.* 1982; Pratt *et al.* 1983). However, sustained yields with repeated biomass harvests have never been measured. Natural and cultivated *Typha* stands were therefore studied over a three year period to evaluate the effect of three harvesting scenarios on *Typha* yields and nutrient status. The efficiency of, and possible mechanical damage caused by standard forage and specially modified harvesting equipment was also evaluated. The three harvesting scenarios considered

were: 1) harvest of aboveground biomass annually in the fall, 2) harvest of aboveground biomass semiannually in mid-summer and fall, and 3) combined harvest of aboveground biomass annually in the fall and belowground biomass biennially in the fall.

MATERIAL AND METHODS

Six experiments were undertaken to evaluate the three harvesting scenarios. The variety of experiments allowed for evaluation of annual sustainable productivity under a range of conditions including different soil types, species, stand age, and location in the state.

General Methods - All Experiments

Sampling consisted of cutting all leaves and flowering shoots at 15 cm above the soil surface level. This was done to provide a more realistic estimate of harvestable aboveground yield since harvesters are generally incapable of harvesting at soil level. Leaving a 15 cm stubble also lessens the risk of mortality from variable or fluctuating water levels covering the cut shoot bases and depriving plants of oxygen. Previous unpublished results have found that the lower 15 cm of aboveground biomass accounts for 15-20% of total aboveground biomass. The lower 15 cm portion was included with rhizome samples to more accurately reflect the harvested belowground biomass product. Rhizomes were excavated by hand or machine to a depth required to remove all rhizomes (generally 30 cm). Rhizomes were washed thoroughly by hand or with a rotary tumbler, and intact root biomass was included with the rhizome sample. Samples were kept in cold storage until further processing.

All samples were dried to constant weight in a 65° C oven (ASAE, 1980), and then weighed to determine biomass yield. In preparation for nutrient analysis, tissue was ground to pass through a 2 mm screen in a Wiley Mill. Total nitrogen was determined using a micro-Kjeldahl digestion technique followed by distillation and titration (Bremner, 1965). An extract was prepared for phosphorus and potassium analysis by dry ashing tissue at 500° C for 12 hours and extracting with 2N HCl. Phosphorus concentration was determined by spectrophotometry at 882 nm using an ascorbic acid/molybdate-blue assay (John, 1970). Potassium concentration was determined by atomic absorption spectroscopy at 766 nm using a Buck Scientific model 200 AA/emission spectrophotometer (Van Loon, 1980). Nitrogen, phosphorus, and potassium standing crop values were calculated for each sample by multiplying nutrient concentration by sample dry weight.

Cultivated Stand - Three Harvest Scenarios.

This experiment was conducted in an existing 4 year old cultivated stand of mixed *Typha* species on a hemic peat soil located in Aitkin County, Minnesota (Pratt *et al.*, 1982). All three harvesting scenarios were included to allow a direct comparison of sustainable productivity under identical environmental conditions. The experiment was designed to cover at least one complete harvesting cycle, which required a two year time frame. The water level in the 0.5 ha paddy was maintained at approximately 15 cm during both growing seasons of the experiment. Fertilizer (70-25-25 kg/ha, NPK) was applied aerially on July 9, 1985.

Because of the rudimentary design of harvesting equipment for *Typha* leaves and rhizomes, two subplots (hand and machine harvest) were included in the experimental design

to prevent biasing the results through inadvertent mechanical damage. This also provided a basis for the evaluation of equipment design and effectiveness.

The experiment was organized in a split-plot design with a structural missing plot. There were three whole plot factors consisting of: 1) annual (fall) aboveground biomass harvest, 2) semi-annual (mid-summer and fall) aboveground biomass harvest, and 3) control plots with no biomass removal. Whole plot size was 10x14 m. There were two sub-plot factors consisting of: 1) hand harvest and 2) mechanical harvest. Since a mechanical harvest subplot was extraneous for control plots, the extra subplot was used to test a combined annual fall aboveground harvest and partial biennial rhizome harvest. Subplot size was 10x7 m. Three replicates of each factor were measured.

Initial treatments were applied during October 1984, preceded by hand sampling of randomly selected one square meter areas within each subplot to determine initial productivity and variability within the *Typha* stand. The partial rhizome harvest consisted of 69 cm wide strips harvested to a depth of 30 cm alternating with 69 cm wide unharvested strips (50% harvest). Mid-summer harvest treatments for the semiannual harvest plots were applied on July 22, 1985 and July 8, 1986; fall treatments for all plots were applied during the first half of October in 1984, 1985 and 1986.

Following treatment application, three 1 m² subsamples were randomly taken from each sub-plot for determination of aboveground biomass productivity. Weeds were also collected to determine treatment effect on competition. Following treatment application, a single 1 m² rhizome sample was taken randomly from each whole plot to assess total plant productivity.

Mechanical harvesting of above- and belowground biomass was accomplished using a Seiga amphibious vehicle (Schertz *et al.* 1985). A modified flail mower, conveyor, and storage box on the Seiga was used to chop and collect aboveground biomass. A modified potato harvester (Pratt *et al.* 1983; Schertz *et al.* 1983; Schertz *et al.* 1985) was used for rhizome harvesting. A comparison of yields in machine harvested areas with yields in hand harvested areas provided an estimate of mechanical damage incurred using the harvesting machinery. Measurements on samples of machine harvested material included whole plot yields, machine harvest efficiency, and shoot moisture content.

Cultivated Stand - Annual Aboveground Harvest

This experiment was conducted on an existing 4 year old cultivated stand of *Typha angustifolia* on a loamy sand soil located in Aitkin County, Minnesota. The 10x60 m stand was established from seed in 1981 (Pratt *et al.* 1982, 1984). In October 1983, the stand was randomly subdivided into four control plots and four harvested plots, each 10x7 m, to observe effects of annual aboveground harvesting on growth patterns in the 1984 growing season (Pratt *et al.* 1985). The same harvest treatments were applied in October, 1984, prior to incorporation in this study in 1985. The stand had been fertilized annually through 1984 (Pratt *et al.*, 1982, 1984) and again on July 9, 1985 at the rate of 70-25-25 kg/ha of NPK. Water levels were maintained at approximately 15cm during the growing seasons.

In mid-October 1985 and 1986, three 1 m² subsamples were randomly taken from each plot for determination of aboveground biomass yields. The annual, aboveground only, harvest treatment was then applied using the Seiga forage harvester previously described. Following the treatment application, a single 1 m² rhizome sample was taken randomly from each plot to assess total plant yield.

Newly Cultivated Stand - Annual Aboveground Harvest.

A 0.2 ha stand of *Typha angustifolia* growing on an alkaline clay soil in Crookston, Minnesota provided an opportunity to test sustainable aboveground yields under soil and environmental conditions different from other sites. Also, due to soil characteristics and water control at the site, the annual fall harvest could be accomplished with conventional harvesting equipment.

The site and water for irrigation were provided by American Crystal Sugar Company. The stand was established using seedlings mechanically planted at a density of 10 per square meter on June 20, 1985. Because the irrigation water contained nutrients from a sugar processing operation, no fertilizer was applied to the site.

Aboveground biomass was sampled from three randomly selected, 1 m² plots in each of 3 blocks at 28 day intervals during the 1985 and 1986 growing seasons. At the end of each growing season, rhizome biomass was sampled from 3 randomly selected 1 m² plots for yield determination. During the 1987 season, aboveground biomass was sampled at 14 day intervals beginning June 9th to correspond with experimental requirements in Experiment 6. Leaf biomass was harvested at the end of the season using a tractor/haybine/baler in 1986 and a tractor/forage chopper in 1987.

Natural Stand - Annual and Semiannual Harvest.

This experiment was conducted in a natural stand of *Typha x glauca* located 10 miles north of St. Paul, Minnesota. The study provided the opportunity to evaluate tradeoffs involved with winter harvests on the frozen marsh surfaces, such as easier equipment access and lower biomass moisture content vs. lower harvest yields because of lodging and snow cover. It also afforded an opportunity to gain experience with the difficulties of harvesting natural stands with uncontrolled water levels.

Twelve plots, each 7x7 m, were laid out in a randomized complete block design with four blocks and three treatment levels. Harvest treatments included an annual winter (January) aboveground biomass harvest, a semiannual aboveground biomass harvest (July and January), and a control.

Three randomly selected subsamples of aboveground biomass (cut at ice or water surface level) from each plot were collected initially in January, 1986, for baseline information and were collected again in October, 1986, for yield comparisons. A July, 1986, sampling also occurred in semiannual treatments. Harvest treatments were applied to the plots following sampling. Final sampling occurred in January, 1987. Winter conditions prevented rhizomes from being sampled.

Greenhouse Study - Timing of Semiannual Harvest

This experiment was established in a greenhouse at St. Paul to provide controlled conditions for observing regrowth patterns and total seasonal biomass production in a semiannual harvest scenario with varying midseason cutting times and a fixed fall cutting time. A complementary study was established in a cultivated stand (described below).

The experiment was begun on May 9, 1987, when *Typha angustifolia* rhizome pieces collected from the Crookston stand were transplanted into 22 l buckets filled with a fertilized organic soil. The experiment was a completely randomized design with five replications of each of nine midseason harvest dates. The first harvest date was June 9 and additional dates

occurred biweekly through September 2. At each sampling date, leaves were harvested by cutting at 15 cm above the soil surface. Leaf yield was then determined. Regrowth was observed at two week intervals from the time of midseason harvest until the second harvest on September 15. Rhizome biomass was also harvested at this time followed by nutrient analysis of all biomass samples.

Cultivated Stand - Timing of Semiannual Harvest

This experiment was established in the cultivated *Typha angustifolia* stand at Crookston (previously used for experiment 3) to provide field conditions for observing regrowth patterns and total seasonal biomass production with different midseason cutting times. The experimental design is similar to that of the greenhouse study described above.

A completely randomized design with four replicates per midseason harvest date was used. At biweekly sampling dates, which began June 9, four 1 m² plots were harvested by cutting leaves at 15 cm above soil level and removing the harvested biomass for yield and nutrient analysis. A 1 m border area around each sampled plot was then harvested to reduce edge effects. Regrowth was observed in each plot at two week intervals from the time of first harvest until the second harvest on October 14th. Aboveground biomass yields and nutrient concentrations in regrowth tissue were determined. A final sampling of all plots occurred on September 2, 1988, to assess subsequent stand damage from the various harvesting dates.

RESULTS

Cultivated Stand - Three Harvest Scenarios.

Measurements were taken prior to treatment application in 1984 to establish baseline yield figures and measure initial variability within the stand. Mean *Typha* aboveground yield in 1984 was 6.2 Mg/ha; mean rhizome yield was 10.1 Mg/ha. Average shoot density was 26 shoots/m². There were no statistically significant differences ($p=0.01$) in yield or density between treatments or blocks, indicating uniform stand characteristics prior to treatment application. All treatments were applied after sampling in October, although the first midseason cutting for the semiannual treatment was not applied until July 7, 1985.

Aboveground yield values for control plots decreased 35% over the two years of the experiment (Figure 2.1), indicating that overall stand productivity was declining. Annually harvested plots had a similar, though less severe, yield reduction from 5.4 Mg/ha in 1984 to 4.1 Mg/ha in 1986 - a 24% decrease. Although the reasons for the decline are unclear, they do not appear related to nutrient status.

Aboveground yield for semi-annually harvested plots fluctuated dramatically (Figure 2.1). From a baseline yield of 6.8 Mg/ha in 1984, the combined midsummer and fall yields in 1985 jumped to 9.1 Mg/ha. Ninety-five percent of this yield (8.6 Mg/ha) was obtained during the July harvest, with only 5% (0.5 Mg/ha) obtained from regenerated shoots in the fall. The increase over baseline yield probably results from a midsummer harvest close to the time of peak seasonal aboveground yields which typically occur in August (Garver *et al.* 1988). In 1986, total seasonal yield dropped 78% from that in 1985 to 2.0 Mg/ha (1.6 Mg/ha in July; 0.4 Mg/ha in October). This figure is half that of the control and annual treatments, indicating that the midsummer harvest had adversely affected stand viability.

Aboveground yield for the combined aboveground and rhizome harvest treatment (Figure 2.1) decreased 47% in 1985 following the 1984 rhizome harvest, but recovered to 4.3 Mg/ha in 1986 - a figure nearly identical to the control and annual treatments. The yield reduction in the year following the rhizome harvest was equal to the percentage of rhizomes removed.

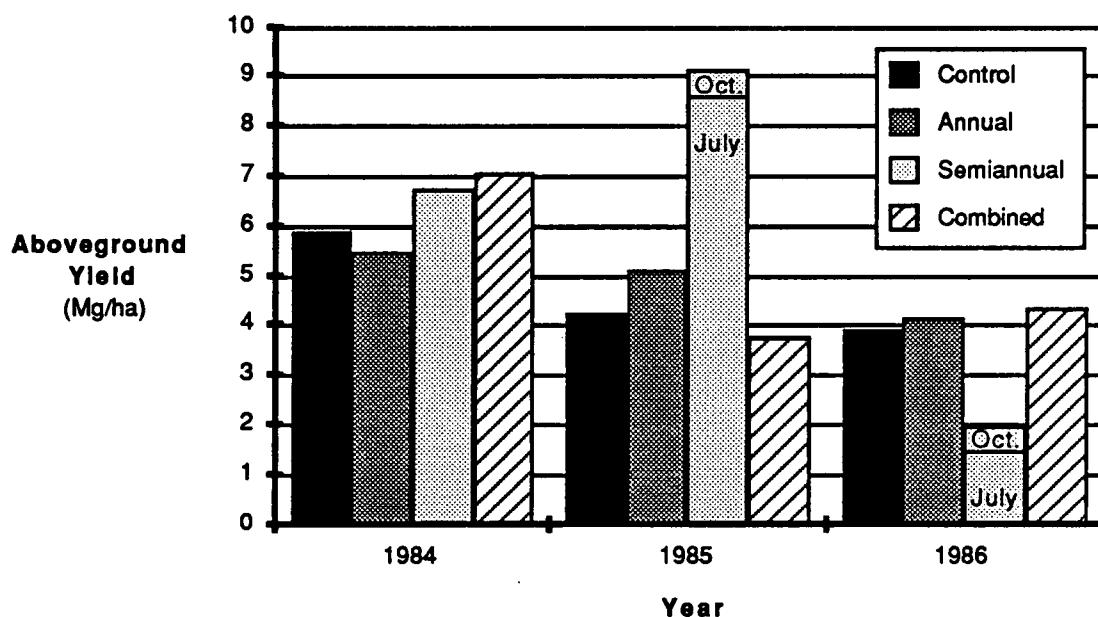


Figure 2.1 - Yearly aboveground biomass yields for three harvest treatments and a control. The 1984 yields are pretreatment baseline amounts. The first midseason harvest for the semiannual treatment occurred in July, 1985.

Contrast analyses of the aboveground yield data show that in 1985, the annual cutting treatment produced significantly ($p=0.05$) more biomass than the control. The combined aboveground/rhizome harvest treatment did not significantly change aboveground biomass yield relative to the control. A comparison between the semi-annual cutting treatment and the control is not meaningful for 1985 since it was the treatment application year.

Contrast analyses for 1986 show no significant difference ($p=0.05$) between aboveground yield for any of the cutting treatments versus the control. The lack of significance is surprising for the semiannual treatment, but results from high variability in the 1986 data.

Mean rhizome standing crop for the control was 8.7, 7.4, and 9.7 Mg/ha in 1984, 1985, and 1986, respectively. For the combined harvest, rhizome standing crop was 6.8 Mg/ha in 1984 and 1985 and 6.5 Mg/ha in 1986. There was no significant difference ($p=0.05$) in rhizome biomass between the combined harvest treatment and other treatments by the end of the 1985 growing season. This indicates that complete rhizome regeneration occurred in the year following a 50% rhizome harvest, thus providing the carbohydrate and nutrient reserves for the previously observed complete regeneration of aboveground biomass in the second year following the harvest.

Combining rhizome harvestable yield (50% of standing crop in 1986) with aboveground yields from 1985 and 1986 for the combined treatment results in a total two year biomass yield of 11.6 Mg/ha, or an average annual yield of 5.8 Mg/ha (Figure 2.2). Of this amount, 4.1 Mg/ha or 71% is aboveground biomass; 1.7 Mg/ha or 29% is belowground biomass. The average annual yield was 4.6 Mg/ha for the annual harvest treatment and 2.0 Mg/ha for the semiannual treatment. The combined and annual treatment yields appear sustainable; the semiannual treatment yield was declining in 1986 and probably is unsustainable.

For comparison, using averages of 1985 and 1986 data, the control had an average annual aboveground standing crop of 4.1 Mg/ha and an average annual belowground standing crop of 8.6 Mg/ha. The large discrepancy between belowground yield and standing crop results primarily from annualizing a 50% harvest occurring biennially. The actual belowground yield in the year harvest occurred was 3.4 Mg/ha.

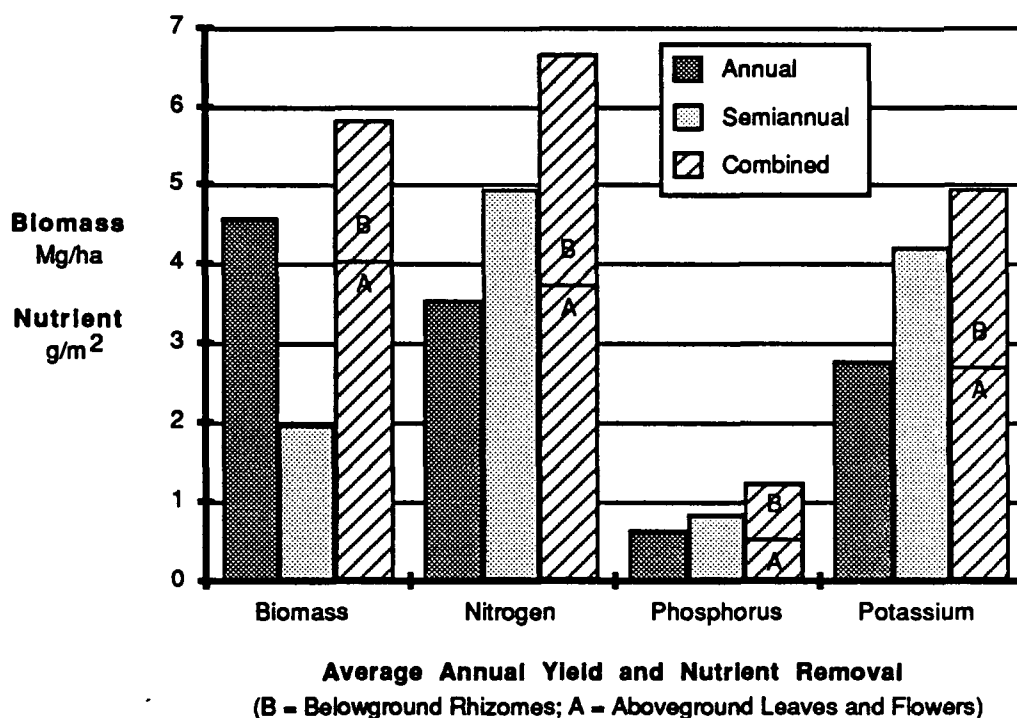


Figure 2.2 - Annualized total biomass yields and nutrient removal for three harvest scenarios. Annual treatment amounts are means of 1985 & 1986 biomass; semiannual treatment amounts are from 1986; combined treatment amounts are means of 1985 & 1986 aboveground biomass plus 25% (50% harvest biennially) of 1986 belowground biomass. Years selected for computation represent at least one complete harvest cycle.

Statistical analysis found that of the three harvest treatments, the combined treatment produced significantly ($p=0.05$) more biomass than the semi-annual treatment. However, biomass produced from an annual cutting was not significantly different than either the combined or semi-annual treatment according to Duncan's multiple range test. This lack of significance is disturbing given the large differences in means, but results from high variability among plots of the same treatment. Although the experiment cannot be considered definitive in

terms of ranking harvest options, the average yield observations and rankings (Figure 2.2) are supported by other qualitative and quantitative observations.

During May and June of 1985, all harvested plots exhibited vigorous new shoot growth, and there were no obvious differences between treatments in which the belowground rhizome material had not been removed. In the treatment where 50% of rhizome biomass had been harvested, the harvested strips showed no signs of stand regeneration from adjacent unharvested strips until late July. By the end of the 1985 growing season, shoot density in the combined shoot/rhizome harvest treatment was 8 shoots/m², considerably lower than the 20 shoots/m² mean values for other treatments.

By mid-summer of 1986, shoot density in combined harvest treatment plots had recovered completely to 22 shoots/m², compared with an average of 18 shoots/m² for the annual cutting treatment and the control. The semi-annual cutting treatment had a shoot density of only 9 shoots/m². By October of 1986, average shoot density for control, annual, and combined treatments ranged from 20 to 22 shoots/m², while average shoot density was 5 shoots/m² in semi-annual harvested plots. Thus, it appears that semi-annual harvests greatly reduces stand regeneration, while stands recover in the second year after a 50% rhizome harvest.

The same method used to calculate average annual yield was used to determine average annual nutrient removal (Figure 2.2). A combined harvest resulted in the greatest removal of nitrogen, phosphorus, and potassium because of the additional nutrient-rich biomass harvested. The semiannual harvest had intermediate levels of nutrient removal despite very low yields. This resulted from the harvest of midseason tissue which has peak concentrations of nutrients prior to translocation (Garver et al. 1988). The annual harvest had the lowest nutrient removal primarily because of the low nutrient concentrations in the aboveground tissue following translocation in late summer.

Statistical analysis found no significant difference ($p=0.05$) in nutrient removal between any of the harvest treatments, although there are again some interesting qualitative differences in the ranking of yield and nutrient removal between treatments. The semi-annual treatment produces only 34% as much biomass as the combined treatment, yet removes 75% as much nitrogen, 66% as much phosphorus, and 85% as much potassium. The annual treatment produces 80% as much biomass as the combined treatment, and only removes 53% as much nitrogen, 52% as much phosphorus, and 56% as much potassium.

In 1985 and 1986, moisture content of shoot biomass was significantly higher for shoots harvested in July (78% moisture) than those harvested in October (65%). The only exception to this observation was semi-annual harvest treatments which had an average moisture content of 75% in October. This high fall moisture content in the semiannual harvest treatment can be explained by the relative immaturity of regenerated shoots which remained green until harvest.

In the experimental design, subplots were established using both machine and hand harvested methods to determine whether mechanical harvesting affects stand productivity. Results in 1985 showed a higher average shoot yield for machine harvested plots (8.4 Mg/ha) than hand harvested (5.3 Mg/ha). Results in 1986 showed the opposite response with an average machine harvested shoot yield of 2.4 Mg/ha vs. 3.7 Mg/ha in hand harvested plots. However, statistical analysis did not reveal any significant difference between shoot yields of machine and hand harvested subplots over the two years of the experiment.

An evaluation of experimental harvesting equipment described earlier showed that the shoot harvester was able to cut and collect 92% of the total aboveground biomass, although

some difficulty was encountered during July harvests with excess harvester weight under wet soil conditions. The rhizome harvester readily cut and lifted soil and rhizomes in strips as it was designed to do. It was not designed to provide mechanical separation of rhizomes from the soil and this step was accomplished using hand labor.

Cultivated Stand - Annual Aboveground Harvest.

An annual harvest of aboveground biomass resulted in significantly higher aboveground, belowground, and total yields than the unharvested control in 1986, three years after treatment application began (Table 2.1). With the exception of total density, 1986 was the first year that differences between treatments were significant. Rhizome biomass is also higher in the harvested treatment which may account for higher aboveground yields, since rhizome carbohydrate and nutrient reserves contribute to the sustainability and vigor of *Typha* stands.

The lower yields for unharvested plots may result from the previous season's litter cover insulating and shading new shoots in the spring which slows early season growth and appears to decrease shoot density. Observations of shoot regrowth in all three years of the experiment revealed that mean shoot density was about 30% less in control than harvested plots in the spring. This density difference remained, to a lesser extent, throughout the season in 1985 and 1986 (Table 2.1). Observations from previous studies have indicated that shoot density affects stand productivity (Pratt *et al.* 1985).

TABLE 2.1
PLANT CHARACTERISTICS AND STANDING CROP YIELDS
FOR ANNUALLY HARVESTED ABOVEGROUND *TYPHA* BIOMASS

<i>Year and Treatment</i>	<i>Total Density</i> (shoots/m ²)	<i>Flower Density</i> (shoots/m ²)	<i>Leaf Biomass</i> (Mg/ha)	<i>Rhizome Biomass</i> (Mg/ha)	<i>Total Biomass</i> (Mg/ha)
1986					
Harvested	61 **	31 *	9.5 **	15.4 *	24.9 **
Control	45	20	6.3	10.6	16.9
1985					
Harvested	72 **	17	10.2	—	—
Control	56	24	10.0	—	—
1984					
Harvested	67	8	11.9	13.3	25.2
Control	63	9	13.1	13.6	27.7
1983					
Pretreatment	90	11	10.3	13.5	23.8

(** significantly different at $p=.01$; * significantly different at $p=.05$)

The reason for the general decline in productivity, particularly in control plots, from 1984 to 1986 is unclear. It is possible that flowering, which began to appear in 1985 and was

quite extensive in 1986, may account for the decline since flowering can have a negative impact on yield, as discussed in Section 3.

Nutrient content of the plant tissue was also analyzed to explore possible reasons for the general decline in stand productivity, and also to see if differences existed between treatments. No significant difference occurred in nitrogen, phosphorus, or potassium concentrations between treatments for either leaf or rhizome plant tissue in 1986. Nutrient concentrations in 1986 remained the same or actually increased from values in 1984. These findings indicate that nutrients were not the cause of differences between treatments or reduced stand productivity.

Newly Cultivated Stand - Annual Leaf Harvest.

Patterns of aboveground biomass accumulation from stand establishment in 1985 through the end of the 1987 season (Figure 2.3) were similar to those observed in previous stand establishment experiments (Pratt *et al.* 1985). Low yield in the establishment season was followed by large yield increases in the next two seasons. In 1986, mean aboveground yield was 5.8 Mg/ha; in 1987 it was 11.6 Mg/ha. Aboveground biomass peaked in late September in 1986 and in August during 1987. In 1988, yield dropped to 1.4 Mg/ha because of an early (September 5) harvest date, early season mortality of portions of the stand possibly caused by high water levels, and high salinity levels (8 ms/cm) in the irrigation water.

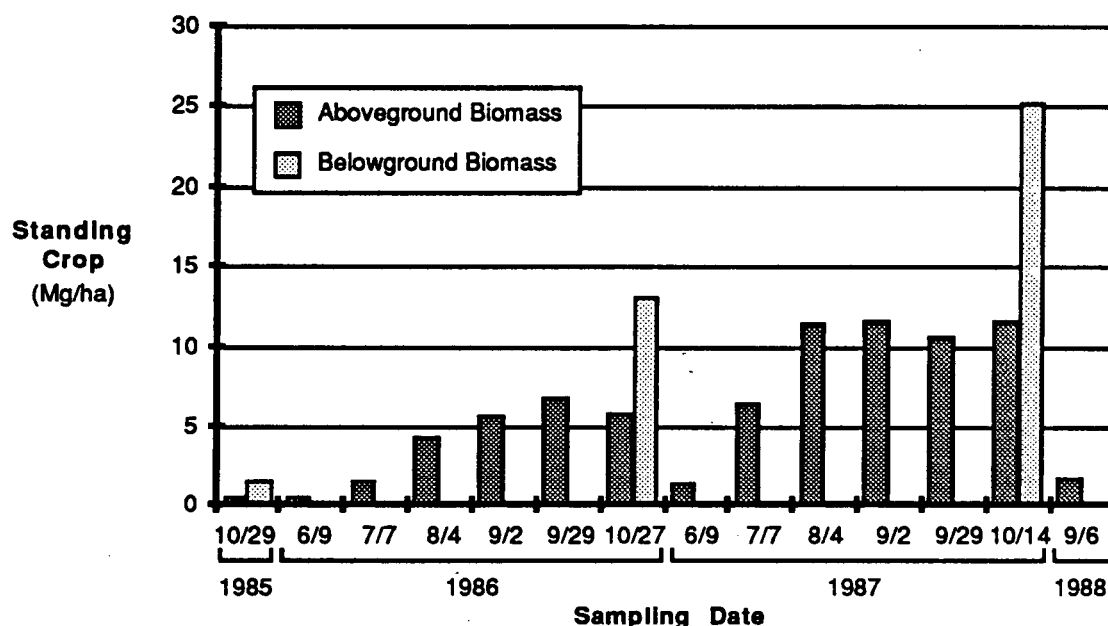


Figure 2.3 - Seasonal patterns in biomass standing crop yields for a cultivated *Typha angustifolia* stand established from seedlings in 1985. Annual mechanized harvests occurred following the 1986 and 1987 seasons.

The improvements in yield and normal patterns of aboveground biomass accumulation indicate that the annual harvests did not damage the stand directly. The mortality experienced in 1988 may be an indirect result of the harvest since cut shoots cannot tolerate

extended periods of submersion. Normally the aerenchyma tissue in the leaf litter provides a conduit for oxygen to the rhizomes which would make an unharvested field more tolerant to fluctuations in water level.

Belowground yields were 13.1 and 25.2 Mg/ha at the end of the 1986 and 1987 seasons, respectively. Aboveground to belowground biomass ratios were 0.44 and 0.46 in 1986 and 1987, respectively. These unusually high yields and aboveground to belowground biomass ratios are unexplained. Usual ratios are approximately one to one (Section 6). The high yields do indicate that stand viability is being maintained, and possibly enhanced, with annual aboveground harvests.

Harvesting equipment and times varied during the study. All harvesting was conducted on a saturated soil with no standing water. In 1986, harvesting was initiated in early November when the soil had frozen. A haybine (forage cutter and swather) operated satisfactorily for cutting and windrowing the *Typha* shoots. However, prior to baling, weather conditions changed which prevented completion of the harvest during the fall. The baling of windrowed *Typha* was completed on April 24, 1987, using a round baler. All equipment performed satisfactorily and the harvest was videotaped for future reference. *Typha* moisture content at the time was 13%. The equipment traffic on the field resulted in slightly uneven growth early the next season, but no apparent mortality. By late in the season, the stand appeared uniform.

A second mechanical harvest took place in late November, 1987. Windrowed biomass was chopped with a forage chopper and collected in a wagon. This equipment also performed satisfactorily, and the harvest was videotaped. *Typha* moisture content at the time was 43%.

Natural Stand - Annual and Semiannual Harvest.

A baseline measurement of harvestable winter biomass was taken at the time of first treatment application in January, 1985. Conditions at the time of harvest were an ice thickness ranging from 0-8 cm, water depth below the ice ranging from 0.3-1.2 m, and snow cover ranging from 0-0.3 m. Although partially lodged, most of the *Typha* aboveground biomass was above the snow and ice. Shoots were cut at the ice surface. Mean harvestable yield under these conditions was 8.6 Mg/ha; mean leaf moisture content was 56%, largely because of wet leaves at the ice interface.

Early spring flooding of the site caused oxygen deprivation in submerged cut shoot ends, resulting in significant differences in shoot regrowth between harvest and control plots. An average shoot density of 2 shoots/m² was observed in harvest plots and 15 shoots/m² in control plots in April, 1985. By the time of mid-season harvest treatment application in July, average shoot height in harvest plots was approximately half that of control plots, and average shoot densities were 24 shoots/m² for harvest plots and 30 shoots/m² for control plots. The first midseason cutting of the semiannual treatment occurred on July 15; mean harvestable yield was 1.2 Mg/ha and moisture content was 85%.

Plots were sampled in October, 1986, and again in January, 1987, so that productivity losses resulting from lodging and snow cover could be assessed. Mean shoot biomass in October for the three treatments was 4.4 Mg/ha for the annual harvest, 1.5 Mg/ha for the semiannual harvest (season total = 2.7 Mg/ha), and 6.0 Mg/ha for the control. The low yield for the annual treatment compared with the control was probably due to high water levels in the spring which flooded the cut ends of the shoot, resulting in significant *Typha* mortality. Mean shoot biomass in January was 3.2 Mg/ha for the annual harvest, 0.8 Mg/ha for the semiannual harvest (season total = 2.0 Mg/ha), and 6.7 Mg/ha for the control. Harvestable biomass was

therefore reduced between 0 and 45% by waiting until winter for the harvest. The larger reduction in the semiannual treatment may be due to more severe lodging resulting from the poor structural support provided by the relatively fewer and smaller shoots.

Analysis of variance found no significant difference ($p=0.05$) in seasonal yield between treatments in October. This lack of significance, despite large differences in mean values, resulted from high variability caused by poor stand uniformity. The January harvest did result in differences between annual and control treatments and semiannual and control treatments according to the Scheffe F-Test ($\alpha=0.05$). No significant difference was observed between annual and semiannual treatments at either sampling, even though mean values were much lower for the semiannual treatment.

In contrast to conditions present at the first winter sampling, the 1987 sampling occurred on frozen soil with a water table below the soil surface. There was no snow cover, ice, or water present to reduce harvestable biomass. This, in addition to the early season mortality from high water levels, limits conclusions which can be drawn because neither winter was typical in terms of temperature, snowfall, or water levels. The atypical winters do, however, point out the difficulties with using natural wetlands where water level and terrain cannot easily be modified.

Greenhouse Study - Timing of Semiannual Harvests

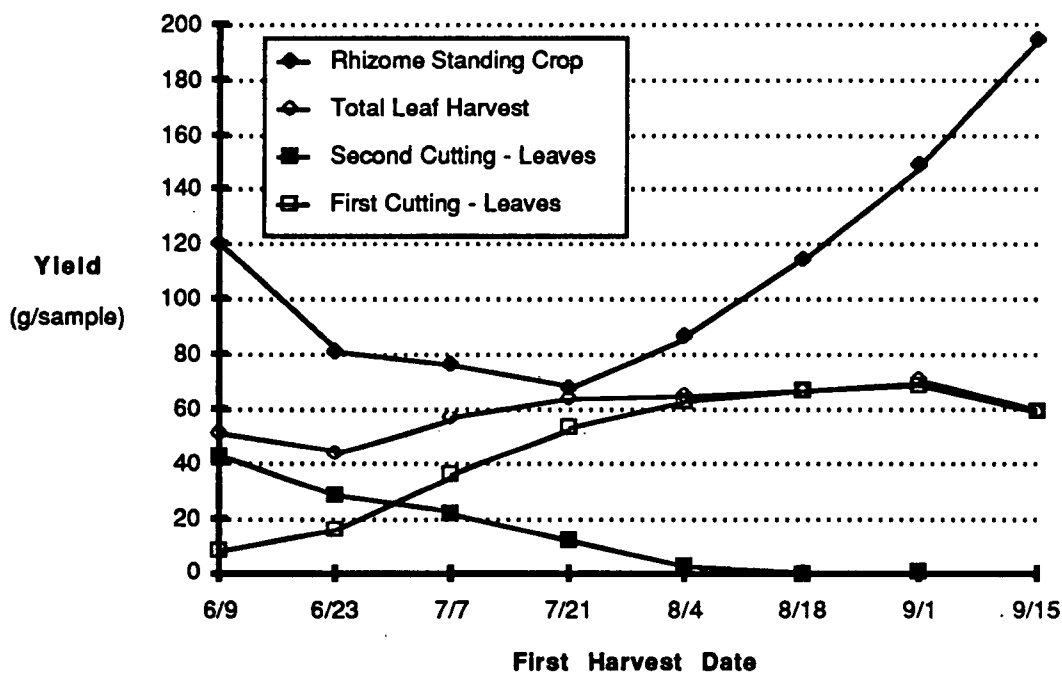


Figure 2.4 - The effect of time of first harvest on aboveground and belowground yields for a semiannual harvest scenario. Results are from a greenhouse study; the second harvest of leaves and the harvest of rhizomes occurred on September 15.

Aboveground yields from the first and second cutting dates were dependent on the time of midseason harvest (Figure 2.4). Prior to the end of June, the majority of biomass was removed

with the second cutting; after the end of June, the majority was removed with the first cutting. Total seasonal aboveground yield did not vary significantly (Waller-Duncan test) based on time of initial cutting with the exception of the June 21 and 23 dates which had the lowest yields. This indicates that no net seasonal yield advantage is achieved with a semi-annual harvesting scenario.

Shoot regrowth patterns did vary considerably based on date of initial cutting, despite the fact that it did not affect final seasonal leaf yield. Poor regrowth occurred any time after a mid-July harvest (Figure 2.4). Prior to that time nearly 100% of all cut shoots were observed to exhibit new growth; after that time only 13 to 23% of cut shoots regrew. Most of the regrowth for all dates resulted from growth from cut shoot bases, rather than from new shoots emerging from the soil.

Belowground rhizome biomass, an indicator of future stand vigor, was affected by timing of the mid-season harvest (Figure 2.4). End of season belowground standing crop was significantly less for first cutting dates between June 23 and August 4 than for other cutting dates according to the Waller-Duncan test. After August 4th, each subsequent cutting date resulted in significantly higher standing crop yields than the previous date, with peak yield occurring with the single harvest on September 15. This indicates that translocation of carbohydrates from leaves to rhizomes was impaired by the mid-season cuttings, and that the following season's shoot growth would probably be adversely affected.

TABLE 2.2
SEASONAL NUTRIENT REMOVAL FOR SEMIANNUAL HARVESTS
AS A FUNCTION OF MIDSUMMER HARVEST DATE: GREENHOUSE STUDY

<i>Midsummer Harvest Date</i>	<i>Mean Seasonal Leaf Nutrient Removal (g/sample)*</i>		
	<i>Nitrogen</i>	<i>Phosphorus</i>	<i>Potassium</i>
June 9	0.57 d	0.10 e	1.29 c
June 23	0.77 bc	0.13 cd	1.45 b
July 7	0.90 ab	0.16 ab	1.78 a
July 21	1.00 a	0.17 a	1.81 a
August 4	0.79 bc	0.14 bc	1.25 c
August 18	0.78 bc	0.12 d	1.32 bc
September 1	0.71 cd	0.10 e	0.99 d
September 15	0.34 e	0.05 f	0.67 e

*Means followed by a common letter are not significantly different using the Waller-Duncan multiple comparison test.

Nutrient removal was also affected by timing of the mid-season harvest (Table 2.2). Peak seasonal nitrogen, phosphorus, and potassium removal in leaf tissue occurred when the first cutting dates were July 7 and 21. The amounts of nutrients removed diminished with other midseason harvest dates, but were always significantly more than a single end of season harvest. Peak amounts were approximately three times higher than the lowest amounts

measured for the September 15th harvest date. Fertilization requirements would, therefore, likely be substantially higher with any semi-annual harvest scenario than with a single fall harvest. These results are only applicable to the first harvest season when all treatments began the season with equal nutrient and carbohydrate reserves. In subsequent seasons, if a semiannual harvest is sustainable, the removal amounts for each date would probably be affected by varying rhizome nutrient and carbohydrate reserves.

Cultivated Stand - Timing of Semiannual Harvests

Analysis of variance showed that total seasonal aboveground yield (Figure 2.5) did not vary significantly based on the time of initial cutting. Furthermore, aboveground yield from the single fall harvest on October 15 was not significantly different from total seasonal yield of any of the twice cut treatments, indicating, as in the greenhouse experiment, that no net seasonal yield advantage is achieved with a semi-annual harvesting scenario. Total seasonal leaf yield ranged from 10.1 Mg/ha for the June 9 cutting treatment to 12.2 Mg/ha for the August 4 cutting treatment.

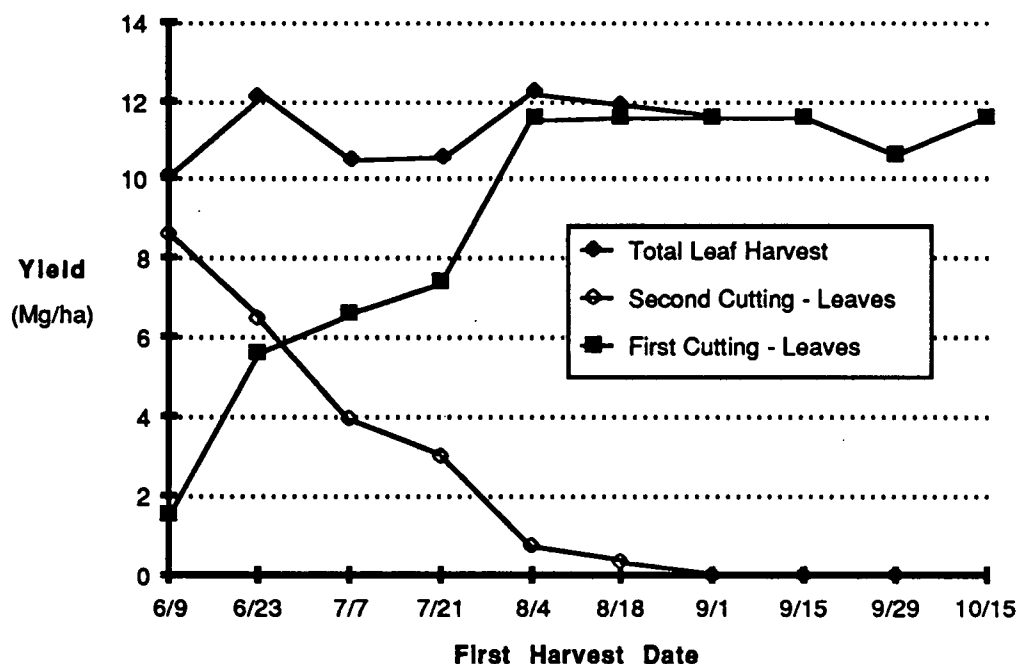


Figure 2.5 - The effect of time of first harvest on aboveground yields for a semiannual harvest scenario. Results are from a cultivated *Typha angustifolia* stand; the second harvest of leaves occurred on October 15.

Again, as in the greenhouse study, shoot regrowth patterns did vary considerably based on date of initial cutting, with poor shoot regrowth occurring any time after a mid-July harvest (Figure 2.5). Prior to that time, 74-100% of all cut shoots were observed to exhibit new growth; after that time only 14-34% of cut shoots regrew. Observation of regrowth patterns revealed that most regrowth for all dates resulted from growth from cut shoot bases rather than from new shoots emerging from the soil.

On September 2, 1988, all plots were sampled again to measure subsequent stand damage resulting from the various semiannual cutting treatments. Unfortunately, early season flooding of cut shoots resulted in significant mortality in one section of the field. Also, water used for irrigation had extremely high salt concentrations (conductivity was 8 ms/cm) which appeared to stunt plant growth. As a result, high variability in yields within treatments occurred and there was no significant difference in yield between treatments. Qualitatively, however, the plots exhibiting the highest mortality were from the July 21st through August 18th cutting treatments. Mean aboveground yield in this group was 0.3 Mg/ha compared with a mean yield of 1.3 Mg/ha in the September 1st to 29th group of treatments. Similarly, mean shoot density was 17/m² in the same midseason group compared with 76/m² in the end of season group. The density difference was significant according to the Waller/Duncan test. The above evidence, while not conclusive, indicates that midseason harvests are not sustainable and can result in serious damage to a *Typha* stand.

Seasonal nutrient removal was another factor affected by the timing of the mid-season harvest (Table 2.3). Both this field experiment and the greenhouse experiment showed the same trend, with total seasonal nutrient removal at a low level for the earliest cutting date, rising to the highest level with cutting dates between late June and the end of August, and falling to the lowest level with the single fall harvest date. This trend and the relative amount of nutrients removed only holds true for the first harvest season. The disruption of normal nutrient accumulation and partitioning caused by midseason harvests and the question of sustainability limits extrapolation of these results to subsequent seasons.

TABLE 2.3
SEASONAL NUTRIENT REMOVAL FOR SEMIANNUAL HARVESTS
AS A FUNCTION OF MIDSUMMER HARVEST DATE: FIELD STUDY

<i>Midsummer Harvest Date</i>	<i>Mean Seasonal Leaf Nutrient Removal (g/m²)*</i>		
	<i>Nitrogen</i>	<i>Phosphorus</i>	<i>Potassium</i>
June 9	12.6 b	1.2 cd	16.3 bc
June 23	18.8 a	2.3 ab	24.1 ab
July 7	19.0 a	2.2 ab	24.0 ab
July 21	18.1 a	2.2 ab	22.1 abc
August 4	21.0 a	2.5 a	26.3 a
August 18	19.9 a	2.3 ab	26.0 a
September 1	17.5 a	1.8 bc	20.9 abc
September 15	11.7 b	1.4 cd	17.7 abc
September 29	10.9 b	1.3 cd	15.1 bc
October 15	9.9 b	0.8 d	13.9 c

*Means followed by a common letter are not different according to the Waller-Duncan multiple comparison procedure.

DISCUSSION AND CONCLUSIONS

Average annual yield, sustainability, and biomass product quality are all affected by each harvest scenario. Potential costs based on such factors as nutrient removal, number of harvest passes required, and equipment development requirements will also vary for each scenario. The goal in selecting a harvesting system is to achieve the highest quantity and quality of biomass product at the minimum cost.

The collective results from experiments described above provide the information needed to assess each harvesting scenario and select the one which best meets the overall goal of this study. Although problems inherent to field studies limit conclusions which can be drawn from some individual experiments, there do not appear to be inconsistencies between experiments which would preclude drawing the following general conclusions.

Annual Aboveground Harvest

At the present time, an annual aboveground harvest appears to be the preferred harvesting scenario for *Typha* species. Across all experiments, the annual harvest did the best job of maximizing yield while minimizing cost. Average annual yield was only 20% less than the combined aboveground and 50% belowground harvest and 43-61% more than the semi-annual harvest treatment. Additionally, all experiments indicate that an annual aboveground harvest has no adverse effect on yield and may actually enhance yield over unharvested stands. This would suggest that the annual scenario is sustainable over the long term.

Cost minimization is achieved in several ways. Nutrient removal was shown to be less with the annual cutting than with the other two harvest options, indicating that long term fertilization costs would be minimized. Harvesting costs would also be less with the annual shoot harvest option since only one harvest pass is required per year, compared to two per year for the semi-annual treatment and 3 every 2 years for the combined aboveground and belowground harvest scenario. Additionally, an annual fall or winter shoot harvest can be accomplished using standard forage harvesting equipment, as demonstrated in these experiments, while rhizome harvesting will certainly require special equipment development. Midseason semiannual biomass harvesting may pose equipment problems due to wet soil conditions.

Biomass moisture content is an important consideration for transportation, storage, and conversion costs. An annual fall or winter harvest results in the driest biomass product. Aboveground biomass moisture content ranged from 43-63% for fall harvested material and from 13-56% for winter harvested material. By contrast, moisture content of midseason harvested tissue was between 78 and 85%.

The biomass product obtained with an annual aboveground harvest is predominantly cellulose and hemicellulose with an ash content less than 5% (Glass, 1980). The energy content of aboveground *Typha* biomass is between 17.6 and 18.9 MJ/kg (7600-8130 BTU/lb) (Pratt *et al.*, 1985). These characteristics are similar to other plant biomass fuel candidates and pose no special handling or conversion problems. The disadvantage of the annual harvest scenario, aside from a slight reduction in yield from a combined harvest, is that the more valuable starch and sugar containing rhizomes are not utilized. However, with current ill-defined energy conversion preferences for raw materials, there does not seem to be a high enough demand for starch and sugar products to warrant the expense of rhizome harvesting.

The only harvesting related problem encountered, which also occurred with the other scenarios, is the potential to damage stands by flooding the cut shoot bases. This deprives the

rhizome system of oxygen and can result in plant mortality. Water level management, especially during the winter and spring, is a necessity.

Semiannual Aboveground Harvest

The semi-annual aboveground harvest does not appear to be a viable harvest option for *Typha* grown in northern latitudes. Semiannual harvest yields were 43-61% less than for the annual harvest option, with a trend toward diminishing yields in subsequent seasons. In addition, semiannual treatment plots showed poor shoot regrowth following a full harvest cycle, indicating that midseason harvest is detrimental to stand vigor and long term sustainability. Furthermore, no yield advantage was gained by adjusting the midseason cutting date, and all midseason harvests resulted in a significant decrease in rhizome biomass production.

In addition to reduced yields and doubtful sustainability, costs associated with the semi-annual harvest scenario would be higher than for an annual harvest. Nutrient removal is significantly higher, particularly from the midseason harvest when nutrient concentrations are highest in the aboveground plant tissue and lowest in the rhizomes. By waiting until fall for a harvest, a majority of these nutrients will be translocated to the belowground rhizome system and preserved for the following season (Garver *et. al*, 1988). The need for an additional harvest pass, and possibly additional draining and reflooding of the paddy, would also increase expenses. Finally, the harvested shoot biomass would have a higher moisture content, increasing costs of drying and transportation.

Wastewater treatment is one situation where a semiannual harvest may be preferred in order to remove the greatest amount of nutrients or contaminants. However, our results indicate that this cannot be done on a continuing basis in northern latitudes without seriously damaging the stand and therefore is not recommended.

Combined Annual Aboveground and Semiannual Belowground Harvest

The combined harvest scenario may be of interest because it includes the harvest of belowground rhizome biomass which has different chemical characteristics than the aboveground leaf biomass. *Typha* rhizomes consist of approximately 40% starch and sugars at the end of the growing season (Glass, 1980) which may be of higher value than cellulosic biomass if fermentation is used for energy conversion. The harvest studies conducted indicate that the combined harvest scenario is a viable option if there is a particular need for the rhizome biomass.

Although a 50% rhizome harvest does appear to depress shoot yield in the subsequent growing season, rhizome standing crop recovers to unharvested levels by the end of the season. Shoot yield fully recovers by the end of the second growing season after rhizome harvest. These results indicate that the combined harvest scenario is not detrimental to stand regeneration and would be sustainable through time. This conclusion is based on a 50% rhizome strip harvest which would likely result in quicker stand regeneration than a higher percentage harvest.

The average annual yield for the combined harvest scenario (shoot and rhizome biomass) was slightly higher than average annual yield for the annual harvest treatment and substantially higher than the semiannual treatment. However, 70% of the average yield for the combined harvest was in the form of aboveground biomass. The low amount of rhizome biomass obtained with a 50% harvest biennially makes questionable the value of harvesting rhizomes, especially in light of the technical difficulties and expense encountered in harvesting operations. A higher percentage harvest undertaken annually may increase

rhizome production initially, but risks weakening the stand and will likely lower aboveground biomass yields.

Although yield and sustainability of the combined harvest trial indicate that it is biologically viable, increased costs associated with this scenario would probably outweigh the yield advantage over the annual shoot harvest. The average annual yield of the combined treatment was 20% more than the annual shoot harvest treatment, but nutrient removal was 52-56% more, indicating that greater fertilization would be required for the combined harvest. Special equipment would need to be developed for successful commercial rhizome harvesting operations, raising the cost of combined harvest considerably over the annual harvest scenario. These increased costs could only be justifiable if the value of the rhizome biomass as a feedstock were considerably more than the shoot biomass.

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SECTION 3

WATER USE EFFICIENCY

INTRODUCTION

Evaluation of the commercial potential of *Typha* plants as an energy resource depends on an understanding of the tradeoffs between productivity and production costs. With this understanding, a *Typha* bio-energy production system can be developed that maximizes output while minimizing inputs, resulting in a renewable energy resource that is economically competitive. An important tradeoff is that between productivity and water management costs since this will determine suitable biomass production sites, potential irrigation costs, and workable machinery configurations.

Although wetlands, with water tables at or near the soil surface, will generally be used for *Typha* bio-energy production, it is possible that irrigation will be required to maintain an equilibrium balance of water inputs to water losses. If irrigation is required, sites will need to be located near streams or other water bodies, dikes will need to be constructed, and annual irrigation costs will be incurred. Irrigation requirements and water control methods will also potentially have an effect on nutrient status through their effects on percolation, runoff, and degree of soil aeration.

Evapotranspiration rates reported for *Typha* spp. range from 100 to 300 cm per growing season (Bernatowicz *et al.*, 1976; Bray, 1962; Krolikowska, 1978; Mehta and Sharma, 1976). By comparison, evapotranspiration rates for corn (*Zea mays*) and alfalfa (*Medicago* spp.) grown in Minnesota are 46-71 cm and 43-66 cm, respectively. Additionally, reported evapotranspiration rates for *Typha* are substantially greater than the 51-79 cm annual precipitation range in Minnesota. This gap between water inputs and potential outputs would severely limit the potential of *Typha* as a bio-energy crop. Because of different climatological sites used in previous studies and questions raised about methodology, additional studies of *Typha* water loss were deemed necessary.

Another aspect of the water use question concerns productivity. Grace and Wetzel (1982) reported that deep water flooding resulted in greater allocation of biomass to leaves and less to rhizomes in both *Typha latifolia* and *Typha angustifolia*. Grace and Wetzel (1981) also reported that *Typha latifolia* plants growing on a mudflat began to senesce during August, but the same species growing in a deep water habitat continued to increase in biomass during the same period. Van der Valk and Davis (1980) similarly reported a decrease in the yield of a *Typha x glauca* stand during seasons which had a mid-summer drawdown as opposed to seasons in which the marsh was continually flooded.

Assuming that water management will be required, it will be important to develop regimes which both minimize evaporative losses and minimize negative effects on productivity. This section examines several possible water management regimes and their effect on productivity, evapotranspiration, and water use efficiency.

MATERIALS AND METHODS

Three different experimental approaches were employed to overcome limitations inherent in each individual approach. A closely controlled environment utilizing physically isolated plants and water inputs and outputs was needed for comparing seasonal water loss between species and irrigation treatments. The first approach, using individual containers for each replicate of each treatment, accomplished the goal of a controlled environment, but had the disadvantage of not closely approximating the microclimate normally encountered in a large contiguous stand. Since Bernatowicz *et al.* (1976) cautioned that differences in microclimate between paddies set up in a terrestrial environment and a natural wetland can cause large differences in evapotranspiration, additional approaches were used.

A natural stand experiment was included to examine *Typha* water use in an environment likely to be encountered in a managed biomass production system. Since a natural system is not a closed system, the initial approach to this study was to develop direct measurement techniques (e.g. porometers) for transpiration which would be used to estimate aggregate seasonal water use. Because of problems related to leaf shape and aerenchyma tissue, this approach proved infeasible as it had for other researchers (McNaughton and Fullem, 1970). An alternative approach using individual containers set in a natural stand was employed instead.

Finally, to provide information on *Typha* water use in an actual managed stand of *Typha*, a site was selected where water inputs and outputs were controllable. The relatively large site minimized microclimatic influences, and the uniform stand minimized edge effects encountered in the containerized experiments. A detailed description of the three experiments follows.

General Methods - All Experiments

Sampling consisted of cutting all leaves and flowering shoots at 15 cm above the soil surface level. This was done to provide a more realistic estimate of harvestable yield since harvesters are generally incapable of harvesting at soil level. Leaving a 15 cm stubble also lessens the risk of mortality from variable or fluctuating water levels covering the cut shoot bases and depriving plants of oxygen. Previous unpublished results have found that the lower 15 cm of aboveground biomass accounts for 15-20% of total aboveground biomass. The lower 15 cm portion was included with rhizome samples to more accurately reflect the harvested belowground biomass product. Rhizomes were excavated by hand to a depth required to remove all rhizomes (generally 30 cm). Rhizomes were washed thoroughly by hand or with a rotary tumbler, and intact root biomass was included with the rhizome sample. Samples were kept in cold storage until further processing.

All samples were dried to constant weight in a 65° C oven (ASAE, 1980), and then weighed to determine biomass yield. In preparation for nutrient analysis, tissue was ground to pass through a 2 mm screen in a Wiley Mill. Total nitrogen was determined using a micro-Kjeldahl digestion technique followed by distillation and titration (Bremner, 1965). An extract was prepared for phosphorus and potassium analysis by dry ashing tissue at 500° C for 12 hours and extracting with 2N HCl. Phosphorus concentration was determined by spectrophotometry at 882 nm using an ascorbic acid/molybdate-blue assay (John, 1970). Potassium concentration was determined by atomic absorption spectroscopy at 766 nm using a Buck Scientific model 200 AA/emission spectrophotometer (Van Loon, 1980). Nitrogen, phosphorus, and potassium standing crop values were calculated for each sample by multiplying nutrient concentration by sample dry weight.

Species and Water Management Comparison - Container Experiment

The first experiment was a 3x3 factorial design with four replicates of each treatment. *Typha* species (*T. angustifolia* L.; *T. latifolia* L.; *T. x glauca* Godr.) and water management practices (constant flooding: water level +15 cm above soil level; saturated soil: +0 cm; and midseason drawdown: +15 cm to -30 cm on August 1) were the treatment factors. Two growing seasons were monitored to obtain results from both establishment season plants and established plants with fully developed rhizome systems, and to reduce variability resulting from seasonal weather variability.

Typha rhizomes were planted at a density of 9/m² into thirty-six, 89 cm diameter, plastic containers filled with a fertilized (150-150-150 kg/ha N-P-K, 70 kg/ha Peter's fritted trace elements, and 20 kg/ha CuSO₄) organic soil (ash content 60%). Water level was adjusted to treatment levels and monitoring begun when shoots reached 15 cm in height. An overwinter survival problem occurred between the two seasons which resulted in the replanting of the experiment in 1986. The ability to monitor established plants was lost when the *Typha* rhizomes failed to survive the winter in exposed, above grade plastic containers. Thus, results for both years are from establishment season plants.

Evapotranspiration was estimated by measuring the amount of water added each day by irrigation and rainfall. Evaporation under the various treatment conditions was estimated by measuring water inputs required to maintain the different water levels in paddies without plants. Transpiration was then calculated as the difference between evapotranspiration and evaporation. The season measured was 16 weeks long – from June 9 to September 29.

At the end of each season, all shoots were cut at 15 cm above soil surface, dried, and weighed to determine harvestable leaf yield of the different species under various water regimes. Following the second (1986) season, rhizomes were also sampled, washed, dried and weighed to determine total plant productivity. These figures were used to calculate efficiency of water use. Plant nitrogen analysis was conducted to determine the effect of water management on nutrient uptake.

Evapotranspiration in Natural Stands - Container Experiment

The second experiment using only *Typha x glauca* rhizomes was planted on May 12, 1986, at a density of 9/m² into four, 89 cm diameter, waterproof containers filled with the same soil used in the previous study. The rhizomes were obtained from a productive natural stand located 10 miles north of St. Paul, which was also the site of the study. The containers were placed within the natural stand. Once shoots emerged, water was adjusted to a level of 15cm and maintained by watering. Evapotranspiration, evaporation, and transpiration were determined in the same manner as the previous study. The season measured was 15 weeks long – from June 9 to September 22.

At the end of the season, all shoots were cut at 15 cm above soil surface, dried, and weighed to determine harvestable aboveground biomass production and calculate water use efficiency.

Evapotranspiration in Cultivated Paddies - Field Experiment

The third experiment used a 0.2 ha stand of *Typha angustifolia* established in June, 1985, by transplanting seedlings at a density of 10/m² on a site provided by the American Crystal Sugar Company in Crookston (northwestern), Minnesota. The site has a double expanding clay subsoil, which virtually eliminated water loss through percolation. All water

added to the stand was metered, and precipitation and pan evaporation data were gathered at the site. Evapotranspiration was estimated by measuring the amount of water added each day by irrigation and rainfall and assuming that percolation did not occur. Evaporation under the various treatment conditions was estimated by measuring water inputs to evaporation pans. Transpiration was then calculated as the difference between evapotranspiration and evaporation.

Two growing seasons were monitored: the first was 16 weeks long from June 27 to October 10; the second was 20 weeks long from May 18 to October 2. Microclimatic factors and *Typha* growth patterns were also monitored throughout the season. Nine, one square meter plots were sampled in October, 1986, to estimate biomass production in the stand and calculate water use efficiency. Four, one square meter plots were sampled for the same reason on October 14, 1987. Sample number differed in the two years because biomass sampling was primarily related to two different harvesting studies (Section 2) and secondarily used for yield estimates in this experiment.

RESULTS

Species and Water Management Comparison - Container Experiment

Over the two seasons studied, significant ($p=0.01$) differences in transpiration, evapotranspiration, biomass yield, and water use efficiency were observed between species. *Typha angustifolia* used less water through transpiration and evapotranspiration than either *T. latifolia* or *T. x glauca* (Table 3.1). However, *T. angustifolia* also had the lowest aboveground biomass yield which might account for lower water use since yield and transpiration are both functions of leaf surface area.

TABLE 3.1
MEAN SEASONAL WATER USE COMPARISON BETWEEN THREE *TYPHA* SPECIES

	Transpiration	Evapo- Transpiration	Aboveground Dry Weight	Water Use Efficiency (aboveground biomass basis)	
	l/container	l/container	g/container	g/l transpired	g/l evapotranspired
<i>T. angustifolia</i>	335 b	601 b	459 c	1.39 a	0.76 b
<i>T. latifolia</i>	439 a	705 a	600 a	1.38 a	0.85 a
<i>T. x glauca</i>	408 a	674 a	525 b	1.29 b	0.78 b

Means followed by a common letter are not significantly different at $\alpha=0.05$ according to the Scheffe test.

Yield and yield rankings among species would be expected to vary with field conditions, climate, and stand management practices (Dubbe *et al.*, 1989). Because of this and the relationship between yield and water use, transpiration or evapotranspiration measurements by themselves are highly variable and imprecise measures of differences between species. To overcome this problem, the water use efficiency of each species can be determined by calculating of the amount of biomass produced per unit of water lost. Using transpiration as the unit of water loss gives a biological water use efficiency of each species. In this study, *T. angustifolia* and *T. latifolia* were significantly more efficient than the hybrid, *T. x glauca* (Table 3.1).

Using evapotranspiration as a unit of water loss in the efficiency calculation provides an overall production system efficiency which is important for determining irrigation requirements. The evaporation component of evapotranspiration is a function of the physical environment and microclimate rather than the biological nature of the stand. However, since the physical environment and microclimate are influenced to some extent by stand characteristics, evaporation may not be a constant between species. This appears to be the case, since the species rankings for water use efficiency is different when calculated on an evapotranspiration basis (Table 3.1). *T. latifolia* remains the most efficient species, while *T. angustifolia* becomes significantly less efficient. *T. x glauca* is in the less efficient group using either water use basis. Although differences between species in water use efficiency are significant, they are relatively small. The most efficient species is only 8-12% more efficient than the least efficient species using either water loss basis.

If rhizomes are harvested in addition to aboveground biomass (see Section 2), total plant productivity (above- and belowground biomass) should be used to figure water use efficiency. When this is done using transpiration to determine biological water use efficiency, *Typha angustifolia* is significantly more efficient at 5.27 g/l than the other two species according to the Scheffe test ($\alpha=0.05$). *T. latifolia* (4.38 g/l) and *T. x glauca* (4.76 g/l) are not different from each other. When efficiency is calculated on a evapotranspiration basis, there is no difference between species, and the mean efficiency is 3.05 g/l.

Using an average aboveground yield figure for all species of 528 g/container and a container surface area of 0.62 m², the range of water use efficiencies would result in total seasonal evapotranspiration between 99.8 and 111.7 cm. This range is comparable to amounts reported in the literature (Bernatowicz *et al.*, 1976; Bray, 1962; Krolikowska, 1978; Mehta and Sharma, 1976). It also is higher than annual precipitation in Minnesota which is 51-79 cm and does not account for additional losses which would occur from percolation in a field setting. Additionally, the yield figure on an area basis is 8.5 Mg/ha, which is on the low end of expected yields (Dubbe *et al.*, 1989), so actual water use could be substantially higher in more productive *Typha* stands. However, these results should be interpreted carefully since they are from individual containers in a terrestrial environment where higher winds, edge effects, and lower humidity levels would be expected to increase water usage over that in a natural or cultivated stand.

Water management treatment had a significant effect on transpiration, evapotranspiration, and aboveground biomass yield (Table 3.2). Continuous flooding during the growing season resulted in the highest transpiration, evapotranspiration, and yield. Water management scenarios incorporating a midseason drawdown or a constantly saturated soil were not significantly different from each other. Mean transpiration and evapotranspiration rates for the drawdown and saturated treatments were 12% below those for flooded treatments and yields were reduced 15%. The near equivalence in water use and aboveground yield reduction resulted in no differences in water use efficiencies between treatments. This holds true whether calculated on a transpiration or evapotranspiration basis.

TABLE 3.2
MEAN SEASONAL WATER USE COMPARISON
BETWEEN THREE WATER MANAGEMENT SCENARIOS

	<i>Transpiration</i>	<i>Evapo- Transpiration</i>	<i>Aboveground Dry Weight</i>	<i>Water Use Efficiency (aboveground biomass basis)</i>	
	<i>l/container</i>	<i>l/container</i>	<i>g/container</i>	<i>g/l transpired</i>	<i>g/l evapotranspired</i>
Flooded	429 a	716 a	585 a	1.38 a	0.82 a
Saturated	394 ab	648 b	513 b	1.36 a	0.79 a
Draw Down	360 b	617 b	487 b	1.31 a	0.79 a

Means followed by a common letter are not significantly different at $\alpha=0.05$ according to the Scheffe test.

Although the continuously flooded treatment resulted in significantly higher aboveground yield, it did not affect belowground or total biomass yield (Table 3.3). For the flooded treatment, 31% of the total biomass was aboveground, while 26 and 27% was aboveground for the saturated and draw down treatments, respectively. This finding generally supports previous findings that deep water flooding results in greater allocation of biomass to leaves and less to rhizomes (Grace and Wetzel, 1982).

TABLE 3.3
MEAN SEASONAL YIELD AND WATER USE COMPARISON
BETWEEN THREE WATER MANAGEMENT SCENARIOS*

	<i>Aboveground Dry Weight</i>	<i>Belowground Dry Weight</i>	<i>Total Dry Weight</i>	<i>Water Use Efficiency (total biomass basis)</i>	
	<i>g/container</i>	<i>g/container</i>	<i>g/container</i>	<i>g/l transpired</i>	<i>g/l evapotranspired</i>
Flooded	610 a	1,376 a	1,986 a	4.36 b	2.90 b
Saturated	519 b	1,515 a	2,034 a	5.22 a	3.17 a
Draw Down	498 b	1,365 a	1,863 a	4.84 a	3.09 ab

**Results are from 1986 season which was the only season with belowground sampling.*

Means followed by a common letter are not significantly different at $\alpha=0.05$ according to the Scheffe test.

Unlike water use efficiencies based on aboveground yields, those based on total plant yield did vary with water management treatment (Table 3.3). Transpiration efficiency was highest for the saturated and drawdown treatments and lowest for the flooded treatment. Evapotranspiration efficiency was highest for the saturated treatment and lowest for the flooded treatment. Since total biomass yields were not different between treatments and efficiencies were, these results suggest that a saturated or draw down water management regime would be preferred for a combined harvest system that utilizes the whole plant (see Section 2).

Water management systems can affect nitrogen availability and losses through their effect on soil aeration. The degree of aeration determines denitrification and organic soil decomposition and nitrification rates. Biomass samples were analyzed to determine if water management had an effect on nitrogen availability. Nitrogen concentration and nitrogen standing crop were used as indicators of nitrogen availability. At the end of the season, aboveground nitrogen concentration averaged 0.75% and analysis of variance found no significant difference between treatments (Table 3.4). By contrast, belowground concentrations were significantly different ($p=0.05$) between treatments with the flooded treatment having the lowest nitrogen concentration.

TABLE 3.4
NITROGEN CONCENTRATION AND STANDING CROP COMPARISONS
BETWEEN THREE WATER MANAGEMENT SCENARIOS

	Aboveground Percent N*	Belowground Percent N*	Aboveground N Standing Crop*	Belowground N Standing Crop*	Total N Standing Crop*
			g/container	g/container	g/container
Flooded	0.78 a	1.14 b	4.4 a	15.7 b	20.6 a
Saturated	0.73 a	1.23 ab	3.7 b	18.6 a	22.5 a
Drawdown	0.75 a	1.35 a	3.6 b	18.5 a	21.8 a

* Belowground and total results are from the second season; aboveground values are from both seasons.
Means followed by a common letter are not significantly different at $\alpha=0.05$ according to the Scheffe test.

Because concentration does not necessarily reflect total nutrient uptake, nitrogen standing crop was also determined to measure total nitrogen assimilation. Both aboveground and belowground samples showed significant differences between treatments in nitrogen standing crop (Table 3.4). For aboveground samples, the flooded treatment had the highest nitrogen standing crop, while for the belowground samples, the flooded treatment had the lowest standing crop. There was no difference between saturated or drawdown treatments. When total plant nitrogen standing crop was calculated, there was no difference between treatments. It appears, therefore, that water management may affect nitrogen translocation within the plant, but not availability to the plant.

For all factors considered, there was no significant interaction between species and water management treatment. This indicates that all species responded similarly to each water management treatment, so there would be no advantage of using one species over another for a particular water management system. It also indicates that for an established cultivated or natural stand of a particular species, the selection of water management systems can be made independently of the species present.

Evapotranspiration in Natural Stands - Container Experiment

At the end of 15 weeks, mean cumulative evaporation was 176 l/container, transpiration was 98 l/container, and evapotranspiration was 274 l/container. Converting these units into rainfall or irrigation equivalents results in evaporation, transpiration, and evapotranspiration amounts of 28, 16, and 44 cm, respectively. These figures compare with evaporation, transpiration, and evapotranspiration amounts of 287, 429, and 716 l/container (or 46, 69, and 115 cm), respectively, for the comparable flooded treatment in the previously described container experiment (Table 3.2). Evapotranspiration of *Typha* plants growing within a natural stand was thus only 38% of that of plants growing in an exposed upland environment. Most of this reduction was attributable to a decrease in transpiration, although evaporation was 39% lower in the natural stand. The low transpiration amount was likely caused by the low productivity in these paddies. Mean aboveground biomass yield was 2.9 Mg/ha.

To account for differences in productivity, water use efficiencies were calculated. Overall efficiency was calculated to be 1.06 grams of aboveground biomass produced per liter of water evapotranspired – 30% more efficient than the upland paddies described previously (Table 3.2). When considering the transpiration or biological efficiency (grams aboveground biomass/liter transpired), the efficiency of the natural stand plants was 2.97 compared with 1.38 in the continuously flooded upland paddies. Thus, it appears that microclimatic conditions have a rather dramatic effect on water loss from *Typha* stands.

Evapotranspiration in a Cultivated Paddy - Field Experiment

This experiment provided the opportunity to examine water loss in a situation analogous to that which would be encountered in a cultivated commercial stand of *Typha*. Water use was monitored for the entire 0.2 ha paddy over the course of two growing seasons (Table 3.5). Although transpiration, evapotranspiration, and yield varied substantially between the two growing seasons, water use efficiency was relatively constant. The 56% increase in aboveground yield in 1987 resulted in a 45% increase in transpiration, demonstrating the close relationship between leaf biomass and transpiration observed in previously described container experiments. The consistency of water use efficiency figures over a range of productivities also increases their predictive value for estimating irrigation requirements.

Water use efficiencies under field conditions (Table 3.5) were substantially higher than those observed in the individual containers in an upland setting described previously (Tables 3.1 and 3.2). The microclimate determined by plant canopy characteristics appears to affect both transpiration and evaporation used to calculate efficiencies. Transpiration in 1986 for the field study was only 42% of that observed in the upland container study even though yields were approximately the same. Evaporation in 1986 for the field study was only 48% of that observed in the upland container study. Some of these differences may be explained by macroclimatic conditions since the two studies were conducted in different parts of the state, but the effect of macroclimate is considered minimal since the mean temperature difference during the growing season between locations is a relatively small 2.4° C (Baker *et al.*, 1985) and the reduced evaporative demand of the cooler northern field site was offset by a 22% higher

average wind speed for that section of the state (Baker, 1983). As further evidence for microclimatic effects, seasonal pan evaporation measured within the stand was 65% of that measured near the stand.

TABLE 3.5
MEAN SEASONAL WATER USE COMPARISON OVER 2 GROWING SEASONS

	Transpiration	Evapo- Transpiration	Aboveground Dry Weight	Water Use Efficiency	
	cm	cm	Mg/ha	g/l transpired	g/l evapotranspired
1986	29	51	6.8	2.34	1.33
1987	42	71	10.6	2.52	1.49

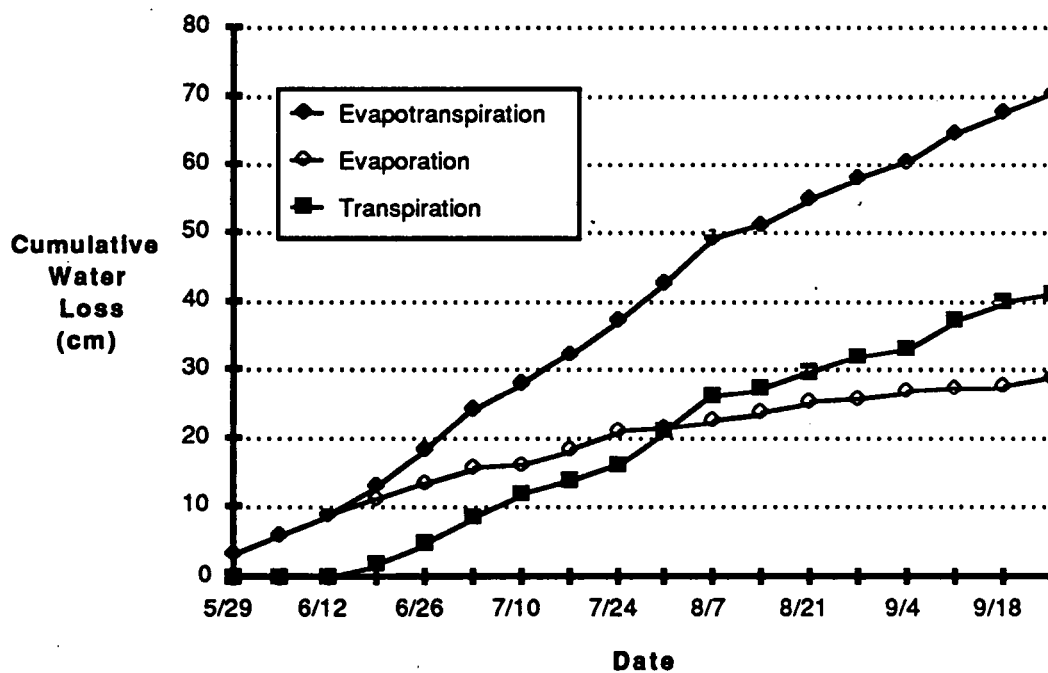


Figure 3.1 Cumulative water loss from a 0.2 ha cultivated stand of *Typha angustifolia* during the 1987 growing season. Measurement interval is weekly.

Water use was calculated at weekly intervals to identify periods of high evaporative demand. Cumulative evaporation, transpiration, and evapotranspiration for the 1987 season was plotted by week (Fig 3.1); the slope of the curves represents the rate of water loss. Through the end of July, evaporation accounted for the majority of water loss since the leaf canopy is still developing during this time. Beginning in August, transpiration was the major source of water loss as the leaf canopy reached maximum development and shielded the water surface from direct solar radiation and wind. The difference in timing of peak transpiration and peak evaporation resulted in a fairly constant rate of water loss throughout the season. Similar results were observed during the 1986 growing season. There would be, therefore, no peak demand period for irrigation, assuming that rainfall occurs uniformly throughout the season.

One caveat to this experiment is the assumption that percolation of water into the subsoil was negligible. If this was true, as anticipated by the selection of the site for its double expanding clay soil, then water loss may be higher at other sites with more permeable soils. If the assumption was false and significant percolation occurred, then evapotranspiration and transpiration would be even lower than that reported (evapotranspiration measurements actually measured total water loss from all outlets; evaporation was measured separately from irrigation pans; transpiration was calculated as the difference between evapotranspiration and evaporation).

DISCUSSION AND CONCLUSIONS

Species selection, water management choices, biomass yields, and microclimate all were found to significantly affect water losses from and, hence, water requirements for a *Typha* bio-energy production system. In the case of species selection, *Typha latifolia* was slightly more efficient in terms of biomass produced per unit of total water lost than either *T. angustifolia* or *T. x glauca*. However, previous studies have shown that *T. latifolia* is generally less productive than the other two species under field conditions (Dubbe, *et al.*, 1989). Selecting *T. latifolia* on the basis of water use efficiency would, therefore, sacrifice yield potential in the attempt to minimize irrigation requirements. This would only be advisable if output considerations were secondary to input considerations, as might be the case in situations where irrigation will definitely be required, expensive, and/or infeasible. In most wetland situations, natural water inflows exceed outflows and little, if any, irrigation would be required. Under these conditions, optimization of yield should be the determinant of species selection.

Water management options were examined not only to see if water use could be minimized, but also to see if soil moisture conditions conducive to operation of conventional farm harvesting equipment could be achieved without a sacrifice in biomass yield. A continuously flooded field limits equipment traction, requires extra flotation, and results in a biomass product with a higher moisture content (Pratt *et al.*, 1982). It is advantageous to be able to draw down the water table to below the soil surface approximately one month prior to a harvest.

In this study, a midseason drawdown reduced water loss compared with a continuously flooded regime, but it also reduced yield. The net result was an identical water use efficiency for flooded and drawdown regimes. Again, the tradeoffs between inputs and outputs needs to be weighed before a recommendation can be made. At present, equipment considerations are probably more important than achieving maximum yields, so a drawdown water management regime is preferable to continuous flooding. It may be possible, depending on soil composition, to

draw down at a later date than used in this study and improve yields. Maintaining a continuously saturated field does not seem to offer any advantages and may have an additional negative aspect of encouraging competition from weed species.

When estimating potential water use or irrigation requirements, anticipated aboveground biomass yield must be taken into consideration. The strong correlation between yield and transpiration is not unexpected since leaf surface area provides the evaporative surface for transpiration. The interesting finding from this study is that water use efficiency is relatively constant over a wide range of yields under similar microclimatic conditions. The efficiencies reported in this study also agree quite closely with those reported elsewhere (Bernatowicz, *et. al.*, 1976). For modeling and planning purposes, efficiencies, therefore, appear to have good predictive value.

Of all the factors studied, microclimate appears to have the most significant effect on water loss from, and irrigation requirements for, *Typha* paddies. The larger, continuous stands of *Typha* which would be encountered in commercial production systems were found to use up to 90% less water for transpiration than some previous estimates (Krolikowska, 1978). Total water loss does not appear to exceed seasonal precipitation in Minnesota (mean = 65 cm), even when biomass yields are high. These results will reduce estimates for production expenses and also make available a larger land resource for biomass production.

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SECTION 4

FLOWERING AND PRODUCTIVITY

INTRODUCTION

Observations in cultivated *Typha* stands have suggested that extensive flowering, which sometimes occurs several years after stand establishment, may reduce biomass yields. To more closely evaluate the impact of flowering on productivity, and to begin to understand environmental/physiological factors controlling the flowering response, a literature review was conducted followed by two experimental studies. The first study consisted of a cultivated stand experiment examining the pattern of rhizome growth and shoot proliferation in response to the removal of flowers early in the growing season. The second study, conducted in small containers, examined the response of aboveground productivity to the removal of flowers early in the growing season for *Typha latifolia*, *T. angustifolia*, and *T. x glauca*.

MATERIALS AND METHODS

Literature Review

The primary source of references was a recent and extensive bibliography on *Typha* spp. compiled by J.M. Penko (Pratt *et al.*, 1984).

Inflorescence Removal - Cultivated Stand

Cultivated four year old stands of *Typha latifolia* and *T. x glauca* in northeastern Minnesota (Pratt *et al.*, 1984) were observed for flowering in early summer. Contemporaneous flowering shoots of *T. latifolia* and *T. x glauca* were tagged, and the immature flowers removed from half the shoots. In the fall, tagged shoots and their attached rhizome systems were excavated and removed from the site. Observations were made on the number of new shoots emanating from each tagged shoot.

Inflorescence Removal - Small Containers

The experiment was set up as a 2x3 factorial in a completely randomized design. The treatment factors were 1) species (*Typha latifolia*, *Typha angustifolia*, *Typha x glauca*) and 2) inflorescences removed or intact. There were three replicates of each treatment combination for a total of 18 observations.

Six 0.3 m² plastic containers of each of the three species were planted with rhizome pieces at a density of 10 shoots/m² in the spring of 1984. Water levels were maintained at approximately 15 cm during the growing seasons. In early summer of 1985, all immature inflorescences were removed as soon as they emerged in half of the paddies (three of each species). In the fall, height, density, and aboveground biomass yield measurements were taken in all containers and analyzed for relationship to inflorescence removal.

RESULTS AND CONCLUSIONS

Literature Review

Observations concerning flower patterns in *Typha* spp. can be found in the literature although flowering is not the focus of most studies. Observations include information on the effect of flowering on growth patterns in *Typha* stands, frequency of flowering, and environmental and physiological factors that may affect flowering.

Flowering shoots have been observed in many studies to produce fewer lateral rhizomes than vegetative shoots, and this has been implicated as ultimately reducing biomass production. Grace and Wetzel (1981b) observed that flowering ramets resulted in a 10-15% reduction in vegetative reproduction compared to vegetative ramets. (A *Typha* ramet is defined as a rhizome and its associated leaves, roots, and, if present, inflorescence (Grace and Wetzel, 1981a,b;1982).) McNaughton (1966) observed that flowering production and rhizome proliferation were generally inversely proportional. Linde *et al.* (1976) also observed that fewer and shorter lateral rhizomes were produced by flowering shoots than vegetative shoots. Effects may extend into the second season after flowering. Grace and Wetzel (1981) indicate that some ramets die the year after flowering, especially in *Typha latifolia*. Linde *et al.* (1976) indicates that shoots originating from flowering shoots the previous year were shorter, on the average, at the end of the second season than shoots originating from vegetative shoots.

In addition to having fewer vegetative offshoots, flowering shoots themselves are usually smaller than their vegetative counterparts. Van der Valk and Davis (1978) noted that flowering shoots reach their maximum weight in July, soon after flowering, while vegetative shoots reach their maximum weight in September. Linde *et al.* (1976) noted that flowering plants terminated height growth soon after flowering and ended up shorter, on the average, than vegetative shoots which continued to grow taller through the end of the season. Pratt *et al.* (1984) have also observed that flowering shoots are generally shorter than vegetative shoots, and begin to senesce soon after flowering.

Although there is evidence in the literature that flowering reduces shoot size and vegetative propagation, actual long term reduction of biomass yield will depend largely on the frequency of flowering. Linde *et al.* (1976) provide evidence that flowering shoots do not vegetatively produce shoots which flower in the following year, suggesting that flowering percent in a stand may be held in check through time. Other authors have observed that flowering percent in natural stands is generally quite low, with *Typha angustifolia* generally exhibiting a higher flowering frequency than *Typha latifolia* (Grace and Wetzel, 1982; McNaughton, 1966; Penko, 1985). Observed flowering frequency ranged from 5 to 20% of shoots according to Grace and Wetzel (1982), and from 2 to 13% of total shoot number according to Penko (1985).

Observations of physiological factors which may, in part, control the flowering response in *Typha* spp. have been made by several researchers. Flowering may be subject to photoperiodic induction (Grace and Wetzel, 1982; McNaughton, 1966; Sharma, 1978), but determination of which shoots will flower must be controlled by some other factors. There is considerable evidence that larger ramets, relative to the rest of the population, are more likely to flower (Grace and Wetzel, 1981a,b;1982). In one study, large relative shoot biomass the week prior to flowering was highly correlated with flowering (Grace and Wetzel, 1982). Van der Valk and Davis (1978) also observed that the average weight of flowering shoots was higher (13% in the populations studied) than those of vegetative shoots. Grace and Wetzel (1982) indicate that rhizome size was also related to flowering in the population studied, with only rhizomes of about 30 g dry mass or more producing inflorescences. But Grace and Wetzel (1981b) also observed that there is no absolute ramet size that predetermines flowering: larger ramets

relative to the rest of a particular population are more likely to flower. Grace and Wetzel (1982) speculate that these observations indicate that floral initials are formed immediately preceding flowering.

Some environmental factors have also been observed to affect flowering in *Typha* spp. Van der Valk and Davis (1980) observed a *Typha x glauca* stand for five years during a cycle of flooding, drawdown, and re-flooding. He observed that flowering percentage dropped sharply during the drawdown and did not recover in the two years following the drawdown. Vegetative production also decreased during the drawdown period, but had recovered entirely in two years. Conversely, Grace and Wetzel (1982) observed that in *Typha angustifolia*, percent of flowering shoots decreases with water depth over a gradient of 30 to 120 cm. In another study, Grace and Wetzel (1981b) observed that disturbed populations of *Typha latifolia* are more likely to flower than protected populations.

Inflorescence Removal - Cultivated Stand

Figure 4-1 is a generalized illustration of the results of this experiment. Flowering shoots with inflorescences intact appeared to have fewer vegetative offshoots than non-flowering shoots, supporting the observations of Grace and Wetzel (1981b), whereas flowering shoots with inflorescences removed generally had the same number of vegetative offshoots as non-flowering shoots. In the *Typha latifolia* stand, shoots which had flowers removed subsequently gave rise to an average of 2.3 new shoots, while shoots on which flowers were allowed to mature gave rise to an average of only 0.5 new shoots. The differences were not as distinct in *Typha x glauca*, where the average number of offshoots for flowers removed and intact were 1.4 and 1.0, respectively.

Although the results from both stands should be viewed with caution because of the small sample size, they do tend to support reports in the literature that flowering reduces vegetative propagation (Grace and Wetzel, 1981a,b; Linde *et al.*, 1976; McNaughton, 1966). The results also suggest that inflorescence removal may overcome the determinant effects of flowering on growth.

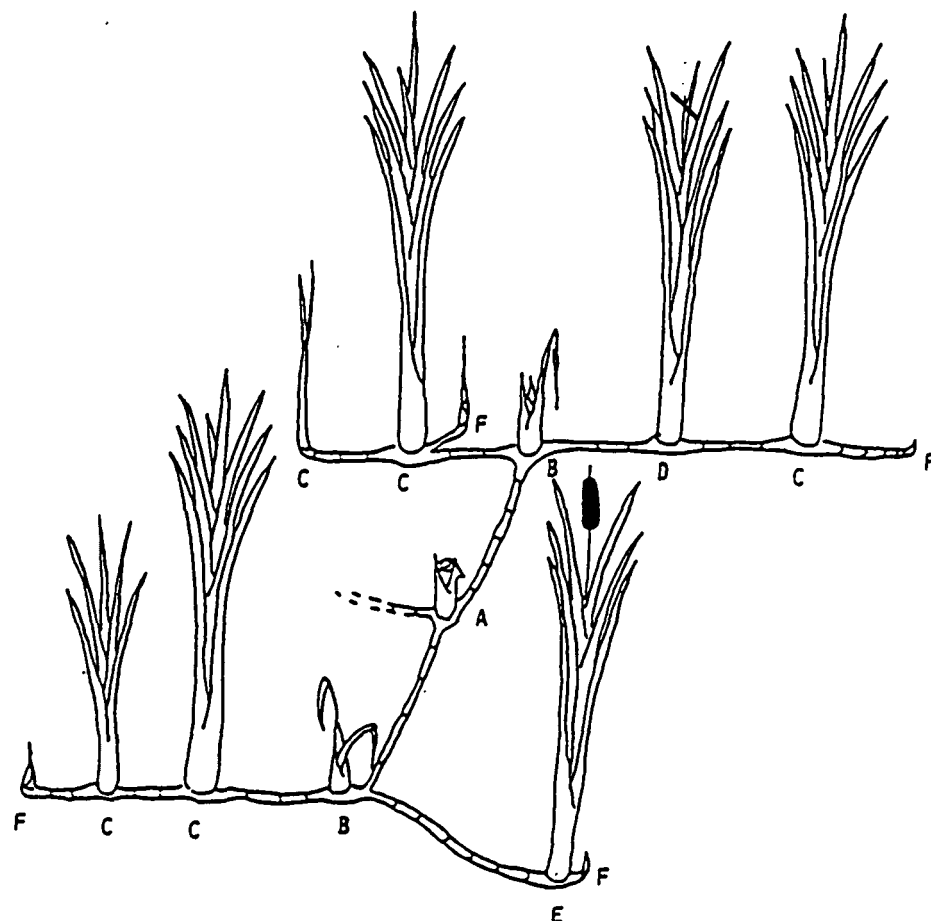
Inflorescence Removal - Small Containers

For each species, the percentage of shoots that flowered in each paddy (Table 4.1) was statistically the same, so the treatments (inflorescence removed or intact) were applied to similar experimental units. The fact that percent flowering was significantly different between species did not pose an analysis problem since the factorial experimental design isolated species as a treatment factor.

Analysis of variance ($p=0.05$) found that inflorescence removal did not increase shoot density or aboveground biomass yield (Table 4.1). Based on the literature review, it was anticipated that inflorescence removal might overcome the determinant effect of flowering on flowering shoot growth and lateral rhizomes production, thus allowing for increased shoot density and biomass productivity (Grace and Wetzel, 1981b; Linde *et al.*, 1976; McNaughton, 1966; van der Valk, 1978).

The fact that no treatment effect was seen on aboveground biomass yields might be accounted for in several ways. First, there is some evidence that inflorescence removal did not overcome the determinant effect of flowering on subsequent growth. At the end of the growing season, flowering shoots with and without inflorescences removed were shorter, on the average, and had senesced earlier than vegetative shoots. Also, there was no significant difference between the heights, dry weights (Table 4.1), or time of senescence of flowering shoots between

the control and treatment plants. No data is available on lateral rhizome production since the experiment was left intact for a second year.



- | | |
|--|---|
| A. 2 year old shoot | E. Current season's shoot with mature inflorescence |
| B. 1 year old shoot | F. Shoot buds |
| C. Current season's shoots | |
| D. Current season's shoots, inflorescence removed immediately after emergence from spathe leaf | |

Figure 4.1: Generalized morphological characteristics of *Typha* plants resulting from inflorescence removal (D) or intact inflorescence (E).

A second possible explanation for the apparent lack of treatment effect on productivity is that a difference in lateral rhizome production will only affect shoot number and, thus, aboveground biomass production in the year following flower removal treatment. Or, it is possible that flowering did not significantly reduce overall productivity despite a determinant

effect on the growth of flowering ramets, because only 2 to 20 percent of the shoots flowered (Table 4-1). The latter possibility is encouraging, since it suggests that the control of flowering may not be required to achieve maximum biomass productivity for *Typha*.

TABLE 4.1
THE EFFECT OF INFLORESCENCE REMOVAL
ON YIELD PARAMETERS FOR THREE *TYPHA* SPECIES

<i>Species</i>	<i>Inflorescence Treatment</i>	<i>Percent of Shoots Flowering</i>	<i>Total Aboveground Dry Weight (g/container)</i>	<i>Flowering Shoot Dry Wt (g/container)</i>	<i>Total Shoot Density (per container)</i>	<i>Flowering Shoot Ht (m)</i>
<i>T. latifolia</i>	intact	9.5	158	119	30	0.98
<i>T. latifolia</i>	removed	6.0	361	39	49	0.90
<i>T. angustifolia</i>	intact	2.7	244	150	43	1.35
<i>T. angustifolia</i>	removed	2.0	269	13	47	1.40
<i>T. x glauca</i>	intact	19.9	400	157	39	1.14
<i>T. x glauca</i>	removed	17.9	319	92	40	1.18

Finally, this experiment confirmed the observations of other researchers that flowering shoots are generally the first to emerge in the spring, and are larger at the time of flowering than vegetative shoots (Grace and Wetzel, 1981a; Linde *et al.*, 1976; van der Valk and Davis, 1978). Seventy-three percent of the shoots which flowered had emerged on the first date of emergence observed in the spring. At the time of flowering, flowering shoots in this experiment were, on the average, taller, had more leaves, and had a greater basal width than non-flowering shoots.

DISCUSSION AND CONCLUSIONS

Evidence from the literature and the limited studies described previously suggest that while flowering can have a negative effect on vegetative propagation and size of shoots in an individual ramet, it generally does not appear to reduce overall stand yields. This is because the number of ramets with flowering shoots is relatively small compared with the number of ramets with nonflowering shoots. As long as the number of shoots flowering remains less than a typical 10-15% of the total shoots present, there should not be any need to develop methods to inhibit flowering to enhance yield.

The flowering process in *Typha* is poorly understood and unpredictable. With indications that flowering can be triggered by environmental factors such as water levels and disturbances - two factors inherent in a commercial *Typha* biomass production system - consideration should be given to the possible impact on flowering from other stand management

practices being evaluated. If these other management practices dramatically increase the percentage of flowering shoots, yields may eventually suffer.

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SECTION 5

TYPHA SPECIES pH TOLERANCE

INTRODUCTION

The development of a biomass crop requires a knowledge of the range of substrate and site conditions under which yields can be maximized. This information can be used to both select suitable sites for specific species, such as *Typha*, and evaluate the potential of these species in areas where land is available for biomass production.

Surveys of natural stands and results from a previous controlled experiment indicate that *Typha* spp. are adaptable to a wide range of physiographic conditions. One study in Michigan (Segadas-Vianna, 1951) found *Typha latifolia*, *Typha angustifolia*, and *Typha x glauca* growing on peat and mineral soils of pH 4.1 to 8.1, with most around pH 6.0. Another study (Veatch, 1933) concluded that *Typha* thrives in decomposed peat and clay soils with a neutral to alkaline pH. In Minnesota, *Typha* stands have been successfully established on soils ranging from pH 5.2 (Garver *et al.*, 1983) to pH 8.6 (Section 2 - Crookston site). The only controlled experiment examining *Typha* pH tolerance found no difference in total plant productivity over a pH range of 4 to 8, but did not examine pH effects on aboveground to belowground biomass ratio (Pratt, 1978).

The objective of this study was to evaluate the effects of substrate pH on growth patterns and total plant productivity of *Typha latifolia*.

MATERIALS AND METHODS

A number of preliminary experiments were conducted to determine the best methodology for this experiment. Factors considered were types of substrate, formulation of nutrient solution, methods of pH adjustment, time of solution stability, and methods of solution replacement. Using results from these preliminary experiments, a greenhouse study was designed using washed silica sand as a medium. A total hydroponic medium was ruled inappropriate since the production of lateral shoots might be affected, thus affecting total productivity. The final greenhouse arrangement consisted of washed silica sand with 0.5 strength Hoagland's nutrient solution adjusted to pH values of 3.5, 5.0, and 6.5, using 5N HCl or 5N NaOH. The Hoagland's solution was modified to contain only one nitrogen source - ammonium.

The greenhouse experiment was set up with four replicates of each of the three pH treatments. *Typha latifolia* seedlings (60 days old; approximately 20 cm tall) were transplanted into sand and flooded with solutions adjusted to the appropriate pH. Plant growth, including height and lateral shoot production, was monitored daily for a period of eleven weeks. The pH of the solutions was also monitored daily since the uptake of ammonium tends to decrease pH. Old solution was replaced with fresh solution when the pH dropped 0.5 units.

RESULTS

Decreasing substrate pH reduces total biomass production, principally through a reduction in aboveground biomass (Figure 5.1). Using a Tukey's studentized range test ($\alpha=0.05$), results showed that mean shoot and total biomass was significantly different between treatments pH 3.5 and 6.5, with shoot biomass at pH 5.0 statistically similar to the other treatments. Since there was no significant difference in belowground biomass produced at the three pH levels, the observed difference in total dry weight can be accounted for by the large differences in aboveground dry weight alone.

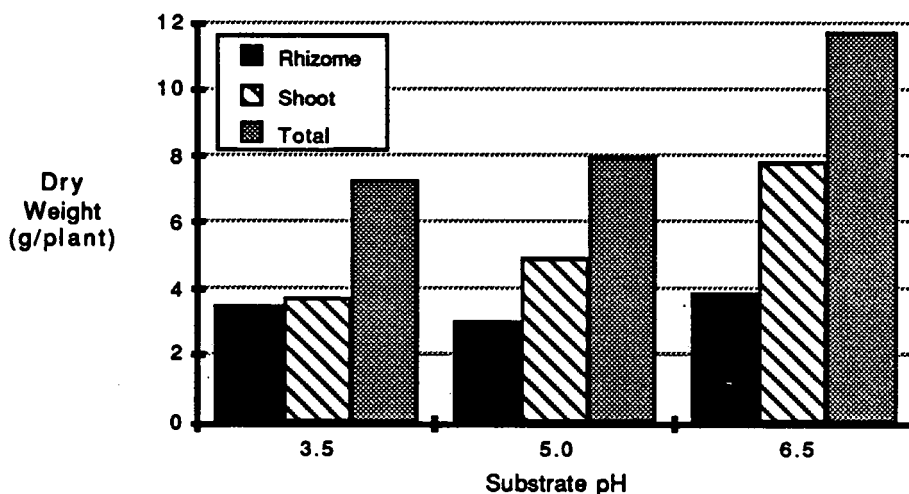


Figure 5.1 Effect of substrate pH on aboveground, belowground, and total biomass productivity.

Analysis of shoot density data found that pH treatment has no effect on lateral shoot production. Shoot biomass yield differences, then, are apparently a result of differences in shoot size, not shoot number.

The results from this limited study using only small seedlings are corroborated by observations across several field experiments in Minnesota (Table 5.1). While yield ranges have been fairly consistent across soils with pH between 5.4 and 8.6, there is an indication that at a soil pH of 5.2 yields begin to be reduced.

DISCUSSION AND CONCLUSIONS

Although tolerant of a wide range of substrate pH conditions, *Typha* spp. appear to be somewhat adversely affected by acidic substrates, especially when pH drops below 5.5. When selecting sites for development of commercial *Typha* stands, soil pH should be a consideration, with emphasis on avoiding highly acidic soils. This requirement will be quite important for certain organic wetland soils, which tend to be relatively acidic.

TABLE 5.1
COMPARATIVE YIELDS FROM CULTIVATED *TYPHA* STANDS
GROWING ON SOIL SUBSTATES OF DIFFERING pH

<i>Soil Type</i>	<i>Soil pH^a</i>	<i>Range of Mean Aboveground Typha Yield (Mg/ha)^b</i>	<i>Reference</i>
Hemic Peat	5.2	4.7-8.1	(Pratt et al., 1984; 1982)
Sapric Peat	5.4	5.8-10.5	(Pratt et al., 1984; 1982)
Loamy Sand	5.4	6.1-13.8	(Pratt et al., 1984; 1982)
Clay	8.6	6.8-11.6	(Section 2 - Crookston)

a) pH in 0.01 M CaCl₂

b) Second or third year stands sampled in late September or early October

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SECTION 6

CONTROL OF ABOVE- TO BELOWGROUND BIOMASS RATIO

INTRODUCTION

Over several years of experimentation with cultivated stands of *Typha* spp., it has been noted that the ratio of shoot to rhizome biomass ranges considerably. Depending on the desired biomass product, it would be beneficial to be able to manipulate environmental or genetic factors to enhance shoot or rhizome productivity. The objective of this study is to identify factors regulating the distribution of biomass within the *Typha* plant so that later efforts may be directed at controlling the appropriate factors. To accomplish this, a literature review and analysis of relevant information gathered from prior experimental data were employed.

MATERIALS AND METHODS

Literature Review

The primary source of references was a recent and extensive bibliography on *Typha* spp. prepared by J.M. Penko (Pratt *et al.*, 1984).

Analysis of Experimental Data

Data from earlier experiments designed to study various *Typha* management practices were summarized and compiled on the basis of factors which may affect the ratio of shoot to rhizome biomass. These factors included age of the stand and species; they also included fertilization (Pratt, *et al.*, 1982;1984), harvesting (Section 2: Cultivated stand - Three harvest scenarios), establishment method and density (Pratt *et al.*, 1982;1984), and soil type (Garver *et al.*, 1988).

RESULTS AND DISCUSSION

It has generally been observed that the shoot to rhizome ratio is lowest in the establishment season when much of the plant's energy is put into vegetative reproduction and colonizing of the site. A dramatic increase in the shoot to rhizome ratio (S/R) was seen in the second season in most stands ranging from a 25% to a 57% increase over the first year (Table 6.1). The shoot to rhizome ratio in some instances stabilized at about the second year level, and in some instances declined, depending on other stand conditions discussed below.

Initial planting density and planting method appear to be the management factors which most greatly influence the absolute level of S/R, and the pattern of change through subsequent seasons. Most past experiments were planted at a density of five or nine shoots/m², resulting in a first season S/R of approximately 0.8 (Table 6.1). One stand successfully started from seed had an initial plant density of 40 shoots/m² and resulted in a first season S/R of 1.3.

Most stands' S/R increased during the second season, with the seeded stand reaching 1.8 and all other stands reaching 1.1, on the average. Most stands stabilized at the second season S/R ratio for the third and fourth seasons, while the seeded stand S/R dropped sharply in the third season and stabilized into the fourth at approximately 0.9.

TABLE 6.1
ABOVEGROUND TO BELOWGROUND RATIOS
AS A FUNCTION OF STAND AGE, SPECIES, AND SITE CHARACTERISTICS.

Experiment	Initial Plant Density (per m ²) & Planting Method*	Species	Soil Type	Aboveground/Belowground Ratio				
				Estab.	2	3	4	5
Fertilization Study**	9/R	<i>T. x glauca</i>	Sapric Peat	0.9	—	—	—	—
Harvest Study**	9/R	<i>T. x glauca</i>	Sapric Peat	—	—	—	0.6	0.9
Establishment Study	40/S	<i>T. angustifolia</i>	Loamy Sand	1.2	1.8	0.9	0.9	—
	9/R	<i>T. latifolia</i>		0.7	1.1	1.3	—	—
Peatland Excavation Study	9/R	<i>T. latifolia</i>	Hemic Peat	0.7	1.1	—	—	—
	9/R	<i>T. x glauca</i>		0.8	1.0	—	—	—
Nutrient Uptake Study	5/SI	<i>T. latifolia</i>	Hemic Peat	1.2	1.6	0.9	—	—
	5/R	<i>T. x glauca</i>		1.2	0.9	0.8	—	—
	5/R	<i>T. angustifolia</i>		0.9	0.7	1.1	—	—

* R=transplanted rhizome pieces; S=seeded; SI=transplanted 90 day old seedlings.

** The harvest study is being conducted in a cultivated *Typha* stand that was previously used for the fertilization study.

Fertilization is another management factor which might be manipulated to affect the ratio of shoots to rhizomes. The work of several researchers suggests that increased nitrogen, phosphorus and potassium together (Boyd, 1971), increased nitrogen and phosphorus together (Bonnewell and Pratt, 1978), and increased nitrogen alone or nitrogen and potassium together (Krolikowska, 1982) increase S/R. Krolikowska (1982) also found that potassium alone

decreased S/R. A factorial experiment looking at the effects of different levels and combinations of nitrogen, phosphorus, and potassium fertilizers was conducted by Pratt *et al.* (1983) at a field site in Aitkin, Minnesota. None of the fertilization treatments had a significant affect on S/R in this experiment.

Water depth has also been observed to affect shoot/rhizome ratio. Merezhko *et al.* (1979) and Sharma and Gopal (1977) observed various *Typha* species on sites ranging from dry to deep flooded, with S/R consistently increasing with increasing water depth. All of our experimental sites have been maintained at 15-30 cm standing water, so no comparison from past experience in cultivated stands is available.

TABLE 6.2
ABOVE- AND BELOWGROUND BIOMASS STANDING CROPS
AS A FUNCTION OF STAND AGE, SPECIES, AND SITE CHARACTERISTICS

Expt.	Initial Plant Density (per m ²) & Planting Method*	Species	Soil Type	Aboveground/Belowground Standing Crop (Mg/ha)				
				Growing Season				
				Estab.	2	3	4	5
Fertilization Study**	9/R	<i>T. x glauca</i>	Sapric Peat	3.7/4.1	8.1/-	-/-	-/-	-/-
Harvest Study**	9/R	<i>T. x glauca</i>	Sapric Peat	-/-	-/-	-/-	6.2/10.1	6.1/6.9
Establishment Study	40/S	<i>T. angustifolia</i>	Loamy Sand	0.5/0.4	13.9/7.8	11.6/13.5	12.5/13.4	12.9/-
	9/R	<i>T. latifolia</i>		0.7/1.0	6.2/5.4	6.4/4.7	-/-	-/-
Peatland Excavation Study	9/R	<i>T. latifolia</i>	Hemic Peat	1.9/2.8	4.7/4.4	3.3/-	-/-	-/-
	9/R	<i>T. x glauca</i>		3.5/4.5	6.9/7.3	4.1/-	-/-	-/-
Nutrient Uptake Study	5/SI	<i>T. latifolia</i>	Hemic Peat	3.5/3.0	7.2/4.4	6.9/7.4	-/-	-/-
	5/R	<i>T. x glauca</i>		2.9/2.4	6.2/6.5	8.0/9.4	-/-	-/-
	5/R	<i>T. angustifolia</i>		1.3/1.4	5.2/7.3	8.8/7.8	-/-	-/-

* R=transplanted rhizome pieces; S=seeded; SI=transplanted 90 day old seedlings.

** The harvest study is being conducted in a cultivated *Typha* stand that was previously used for the fertilization study.

Merezhko *et al.* (1979) also observed that type of substrate affects the ratio of shoots to rhizomes. Mineral soils ranging from sand to loamy sand were observed, with lower S/R observed in the coarser substrates. Experiments in Minnesota have been established on soils ranging from loamy sand to hemic peat (Table 6.1). Data from the first growing season of several experiments planted at five or nine shoots/m² seem to support Merezhko's observation, with *Typha* on the coarser soil (loamy sand) exhibiting a lower S/R than on the sapric peat (containing 57% mineral fraction), which in turn was associated with a lower S/R than most stands on the hemic peat (containing 12% mineral fraction). These differences did not persist through subsequent years of the experiments.

Genetic factors probably also contribute to controlling S/R. Dykyjova *et al.* (1971) observed that *Typha latifolia* had an S/R twice that of *Typha angustifolia* grown under the same conditions. However, the fact that extensive flowering occurred in the *Typha latifolia* but not in the *Typha angustifolia* may confound this observation. Studies in Minnesota showed no discernible relationship between species and S/R ratio, but other management factors which differed between experiments may have hidden any actual species differences.

Table 6.2 shows the actual shoot and rhizome yield figures which were used to determine the S/R ratio in Table 6.1. The data show that trends in S/R ratio are fairly independent of stand productivity: the establishment season S/R ratio, for instance, was between 0.7 and 1.2 for all stands whereas the total productivity ranged from 0.9 to 7.8 Mg/ha. It is important to note that the shoot yield figures in Table 6.2 represent annual productivity, while the rhizome yield figures include rhizomes produced in years preceding the stated season. This obviously affects the trends in S/R ratio noted in Table 6.1. If only shoot biomass is harvested for energy from *Typha*, then the patterns of S/R ratio over time could be expected to be very similar to that seen in Table 6.1. If a partial rhizome harvest were to occur every other year, however, the patterns of productivity and S/R ratio over time would be very different.

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