WATER RELATIONS AND CUTTING MANAGEMENT OF SWITCHGRASS

by

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(ABSTRACT)

Switchgrass (*Panicum virgatum* L.), a warm-season grass, grows most rapidly in mid-summer when cool-season species such as tall fescue (*Festuca arundinacea* Schreb.) may have limited growth due to high temperature and low soil moisture availability. The objectives of this study were to investigate physiological factors and to determine management strategies that could optimize growth of switchgrass.

The influences of two successive drought cycles on performance and water relation parameters of switchgrass and tall fescue were studied in growth chamber conditions. Water was withheld from conditioned plants until elongation of tillers stopped. Then pots were rewatered and a new drought cycle followed. Control plants remained well watered during this time. Both conditioned and control plants were then subjected to a challenge water stress. Total leaf elongation and soil water content (SWC) were measured daily. Leaf water potential (Ψ), osmotic potential (Π), relative water content, and concentrations of K, Na, Ca, and total free sugars were measured at the end of each water-stress cycle. Osmotic potential at full turgor (Π_{100}), symplastic water content (SYM) , and modulus of elasticity (ϵ) were determined from pressure-volume curves at the end of the two conditioning cycles. Conditioned plants of both species elongated more during the challenge water-stress than control plants and had lower SWC and Ψ when their leaf elongation ceased. Conditioned plants exhibited osmotic adjustment, accumulating free sugars and K, as a result of drought stress. Switchgrass SYM did not change, while Π_{100} decreased, suggesting active salt accumulation. Increased ϵ somewhat counteracted the beneficial influence of osmotic adjustment. Tall fescue SYM increased, while Π_{100} did not change. Decreased ϵ improved drought tolerance of tall fescue.

Field experiments were conducted to investigate the influence of date of first harvest and cutting height on yield distribution and canopy characteristics of 'Pathfinder' (2-yr study), 'Cave-in-rock', and 'Blackwell' (1-yr study) switchgrass. Seasonal distribution of dry matter production was established by measuring first-harvest yields and regrowth. The canopy of Pathfinder was characterized by determining number and weight of tillers, light penetration, leafiness, specific leaf weight, and leaf area index in profiles of the canopy before harvest and in regrowth. First-harvest yields increased as date of first cut was delayed and cutting height was lowered. Cutting at 20 cm decreased the yield of first cutting in a second growing season. Plots not harvested in the first growing season gave higher yields in the second growing season compared with previously harvested plots, suggesting that any harvest may decrease subsequent yield potential. Regrowth decreased as date of first cut was delayed. A cutting height of 30 cm produced greater regrowth than cutting at 20 cm. Yields and canopy characteristics suggest that removal of growing points decreased second-harvest yields and weakened regrowth potential in the following year. To maximize regrowth to be used for grazing during July and August, switchgrass hay should be cut after 10 June and before 21 June.

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Chapter 1

Introduction

Switchgrass, a warm-season species, can produce high yields during hot, dry, mid-summer days, and thus complementing cool-season grasses, such as tall fescue, which may have limited growth in mid-summer. Tall fescue and switchgrass in separate pasture can provide a sufficient forage supply for livestock throughout the growing season if properly managed. Both grasses may be subject to sublethal water-stresses during late spring and early summer. This succession of sublethal water-stress cycles may decrease yield, but it possibly makes these grasses able to survive periods of subsequent water deficiency with less yield loss. Objectives of the first part of this study were to compare tall fescue and switchgrass responses to repeated water-stresses. If osmotic adjustment occurs, growth might continue longer during a subsequent stress period. However, tall fescue may be unable to grow during periods of severe moisture deficiency. The goal of switchgrass cutting management is to provide high quality and quantity of switchgrass forage during this time of summer slump. Therefore the objective of the second part of this study was to determine the time of first harvest and the cutting height that result in the most regrowth in this period.

Switchgrass, as a grass with tropical origin, exhibits C4 photosynthesis, therefore switchgrass is able to decrease transpiration and maintain photosynthesis during hot and dry days. As a consequence of C4 photosynthesis, switchgrass tolerates water stress and gives high yields during the summer slump. On the other hand tall fescue originated from humid, temperate areas and exhibits C3 photosynthesis. This may be the reason for low production of tall fescue during hot and dry days. Tall fescue, however, tolerates water deficiency best among cool season grasses. Water relations of tall fescue were studied [15] but there is no information about water relations of switchgrass.

Yield of forage grasses such as switchgrass and tall fescue is determined in part by elongation of tillers. Elongation is the first physiological process influenced by moisture deficiency [12]. This statement is supported by recent water relation experiments, although the underlying physiological processes are still uncertain [14,23,30]. Knowledge of these underlying physiological processes can give agronomists the capability to increase the yield of crops in geographic areas of water deficiency. In spite of uncertainity about a mechanism for elongation decreases, researchers try to reduce sensitivity of elongation to drought in order to increase yield of crops [2,5,7]. Osmotic adjustment can reduce elongation decreases during drought. Osmotic adjustment is the active accumulation of salts in the plant cell during water stress, which decreases osmotic potential of the cell. The influence of osmotic adjustment on decreased growth due to water-stress was explained by the influence of osmotic adjustment on turgor maintenance [13]. When there is no osmotic adjustment, leaf water potential of plants subjected to moisture deficiency decreases, therefore as a component of leaf water potential, turgor pressure decreases reducing growth of cells. However, with active accumulation of salts, cells can lower their osmotic potential during drought, making it possible to maintain turgor pressure and therefore continue growth.

Studies prove the validity of this theory. For example, Acevedo et al. [1] reported that growth of corn (*Zea mays* L.) leaves was extremly sensitive to changes in water relations, and decrease of leaf elongation was closely related to turgor reduction. Blum [2] investigated growth of barley (*Hordeum vulgare* L.) genotypes subjected to water-stress and concluded that elongation and osmotic adjustment have a negative, nonlinear correlation. Sloane et al. [26] compared drought resistance of two soybean cultivars, and found that the newer cultivar, which wilted later than the other cultivar, kept a higher turgor potential and lower osmotic potential and had higher yield during moisture deficiency than the older cultivar.

However, recent results by other researchers show that turgor pressure does not have a determining role in growth reduction of plants subjected to drought. In pearl millet (*Pennisetum americanum* L.), an important drought resistant crop, osmotic adjustment maintained turgor, but yield reduction was higher than in Channel millet (*Echinochloa turneriana* Domin.), a wild native grass [6]. On the other hand there was no connection between osmotic adjustment and turgor of Channel millet, (which exhibited higher yield than pearl millet). Boyer [3] found no correlation between turgor and cell expansion in sunflower. His results suggest that low soil moisture conditions decrease the water potential gradient between soil and leaves resulting in reduced growth. Chu and McPherson [4] provided evidence that leaf water potential and elongation can vary within the same group of plants, over a short period of time depending on envirionmental conditions. The authors emphasized that leaf water potential measurements have to be done in the site of elongation, and suggested that these are the reasons for recent discrepancies in leaf water relation studies. Ramati et al. [21] found no connection between osmotic adjustment and growth of *Pannicum repens*. Despite a declining osmotic potential, growth of water stressed plants did not improve. This was explained as a result of unbalanced distribution of ions produced by osmoregulation during osmotic adjustment. Kuang et al. [17] reported that turgor pressure, osmotic adjustment, and growth were independent of each other in wheat (*Triticum eastivum* L.) and lupin (*Lupinus cosentinii* Guss.). On the other hand, they found a strong correlation between soil water content and leaf growth. Kuang et al. concluded that osmoregulation, growth, and leaf conductance could be driven by phytohormones produced by roots. Recent studies suggest that moisture deficiency responses of species and cultivars differ [6] and depend on environmental conditions, site and method of measurement of water relation parameters [4], and water-stress history of [15].

Switchrass is common in plains states, but are not traditionally grown in Virginia. Because of their limited importance in Virginia there is little known about their management. However, some research was conducted examining the influence of harvest date, cutting frequency, and cutting height on the yield of warm-season grasses

Influence of cutting frequency on prairie grasses was studied first by Aldous [1]. He reported that increasing frequency of cutting decreases yield. Harlan and Ahring [12]suggested to cut 'Caddo' switchgrass twice in a year and established that switchgrass varieties give different responses to the same cutting management. Study of Newel [15] shows that frequent clipping slowed the growth of switchgrass in the following year. Blue - green, short switchgrass strains were less sensitive to cutting frequency than green, tall strains. Berg [7] concluded that frequent harvest does not allow switchgrass to store enough energy for winter survival and spring growth. Henry et al. [14] found that cutting warm-season grasses monthly instead of twice in a growing season reduced yield if cutting height was low, 8 to 15 cm. Beaty and Powell [6] reported that frequent clipping decreased elongation of tillers on the following spring. Haferkamp and Copeland [11] observed development of switchgrass as influenced by frequency of harvest. The authors concluded that switchgrass plants harvested twice had more aerial, nonrooted shoots than switchgrass plants harvested once and the aerial, nonrooted shoots were more sensitive to winter frost.

Influence of date for first harvest on yield and persistance of switchgrass was investigated more intensively than influence of cutting height or frequency. Baker et al. [4] concluded from their experiment that early cutting decreased the weight of the stem and increased weed development. Sims et al. [17] found that early spring harvest did not influence seedhead production while late spring harvest decreased seedhead production. Henry et al. [14] reported that the best yield of switchgrass can be reached with harvesting dates in July and October or in August and October. Beaty and Powell [6] concluded that under southern conditions switchgrass can be harvested in early spring because in southern areas weed contamination of switchgrass stand was less than in northern areas. Anderson and Matches [2] showed that delaying the date of first harvest reduced regrowth. Haferkamp and Copeland [11] investigated growth and development of switchgrass as affected by three dates of first harvest. The authors observed decreased weight of primary compound shoot, reduced plant vigor, and slow regrowth when switchgrass was mowed in April. Late spring mowing increased the number and weight of secondary, nonrooted, and aerial roots and caused smaller vigor loss than early spring mowing. Further delay of harvest produced additional increase in number of secondary and tertiary shoots. Anderson [3] et al. reported that delaying the date of first cutting weekly increased the yield of first harvest but decreased regrowth. Tiller density at first cutting increased as date of harvest was delayed but tiller density at second cutting was not affected by date of first harvest. George and Obermann [8] found that switchgrass produce high yields in June when cool-season grasses are dormant. They observed the greatest regrowth when the first harvest was taken in early or mid June. Leaf stem ratio was decreased if the first cut was delayed.

Optimal height of cutting strongly correlated with time and frequency of harvest, maturity and height of tillers. Researchers emphasize that removal of growing points weakens switchgrass, reduces yield, increases number of nonrooted, aerial shoots [13,5,17]. Sims et al. [17] mowed switchgrass at 3 cm aboveground and observed decreased yield, ceased elongation of reproductive shoots, and tillering from rhizomes and proaxes. Henry et al. [14] obtained the best stand of switchgrass at a cutting height of 23 cm at all dates of first harvest and the best yield of switchgrass at a cutting height of 8 cm if plants were harvested twice in a year. Anderson and Matches [2] compared yield and regrowth of switchgrass cut at 8 and 23 cm. They reported that cutting at 8 cm resulted in higher yield than cutting at 23 cm. After harvest at 8 cm more than half of the regrowth originated from crown tillers, other half originated from stem buds. After harvest at 23 cm primary shoot development continued. George and Reigh [9] hypothesized that the best basis for cutting management was the relationship between height of leaf tips, upper collar, and apical meristem. However this relationship showed too big variation among cultivars, harvesting dates, nitrogen levels, and years. George and Obermann [8] concluded from their experiment that higher cutting height made possible continious growth of apical meristem and resulted in greater regrowth.

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Chapter 2

Influence of water-stress conditioning on elongation, water relations, and osmotic adjustment of switchgrass and tall fescue

Abstract

Yields of switchgrass (*Panicum virgatum* L.) and tall fescue (*Festuca arundinacea* Schreb.) can be limited by soil moisture deficiency. The objective of this study was to investigate the influence of water-stress and water-stress conditioning on soil water depletion, leaf elongation, tiller characteristics, water relation parameters, and concentrations of free sugars, Na, K, and Ca ions. 'Pathfinder' switchgrass and 'Kentucky 31' tall fescue propagules were placed in pots in growth chambers. After 3 weeks, the tillers were subjected to two treatments. Plants receiving the conditioning treatment were subjected to water deficiency until elongation of plants stopped. At this point, plants were watered and a second water-stress cycle followed. Control plants were kept well watered. After conditioning, both the conditioned and control treatments were subjected to a challenge water-stress cycle to observe the influence of previous water-stress cycles on water-stress response. Both species depleted the soil water more thoroughly during the challenge cycle as a result of conditioning. During conditioning cycles, leaf elongation of plants decreased. In the challenge water-stress cycle, leaf elongation of conditioned plants was greater than control plants. Specific leaf weight (SLW) of switchgrass decreased. Blade-nonblade ratio, and number of leaves per tiller of tall fescue decreased and SLW increased by the end of the experiment. At the end of the challenge water-stress cycle, leaf water potential and osmotic potential of conditioned tall fescue tillers were lower than control tall fescue tillers at the same relative water content. Osmotic adjustment of tall fescue tillers may be a result of accumulation of K ions and free sugars. Pressure-volume curve of tall fescue showed that symplastic water content of tillers increased after conditioning, while osmotic potential at full turgor did not change. Conditioned and control switchgrass tillers had similar leaf water potential and osmotic potential at the end of the challenge water stress cycle. Switchgrass tillers also exhibited osmotic adjustment as indicated by accumulation of free sugars and K ions and as supported by the pressure-volume curve. Symplastic water content of switchgrass did not change, while osmotic potential at full turgor decreased after conditioning. Water stress cycles induced osmotic adjustment of both grasses, increased leaf elongation of switchgrass more than tall fescue during subsequent water-stress, and reduced yield of tall fescue more than switchgrass.

Introduction

Environmental conditions affect growth and yield of plants via physiological processes. Therefore, understanding how environmental factors influence physiology of plants is important for increasing crop yield. Water is the main component of plants, used as a solvent and reactant for biochemical processes, as cooling substance, and maintains turgor pressure which is important for growth of plants. Hence, water is one of the most important environmental factors affecting physiology and yield of plants.

Plants respond to drought with yield decrease. Differences in drought response induced by a difference in water-stress history or species can lead reaserchers closer to the solution of the uncertainities in water relation studies. Differences in water-stress history of plants can be produced under experimental conditions with water-stress conditioning. With water-stress conditioning plants are subjected to sublethal moisture deficiency and become less sensitive to subsequent drought. The influence of water-stress conditioning, or hardening, on drought response of plants is well known and widely applied in crop cultivation. However, there is little information about the physiological changes underlying the drought responses of different crops. Cutler and Rains [7] investigated stomatal and growth responses of cotton (*Gossypium hirsutum* L.) plants exposed to various irrigation regimes. They found that stomata of less frequently watered cotton closed at a lower leaf water potential than stomata of more frequently watered cotton during water stress. Moreover, hardened plants elongated until a lower leaf water potential compared to non-hardened plants. King and Bush [15] reported that prestressed tall fescue tillers had higher leaf elongation rates and used less water during moisture deficiency than unconditioned tillers. However, turgor, osmotic, and leaf water potential of prestressed and not prestressed tall fescue were the same; therefore, there was no correlation between turgor potential and elongation of leaves. Steponkus et al. [28] investigated the influence of water-stress conditioning on growth and water relations of various rice (*Oriza sativa* L.) cultivars subjected to moisture deficiency. Conditioned plants had higher turgor pressure and lower osmotic potential at a given relative water content and they had higher turgor pressures over a range of water potential than nonconditioned plants. Turgor of conditioned plants became zero at a significantly lower leaf water potential level than in nonconditioned plants. These changes of water relation parameters were investigated in several rice cultivars. There were differences in elongation response of different cultivars. On the other hand, all conditioned rice cultivars continued elongating until a lower leaf water potential was achived. Clemens and Jones [5] observed height, leaf area, water use, and root and stem conductance of Acacia (*Acacia longifolia* L.) and Eucalyptus (*Eucalyptus robusta* L.). They concluded that, although height and leaf area of conditioned and nonconditioned plants were the same, conditioned plants exhibited lower water use, lower root and shoot conductivity, and smaller root weight than nonconditioned plants. The authors emphasized the beneficial influence of conditioning without any negative effect on the appearance of the trees. Conditioning improved survival and establishment of nursery seedlings after outplanting. Seiler and Johnson investigated the influence of moisture-stress conditioning on photosynthesis, transpiration [24], water use efficiency, and morphological changes of various families of loblolly pine [25]. The authors reported that, while conditioning reduced transpiration, because of decreased needle conductance, initial photosynthesis rates of plants after conditioning was unaffected and resulted in improved water use efficiency. The plants experienced greater growth reduction of roots than shoots during conditioning, which led to a decreased root-shoot ratio.

Switchgrass and tall fescue, two valuable forage grasses, complement each other in yield timing. Switchgrass gives the best yield in the hot, dry days of summer when tall fescue tillers have low production. However, yield of both grasses can be limited by soil moisture [29]. Knowing the influence of water-stress conditioning on drought responses of switchgrass and tall fescue could help to determine proper irrigation management for these grasses and provide information about the physiological processes behind their drought tolerance. The purpose of this experiment was to observe the influence of water-stress conditioning on drought response of switchgrass and tall fescue. Soil water depletion, leaf elongation, leaf water potential, osmotic potential, relative water content, tiller characteristics, total free sugar concentration, and ion concentration of conditioned and nonconditioned switchgrass and tall fescue were investigated.

Materials and Methods

Plant material. 'Pathfinder' switchgrass and 'Kentucky 31' tall fescue propagules were transplanted from vigorous field stands to pots (20-cm diameter and 17-cm height) in April. Five propagules were placed in pots, containing clay-loam soil (Groseclose - Poplimento). The soil had a pH of 6.8 and P, K concentration of 29, 157 mg/kg respectively. Soil was watered daily. Immediately after transplanting, Peter's soluble fertilizer (Peters General Purpose, Fogelsville, PA) containing 214 mg N/g (5.20% nitrate N, 3.75% ammoniacal N, 11.05% urea N), 89 mg P/g, and 160 mg K/g was applied to each pot. Switchgrass pots were kept in a growth chamber with average daily temperature of 29.6 ± 1.0°C, average night temperature of 21.2 ± 0.6°C, average relative humidity of 77 ± 7%, and photosynthetically active radiation (PAR) of $517 \pm 126\mu E/m^2s$ (provided by flourescent and metal halide lamps). Tall fescue pots were kept in a growth chamber, with average daily temperature of 24.6 ± 0.8°C, average relative humidity of 61 ± 11%, PAR of $325 \pm 87\mu E/m^2s$ (provided by flourescent lamps). The photoperiod was 12 h for both chambers. Plants were treated with malathion solution (0,0 - Dimethyl s - (1,2 dicarbeth - oxyethyl phosphorodithioate)) daily to protect against infestation of thrips (order: Thysanoptera) during the first week.

Treatments. Switchgrass tillers had approximately four collared leaves and an average height of 22 cm on 20 April 1990 when treatments started. Tall fescue tillers had approximately three collared leaves and an average height of 31 cm. Both species were subjected to two water-stress conditioning treatments during the following 21 days. Control (non-conditioned) plants were well-watered during this 21 days. Water was withheld from the soil of pots that were assigned to the water-stress conditioning treatment to impose moisture deficit cycles. Elongation of one tiller per pot was measured during soil water content decline. When elongation of tillers stopped, a stress cycle was completed and pots were subirrigated to nearly soil saturation. Two water-stress cycles were used to induce water-stress conditioning of plants. Water was then withheld from all pots during a challenge water stress cycle.

Measurements. Leaf elongation of tillers and soil water content of pots were monitored during drying cycles. Leaf water potential, osmotic potential, relative water content, and total free sugar, Na, K, and Ca concentration were measured at the end of all three water-stress cycles. Measurements for establishing pressure-volume curves were made for control and conditioned plants at the end of the second conditioning cycle, between 16 and 20 h after adding water. Blade-nonblade ratio, specific leaf weight, and number of leaves per tiller were determined at the end of the challenge water stress cycle.

Soil water content (SWC) of pots was measured daily and was calculated according to the following equation:

$$SWC = 100 \times \frac{MW - DW}{DW}$$

where MW was weight of soil plus water in pot, DW was dry weight of soil in pot. Gravimetric measurements were corrected at the end of the experiment to take into account the weight of plants. Soil samples for water content measurement were taken along with gravimetric measurements and a regression was calculated. Elongation of leaves on a tiller from each pot was measured daily. Elongation was considered zero on the day when two successive measurements were the same. At that time, conditioned plants were rewatered. Total leaf elongation was calculated as the sum of daily elongations of all leaves. Leaf water potential, osmotic potential, and relative water content of the upper most, fully exposed leaf blade from separate, randomly chosen tillers were measured for both conditioned and control pots. Measurements were taken before illumination and watering to conclude a stress cycle. Leaf water potential was measured with a pressure chamber (Soilmoisture Equipment Corp., Santa Barbara, CA) as described by Kirkham [16]. To improve the endpoint detection, only the mid-vein of the blades was secured into the pressure chamber. Appearance of water was detected using a magnifying lens. The wall of the chamber was covered by a wet paper towel to avoid water loss during measurement. All air used for pressurization entered the chamber through a moist filter.

Osmotic potential was measured with Peltier thermocouple psychrometers (J.R.D. Merrill Speciality Equipment, Logan, Utah). Three, not rehydrated, 5 mm disks from a leaf blade were placed in psychrometer chambers, and the chambers were placed into a freezer at -18°C for approximately 3 h. Osmotic potential was measured in a 30°C water bath using a 10-sec cooling time and 5-sec delay time.

To determine relative water content, fresh weight (FW) of leaves was measured, leaves were put into water, and after 2 to 3 h of hydration, wet weight (WW) of leaves was measured. Samples were dried for 24 hr at 70°C, and dry weight (DW) was determined. Relative water content (RWC) was calculated according to the following equation:

$$RWC = 100 \times \frac{FW - DW}{WW - DW}$$

Leaf blades for determination of total free sugar, Na, K, and Ca concentration were sampled the same time when the water relation parameters were measured (at the end of each water-stress cycle). Leaves were dried on 70°C for 24 hr. Total free sugar concentration (TFSC) was determined using an automated procedure described by Davies [9] and expressed as glucose equivalents. The Na, K, and Ca concentrations were determined by inductively coupled plasma emission spectrograph as described by Donohue [10].

Pressure-volume curves for control and conditioned switchgrass and tall fescue leaves were determined using a pressure chamber one day after the end of conditioning treatment. The purpose of pressure-volume curve determination was to investigate the way of osmotic adjustment in switchgrass and tall fescue if psychrometer measurements of osmotic potential suggested the presence of osmotic adjustment. On the day when leaf elongation was zero in the second conditioning water-stress cycle, plants were rewatered until near soil saturation. Before illumination, on the following day, a leaf was randomly chosen, and a pressure-volume curve was determined according to the method of Cutler et al. [8]. The sap collector was reweighed from time to time until two successive weight measurements were the same indicating no additional water was coming from the leaf at a given pressure. Weight of leaves was determined before pressure-volume curve measurements were taken. Four to 6 h were required to obtain one pressure-volume curve. Six replications of pressure-volume curve were established for control and conditioned leaves of both species.

Blade-nonblade ratio, specific leaf weight, and number of leaves for tillers were determined at the end of the challenge water-stress cycle. Leaf blades were separated from stems of five randomly chosen tillers from each pot. Leaf area (LA) was measured using an automatic area meter (Hayashi Denko Co., LTD. Tokyo, Japan). Leaf blade and stem dry weights were used to calculate blade-nonblade ratio. Specific leaf weights (SLW) were calculated according to the following equation:

$$SLW = \frac{DWL}{LA}$$

where DWL was dry weight of leaves.

*Statistics.*A factorial combination of the two species and two water conditioning treatments were arranged in a completely random design. Twelve replications of switchgrass were placed in one growth chamber and ten replications of tall fescue were placed in another growth chamber. Pots were rerandomized in the growth chamber each day. General linear model procedures [22] were used for statistical analysis, and least significant differences were calculated at the 0.05 level. Each species was considered a separate experiment so statistical comparisons between species was not possible.

Pressure-volume curve data points were plotted and a portion of data points was chosen for linear regression [8]. An equation was calculated for the linear part of pressure-volume curve for each tiller. Using these equations, osmotic potential at full turgor and relative symplastic water content were calculated [8]. Bulk modulus of elasticity was calculated according to the following equation:

$$\epsilon = \frac{\Delta\Psi}{\Delta RWC}$$

where $\Delta\Psi$ was change of leaf water potential and ΔRWC was the change of relative water content over the region of positive turgor [6]. Osmotic potential at full turgor, symplastic water content, and bulk modulus of elasticity for conditioned and control tall fescue and switchgrass tillers were analyzed using general linear models procedures and least significant differences were calculated.

Results and Discussion

Soil water content. Conditioned plants depleted the soil water content to a lower level than control plants when the elongation of tillers stopped in the challenge water stress cycle (Table 2. 1). This difference in soil water depletion between conditioned and control plants indicated that water-stress conditioning of both switchgrass and tall fescue increased water depletion capabilities. Osmotic adjustment was a possible mechanism to induce greater water uptake and promote elongation when leaf water potential decreased.

Root development of conditioned and control plants was compared at the end of the experiment. There was no difference between root weights of randomly selected conditioned and control plants. Therefore, difference between soil water depletion of conditioned and control tillers was not a result of the difference between their root development.

Elongation. Total leaf elongation of switchgrass and tall fescue was reduced by 50 and 61%, respectively, due to the two conditioning water-stress cycles (Table 2. 2). The influence of water stress conditioning on leaf elongation became evident during the challenge water-stress cycle when total leaf elongation of conditioned switchgrass was 179% more than total leaf elongation of control switchgrass and total leaf elongation of conditioned tall fescue was 122% more than total leaf elongation of control tall fescue. The average length of one water stress cycle for tall fescue was 6.5 days, for switchgrass was 8 days. Greater total leaf elongation of conditioned plants during the challenge water stress could be an evidence of stored growth [1]. Stored growth is the rapid growth of plants after release of water stress. Stored growth is made possible by the accumulation of photosynthates during drought when lack of turgor inhibits growth.

Table 2.1: Soil water content of conditioned and control switchgrass and tall fescue pots at the end of the challenge water stress. Conditioned plants were subjected to two water stress cycles, while control plants were well-watered before the challenge water stress was imposed. Soil water content was measured on the day when elongation of plants became zero in the challenge water stress.

Treatments	Species	
	Switchgrass	Tall fescue
	%	
Conditioned	7.8a*	7.5a
Control	11.5b	10.6b

*Numbers followed by the same letter within column are not significantly different at P=0.05 by LSD test.

Table 2.2: Total leaf elongation of conditioned and control switchgrass and tall fescue tillers during two conditioning water stress cycles and a subsequent challenge water stress. Control plants were well-watered before the challenge water stress was imposed.

Treatments	Species	
	Switchgrass	Tall fescue
	– – – – – – – – – – – *mm/tiller* – – – – – – – – – – –	
	Total leaf elongation during conditioning	
Conditioned	909a*	244a
Control	1812b	632b
	Total leaf elongation during challenge water stress	
Conditioned	324a	122a
Control	116b	55b

*Numbers followed by the same letter within column and within a measurement period are not significantly different at P=0.05 by LSD test.

Tiller characteristics. Conditioning did not change blade-nonblade ratio of switchgrass, while blade-nonblade ratio of tall fescue decreased by 15% (Table 2. 3). Switchgrass continued production of leaf tissue during water-stress. Tall fescue had less production of leaf tissue as a result of conditioning. Decreased leafiness led to reduction of evaporative surface area.

Conditioning of switchgrass tillers decreased SLW by 19%, which means that switchgrass plants became lighter per unit LA (Table 2. 3). On the other hand, conditioning of tall fescue tillers increased SLW by 16%, therefore tall fescue leaves became more dense. Mooney [19] reported that specific leaf weight of *Eucalyptus* species adjusted to arid conditions. SLW of *Eucaliptus* leaves increased and made possible reduction of the evaporative surface per unit of leaf weight. Conditioning did not influence the number of leaves per switchgrass tiller, but it decreased the number of leaves per tall fescue tiller (Table 2. 3).

Leaf water potential. Leaf water potential, as expected, decreased for tall fescue and switchgrass during both conditioning water-stress cycles The leaf water potentials measured represent the water status of switchgrass and tall fescue leaves that are no longer able to develope turgor sufficient for elongation. The first water-stress cycle produced a 1.83 MPa decrease in leaf water potential, and the second water-stress cycle produced 1.93 MPa decrease. At the end of the challenge water stress cycle, conditioned tall fescue stopped elongating at a lower leaf water potential than control tall fescue. Although not significantly different (P=0.05), conditioned switchgrass continued to elongate to a lower leaf water potential than control switchgrass.

Osmotic potential. Water stress conditioning caused a 1.04 MPa decrease in osmotic potential in the first conditioning cycle and a 1.31 MPa decrease in the second conditioning cycle. Osmotic potential at the end of the challenge water-stress

Table 2.3: Tiller characteristics of conditioned and control switchgrass and tall fescue. Conditioned plants were subjected to three water stress cycles. Control plants were subjected to one water stress cycle. †

Treatments	Species	
	Switchgrass	Tall fescue
	– – –Blade-nonblade ratio (g/g) – ––	
Conditioned	0.96a*	3.16a
Control	1.00a	3.72b
	––Specific leaf weight (mg/cm^2) – –	
Conditioned	3.97a	5.78a
Control	4.74b	4.83b
	– – – – – ––Leaves/tiller– – – – – ––	
Conditioned	6.7a	3.6a
Control	7.1a	4.1b

*Numbers followed by the same letter within column are not significantly different at P=0.05 by LSD test.

†Measurements were taken at the end of the challenge water stress.

cycle did not differ for conditioned and control switchgrass (Table 2.4). Conditioned tall fescue stopped elongating at 0.48 MPa lower osmotic potential than the control. The change in osmotic potential of tall fescue during conditioning was the same direction and the same magnitude as the change in leaf water potential. The difference between osmotic potential of conditioned and control tall fescue at the end of the challenge water-stress cycle indicates that conditioning led to osmotic adjustment.

Relative water content. The first water stress cycle caused a 14.3% relative water content (RWC) difference and the second water stress cycle caused a 18.6% RWC difference. RWC of treatments did not differ at the end of the challenge water-stress

Relative water content, leaf water potential, and osmotic potential at the end of the challenge water-stress provided good evidence of osmotic adjustment occuring in tall fescue during conditioning (Table 2.4). Conditioned tall fescue tillers had significantly lower osmotic potential and leaf water potential than control plants at the same RWC.

Total free sugar concentration. Osmoregulation in cells can happen by means of dehydration or active uptake of ions or sugar accumulation. Munns and Weir [20] reported that wheat leaves under water deficiency adjusted osmotically by means of sugar accumulation. There were 156% and 68% increases of total free sugar concentration (TFSC) during water-stress, for switchgrass and tall fescue, respectively (Table 2.5). At the end of the challenge water-stress, conditioned tall fescue tillers had 33% more TFSC than control tall fescue tillers. TFSC of conditioned and control switchgrass tillers were the same at the end of the challenge water-stress. These results are consistent with leaf water potential and osmotic potential data and suggest that there was osmotic adjustment in both species, but switchgrass adjusted osmotically in the very first water-stress cycle, while tall fescue exhibited

Table 2.4: Water relation parameters of conditioned and control switchgrass and tall fescue at the end of the challenge water stress. (Water stress ceased when elongation of plants became zero.)

Treatments	Species	
	Switchgrass	Tall fescue
	– – ––Leaf water potential (MPa) – – – –	
Conditioned	-2.50a*	-2.29a
Control	-2.27a	-1.85b
	– – ––Osmotic potential (MPa) – – – –	
Conditioned	-2.07a	-2.09a
Control	-2.04a	-1.61b
	– – ––Relative water content (%) – – – –	
Conditioned	79.3a	72.6a
Control	73.9a	80.5a

*Numbers followed by the same letter within column are not significantly different at P=0.05 by LSD test.

Table 2.5: Total free sugar concentration of conditioned and control switchgrass and tall fescue after the first and second, conditioning water stress cycles, when control plants were well-watered, and after the third, challenge water stress, when both conditioned and control plants were subjected to water stress.

Treatments	Species	
	Switchgrass	Tall fescue
	– – – – – – – – – *mg/g* – – – – – – – – –	
	First conditioning water stress cycle	
Conditioned	87a*	47a
Control	34b	28b
	Second conditioning water stress cycle	
Conditioned	62a	56a
Control	36b	33b
	Challenge water stress cycle	
Conditioned	72a	44a
Control	68a	33b

*Numbers followed by the same letter within column and within a measurement period are not significantly different at P=0.05 by LSD test.

increased osmotic adjustment during successive water-stress cycles.

Na, K, and Ca. Ford and Wilson [11] found, that in tropical grasses, osmoregulation is the result of Na, K, and Cl^+ accumulation in cells. Na concentration was the same for conditioned and control plants at the end of the challenge water-stress cycle. Neither switchgrass nor tall fescue tillers accumulated Na ion as an osmoticum for osmoregulation during conditioning.

K concentration (Table 2. 6) of switchgrass tillers did not change after one water-stress cycle. Conditioned switchgrass tillers accumulated K ions during the second water-stress cycle. At the end of second water-stress cycle, K concentration of conditioned switchgrass was 55 ppm higher than K concentration of control switchgrass. K concentration of conditioned tall fescue tillers became 91 ppm higher in the first water-stress cycle than is control plants. Conditioned tall fescue and switchgrass — subjected to three drought stress cycles — had 0.09 and 0.08 g/100g higher K concentration than control plants — subjected to one drought stress, respectively. K ion had role in osmoregulation of tall fescue and switchgrass. Both species accumulated K ion during moisture deficiency. However, switchgrass tillers accumulated K ion gradually, during two water-stress cycles, while tall fescue tillers accumulated K ion immediately in the first water-stress cycle.

Ca concentrations of conditioned and control switchgrass were different after one water-stress cycle. Conditioned switchgrass had 13 ppm higher Ca concentration than control switchgrass. However, in the second water-stress cycle Ca concentration of conditioned plants decreased, while Ca concentration of control plants did not change. Therefore Ca concentration of conditioned and control switchgrass became equal. In the challenge water-stress, no further change occured in Ca concentration of conditioned plants. At the end of the challenge water-stress cycle, there was no difference in Ca concentrations of conditioned and control switchgrass

Table 2.6: K concentrations of conditioned and control switchgrass and tall fescue after the first and second, conditioning water stress cycles, when control plants were well-watered, and after the third, challenge water stress, when both conditioned and control plants were subjected to water stress.

Treatments	Species	
	Switchgrass	Tall fescue
	———— $g/100g$ ————	
	First conditioning water stress cycle	
Conditioned	.672a*	1.552a
Control	.684a	1.188b
	Second conditioning water stress cycle	
Conditioned	.936a	1.624a
Control	.732b	1.308b
	Challenge water stress cycle	
Conditioned	.884a	1.588a
Control	.796b	1.512b

*Numbers followed by the same letter within column and within a measurement period are not significantly different at P=0.05 by LSD test.

tillers. Ca concentration of conditioned and control tall fescue tillers were equal in every water-stress cycle. Ca ion apparently did not have any role in osmotic adjustment of tall fescue.

Pressure-volume curve. Pressure-volume curve of tall fescue (Figure 2.1) shows that during two conditioning water-stress cycles osmotic potential of tillers at full turgor did not change, while symplastic water content increased by 26%, and bulk modulus of elasticity decreased by 16 MPa. Control tall fescue tillers lost less water at the highest pressure which could be reached using a pressure bomb than conditioned tall fescue tillers. As a result, for the linear portion of control tall fescue pressure-volume curves less data points were obtained at high relative water deficite than for conditioned tall fescue. Therefore, linear regression of control tall fescue pressure-volume curves can give missleading results and produce low values of symplastic water content. However, difference between osmotic potential of conditioned and control tall fescue at the end of the challenge water stress suggests (Table 2.4) that tall fescue exhibited osmotic adjustment. Although osmotic potential at full turgor did not change in tall fescue leaves during water deficiency, to maintain the original osmotic potential while symplastic water content increased, plants had to take up salts actively. Therefore, active osmotic adjustment took place in tall fescue plants, too, just like in switchgrass plants. However, in case of tall fescue the osmotic adjustment was achived probably by salt movement from apoplast to symplast as it is suggested by Meinzer et al. [18]. Meinzer et al. investigated water relations of *Larrea tridentata*, a desert shrub and they found that symplastic water fraction of hydrated plants was 33% lower than symplastic water fraction of dehydrated plants. The authors propose that water movement from apoplast to symplast was triggered by previous salt movement from the apoplast to the symplast, to maintain osmotic potential. Meinzer et al. observed similar osmotic potential of dehydrated

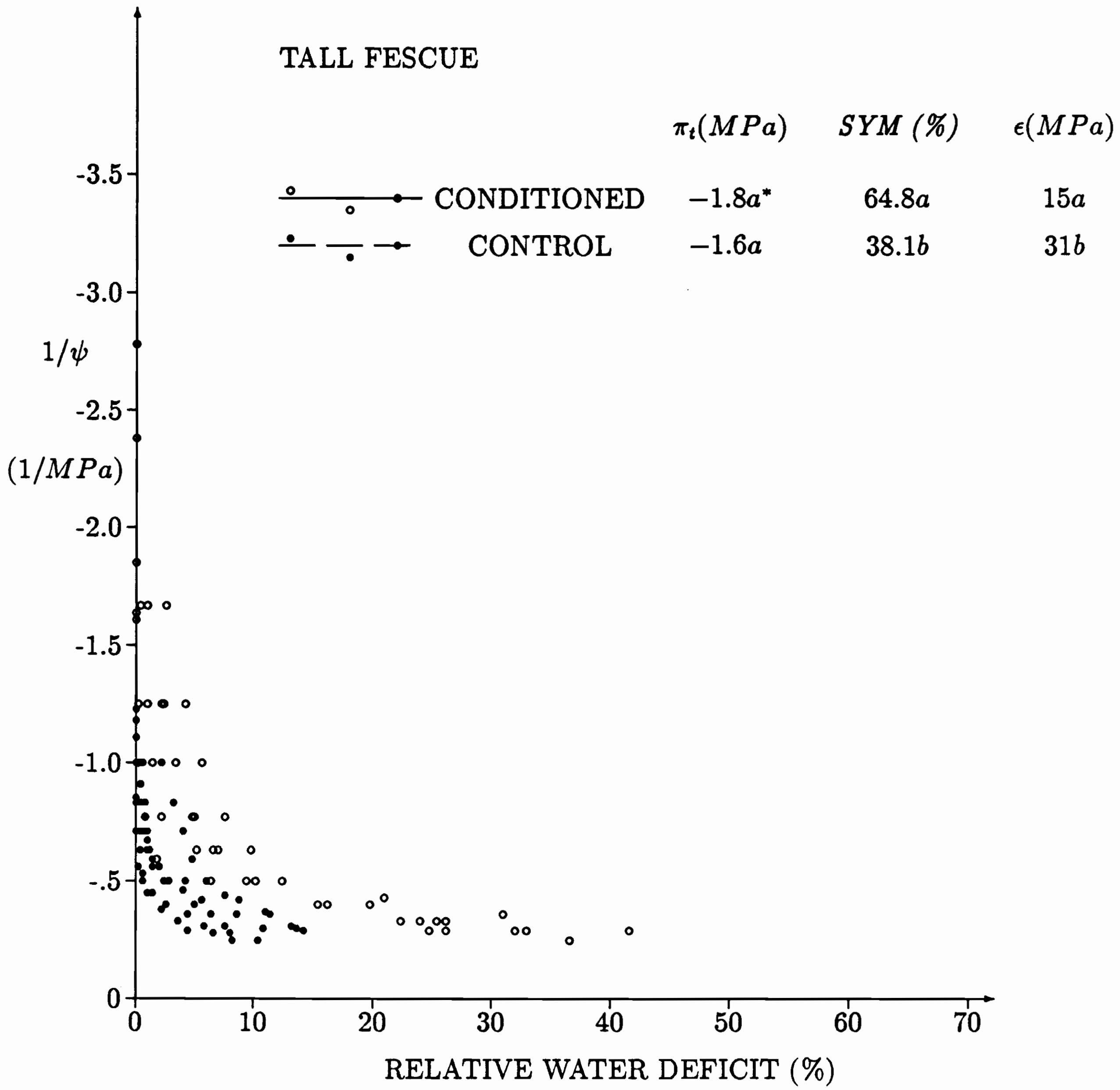

Figure 2.1: Pressure-volume curve for conditioned and control tall fescue plants. Osmotic potential at full turgor (π_t), symplastic water content (SYM), modulus of elasticity (ϵ) of conditioned and nonconditioned plants are presented.

*Numbers followed by the same letter within coloumns are not significantly different at P=0.05 by LSD test.

and hydrated plants, which supports their suggestion of water movement between apoplast and symplast. Osmotic potential at full turgor for water-stressed and control plants was the same in this experiment, too. The influence of conditioning was beneficial on the bulk modulus of elasticity of tall fescue. Conditioned plants had significantly lower bulk modulus of elasticity, which means that cell wall became less rigid and made possible slower pressure decrease and later plasmolysis of the cell than a more rigid cell wall [13].

Pressure-volume curve of switchgrass (Figure 2. 2) shows that, during two conditioning water-stress cycles, osmotic potential of tillers decreased by 0.6 MPa, while symplastic water content did not change, and bulk modulus of elasticity increased by 7 MPa. These changes in the pressure-volume curve suggest that conditioning induced osmotic adjustment in leaves of switchgrass. Despite the equal symplastic water content of tillers, the osmotic potential decreased. Switchgrass actively took up salts from the soil to maintain potential gradient between the drying soil and the plant tissue and provide driving force for water uptake during drought. On the other hand, influence of conditioning on the bulk modulus of elasticity counteracted the advantage of osmotic adjustment. The increased bulk modulus of elasticity for conditioned switchgrass suggests that the cell walls became more rigid as a result of water deficiency. A more rigid cell wall results in more rapid decrease of turgor pressure on the cell wall and earlier plasmolysis of the cell during water loss than a less rigid cell wall [13].

The most obvious influence of water-stress on switchgrass was elongation reduction when compared with well watered controls. Elongation of switchgrass leaves decreased by 50% during conditioning. However, in the challenge water-stress cycle, conditioned plants elongated 179% more and depleted soil water content (SWC) 3.7% lower than control plants. Conditioning of switchgrass decreased SLW, while

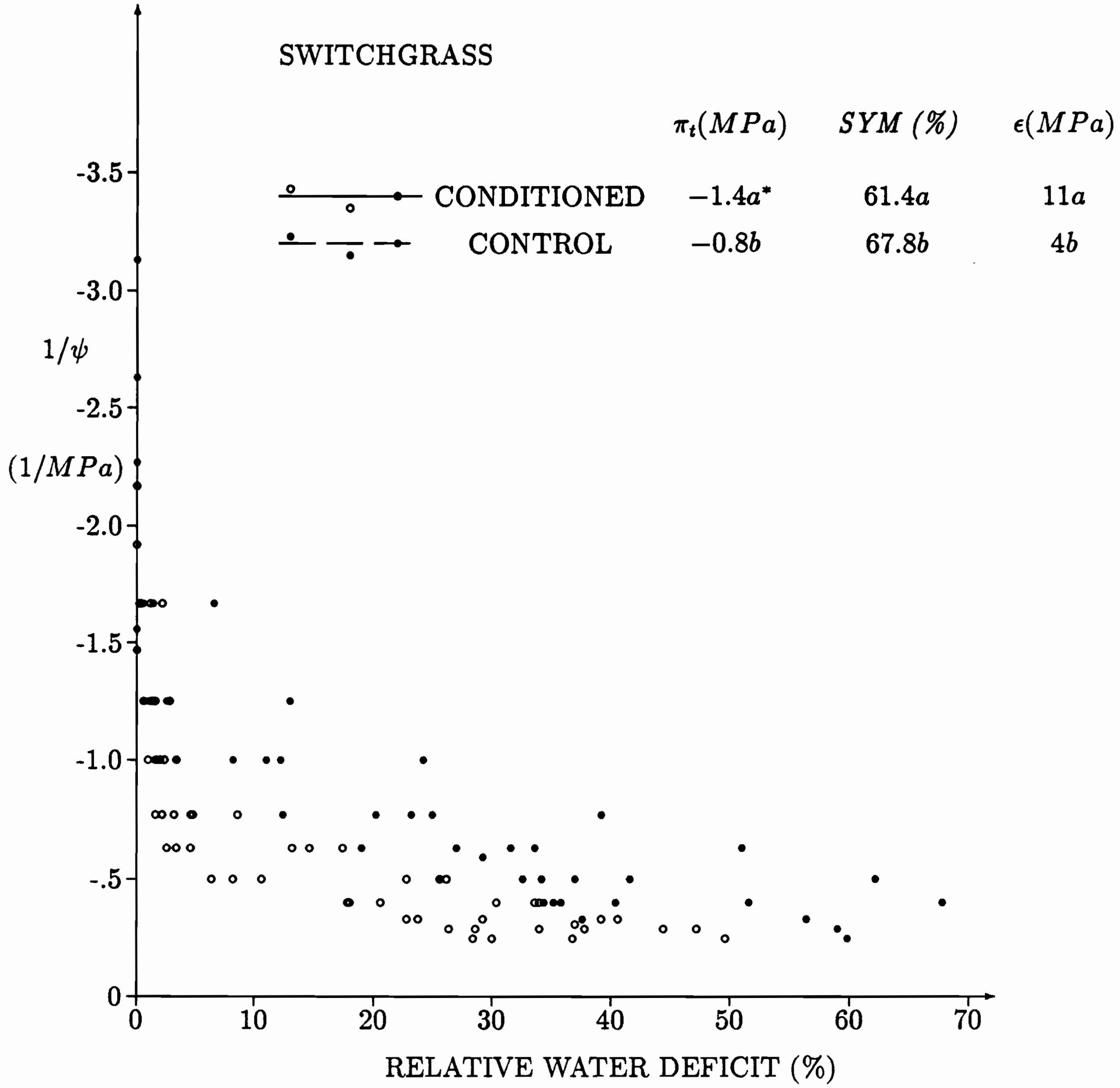

Figure 2.2: Pressure-volume curve for conditioned and control switchgrass plants. Osmotic potential at full turgor (π_t), symplastic water content (SYM), modulus of elasticity (ϵ) of conditioned and nonconditioned plants are presented.

*Numbers followed by the same letter within coloumns are not significantly different at P=0.05 by LSD test.

blade-nonblade ratio and number of leaves per tiller did not change. Conditioning did not change water relation parameters of switchgrass under decreasing soil water content. At the end of the challenge water-stress cycle, conditioned and control switchgrass tillers had equal leaf water potentials and osmotic potentials. TFSC of conditioned switchgrass increased immediately in the first conditioning water-stress cycle,but there were no differences in TFSC of conditioned and control tillers at the end of the challenge water-stress cycle. K concentration of conditioned switchgrass increased gradually during two water-stress cycles. This resulted in a K concentration difference between conditioned and control tillers at the end of the challenge water-stress cycle. Na and Ca concentrations of switchgrass were unaffected by water-stress. Pressure-volume curve of conditioned and control switchgrass showed that tillers exhibited active osmotic adjustment, because osmotic potential at full turgor for conditioned switchgrass plants was 0.6 MPa lower than for control switchgrass plants. At the same time, symplastic water content of tillers did not change. On the other hand, bulk modulus of elasticity increased during conditioning by 7 MPa, which has a negative influence on water deficiency tolerance of switchgrass.

The most obvious influence of water-stress on tall fescue was elongation reduction when compared with well watered controls. Elongation of tall fescue decreased by 60% during conditioning. However, in the challenge water-stress cycle, conditioned plants elongated 122% more and depleted soil water content (SWC) 3.1% lower than control plants. Conditioning of tall fescue increased SLW, while blade-nonblade ratio and the number of leaves per tiller decreased. Conditioning changed the water relation parameters of tall fescue to decreasing SWC. At the end of the challenge water-stress cycle, leaf water potential of conditioned plants was 0.44 MPa lo the same for both conditioned and control tall fescue tillers. These results show that tall fescue tillers exhibited active osmotic adjustment. TFSC and K concentration of conditioned tall fescue increased immediately in the first conditioning water-stress cycle. No further increase occurred in K concentration in successive water stress cycles; therefore, there were no difference in K concentrations of conditioned and control tillers at the end of the challenge water-stress cycle. However, conditioned tall fescue tillers had higher TFSC at the end of the challenge water-stress cycle than control tall fescue tillers. Na concentrations of conditioned tall fescue decreased in the first water-stress cycle, but were not different for conditioned and control tillers at the end of the challenge water-stress cycles. Ca concentrations of tall fescue were unaffected by water-stress. Pressure-volume curves of conditioned and control tall fescue showed that tillers exhibited active osmotic adjustment. Osmotic potential at full turgor for conditioned tall fescue plants was the same as for control tall fescue plants. At the same time, symplastic water content of tillers increased by 26.7%. As suggested by Meinzer [18], increased symplastic water content could be the result of water movement from apoplast to symplast. Bulk modulus of elasticity decreased during conditioning by 16 MPa, which has positive influence on water deficiency tolerance of tall fescue.

Conclusion

Comparing elongation and tiller characteristics of species, a more beneficial influence of water-stress conditioning can be observed on switchgrass than on tall fescue. During conditioning, elongation reduction of tall fescue was higher than elongation reduction of switchgrass. Conditioning caused decrease of leaf number per tiller and blade - nonblade ratio for tall fescue but not for switchgrass. On the other hand, in the challenge water-stress cycle, conditioned switchgrass tillers elongated 179% more than control switchgrass tillers, while conditioned tall fescue tillers elongated 122% more than control tall fescue tillers.

Greater elongation of conditioned switchgrass than control switchgrass in the challenge water stress could be explained by "stored growth" [1]. Stored growth of switchgrass, accumulated during water stress conditioning by early summer droughts, could be utilized in the summer slump. Although, switchgrass yield would be reduced in the early summer, a portion of this yield decrease could be regained at the time when cool season grasses are unproductive. Moreover, yield decrease of switchgrass in the early summer will not reduce animal performance because of the abundance of cool season grasses at this time.

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Chapter 3

Yield and canopy characteristics of switchgrass as influenced by cutting management

Abstract

Switchgrass (*Panicum virgatum* L.) growth during the summer months can provide forage for livestock when cool-season grasses are unproductive. The influence of date of first harvest and cutting height on regrowth and canopy structure of 'Pathfinder', 'Blackwell', and 'Cave in rock' switchgrass was studied in order to determine seasonal distribution of dry matter production. Experiments were conducted in Blacksburg, VA on Groseclose-Poplimento soil to determine the influence of three dates of first harvest (10 June, 20 June, and 3 July) and two cutting heights (20 and 30 cm) on yield of switchgrass in 1989 and 1990. To characterize the change of canopy structure before and after harvest the number and weight of tillers in various height categories, yield distribution, light penetration, leafiness, specific leaf weight (SLW), and leaf area index (LAI) of canopy profiles were investigated. First harvest yields of all cultivars increased as date of first harvest was delayed and cutting height decreased. However, in the second growing season cutting height

did not influence yields of first harvest. Yields from 20 and 30 cm cutting heights were equal for Pathfinder switchgrass because of the harmful influence of the 20 cm treatment the previous year. Yields of nontreated plots were higher than yields of plots harvested in the first growing season. Regrowth of all cultivars decreased as date of first harvest was delayed. Height of canopy and height of dominant tillers were decreased as date of first harvest was delayed. As date of first harvest was delayed yield became less uniformly distributed along canopy profiles with more light penetrating to the bottom of the canopy, SLW decreased and LAI decreased. When plants were cut at 30 cm height, yield was more uniformly distributed along canopy profiles, light penetration to the bottom profile decreased, leafiness at lower height levels decreased, and LAI increased as compared with the 20 cm height. In order to shift some growth having high forage quality from early June to July or August, hay should be cut after June 10 but before June 21 when switchgrass development is similar to this study. A cutting height of 30 cm resulted in greater regrowth than 20 cm.

Introduction

Perennial warm-season grasses, such as switchgrass, have great advantages. They complement cool-season species by filling the summer period of low grass production generally refered to as summer-slump. These grasses help to prevent possible weight loss of cattle in the middle of the grazing season and allow for higher stocking rates than would be possible with cool-season grasses only. Also they are well adapted to marginal soils with low productive potential not suited for other agricultural applications. These grasses are common in plains states, but are not traditionally grown in Virginia. Because of their limited importance in Virginia there is little known about their management. However, some research was conducted examining the influence of harvest date, cutting frequency, and cutting height on the yield of warm-season grasses

Influence of cutting frequency on prairie grasses was studied first by Aldous [1]. He reported that increasing frequency of cutting decreases yield. Harlan and Ahring [12]suggested to cut 'Caddo' switchgrass twice in a year and established that switchgrass varieties give different responses to the same cutting management. Study of Newel [15] shows that frequent clipping slowed the growth of switchgrass in the following year. Blue - green, short switchgrass strains were less sensitive to cutting frequency than green, tall strains. Berg [7] concluded that frequent harvest does not allow switchgrass to store enough energy for winter survival and spring growth. Henry et al. [14] found that cutting warm-season grasses monthly instead of twice in a growing season reduced yield if cutting height was low, 8 to 15 cm. Beaty and Powell [6] reported that frequent clipping decreased elongation of tillers on the following spring. Haferkamp and Copeland [11] observed development of switchgrass as influenced by frequency of harvest. The authors concluded that switchgrass plants harvested twice had more aerial, nonrooted shoots than switchgrass plants harvested once and the aerial, nonrooted shoots were more sensitive to winter frost.

Influence of date for first harvest on yield and persistance of switchgrass was investigated more intensively than influence of cutting height or frequency. Baker et al. [4] concluded from their experiment that early cutting decreased the weight of the stem and increased weed development. Sims et al. [17] found that early spring harvest did not influence seedhead production while late spring harvest decreased seedhead production. Henry et al. [14] reported that the best yield of switchgrass can be reached with harvesting dates in July and October or in August and October. Beaty and Powell [6] concluded that under southern conditions switchgrass can be harvested in early spring because in southern areas weed contamination of switchgrass stand was less than in northern areas. Anderson and Matches [2] showed that delaying the date of first harvest reduced regrowth. Haferkamp and Copeland [11] investigated growth and development of switchgrass as affected by three dates of first harvest. The authors observed decreased weight of primary compound shoot, reduced plant vigor, and slow regrowth when switchgrass was mowed in April. Late spring mowing increased the number and weight of secondary, nonrooted, and aerial roots and caused smaller vigor loss than early spring mowing. Further delay of harvest produced additional increase in number of secondary and tertiary shoots. Anderson [3] et al. reported that delaying the date of first cutting weekly increased the yield of first harvest but decreased regrowth. Tiller density at first cutting increased as date of harvest was delayed but tiller density at second cutting was not affected by date of first harvest. George and Obermann [8] found that switchgrass produce high yields in June when cool-season grasses are dormant. They observed the greatest regrowth when the first harvest was taken in early or mid June. Leaf stem ratio was decreased if the first cut was delayed.

Optimal height of cutting strongly correlated with time and frequency of harvest, maturity and height of tillers. Researchers emphasize that removal of growing points weakens switchgrass, reduces yield, increases number of nonrooted, aerial shoots [13,5,17]. Sims et al. [17] mowed switchgrass at 3 cm aboveground and observed decreased yield, ceased elongation of reproductive shoots, and tillering from rhizomes and proaxes. Henry et al. [14] obtained the best stand of switchgrass at a cutting height of 23 cm at all dates of first harvest and the best yield of switchgrass at a cutting height of 8 cm if plants were harvested twice in a year. Anderson and Matches [2] compared yield and regrowth of switchgrass cut at 8 and 23 cm. They reported that cutting at 8 cm resulted in higher yield than cutting at 23 cm. After harvest at 8 cm more than half of the regrowth originated from crown tillers, other half originated from stem buds. After harvest at 23 cm primary shoot development continued. George and Reigh [9] hypothesized that the best basis for cutting management was the relationship between height of leaf tips, upper collar, and apical meristem. However this relationship showed too big variation among cultivars, harvesting dates, nitrogen levels, and years. George and Obermann [8] concluded from their experiment that higher cutting height made possible continious growth of apical meristem and resulted in greater regrowth.

Objectives of our study were to investigate the influence of date of first harvest and cutting height on the yield, regrowth, and yield distribution over the growing season for switchgrass cultivars and describe the change of tiller and canopy characteristics of switchgrass stand before and after harvests. Experiments included a two-yr study of Pathfinder switchgrass and a 1-yr study of Blackwell and Cave-in-rock switchgrass.

Methods and Materials

Field studies were conducted in 1989 and 1990 on the research farm of Department of Crop and Soil Environmental Sciences in Blacksburg VA (37°11″N latitude, 80°25″W longitude, 610 m elevation). The soil was Groseclose - Poplimento soils (deep, well drained, with clayey subsoil, formed on limestone, shale, and sandstone residuum and colluvium).

Pathfinder (Experiment 1) The experiment was conducted on 96 plots (each with a size of 1.5 by 6 m) of Pathfinder switchgrass established in the spring of 1987 and harvested once in 1988. The stand was burned in early spring of 1989. Simazine (2.2 kg/ha) was applied in May of 1989 and 1990. During the growing season dandelion (*Taraxacum officinale*) and bermuda grass (*Cynodon dactylon*) was rogued. Nitrogen was applied in May of 1989 at 88 kg/ha and in May of 1990 at 57 kg/ha. Soil samples taken in May of 1989 showed a pH of 6.35, phosphorus concentration of soil was 60 ppm, potassium concentration was 157 ppm, calcium concentration was 986 ppm, magnesium concentration was 120 ppm.

Plots were arranged in a randomized complete block design. Ten and eleven cutting treatments, with different dates of first harvest and cutting heights, were randomly assigned within four replicates of Pathfinder switchgrass in 1989 and 1990 respectively (Table 3. 1) Yield of Pathfinder switchgrass was investigated as influenced by three dates of first cut, two dates of second cut, and two cutting heights in 1989. Partial statistical analysis of data showed that different dates of second cut did not have a significant influence on yield. Therefore in the following year treatments were changed, influence of four dates of first harvest, one date of second harvest, and two cutting heights on the yield of switchgrass was investigated (Table 3. 1). Additionally the influence of treatments from the previous year on

Table 3.1: Treatments imposed on 'Pathfinder' switchgrass in 1989 and 1990 to investigate the influence of several dates of first and second harvests with different cutting heights. [†]

Harvest number	Date of first cut		Date of regrowth cut		Cutting heights
	1989	1990	1989	1990	
					cm
1	June 10	June 6	July 3	July 3	20 30
			July 14	—	20 30
	Check[‡]	June 6	Check	July 3	20 30
2	June 21	June 19	July 14	July 17	20 30
			July 26	—	20 30
	Check	June 19	Check	July 17	20 30
3	July 3	July 3	Aug. 8	—	30
	Check	July 3	Check	—	20 30

[†] All plots cut to 10 cm on Nov. 3.

[‡] Check treatments were not harvested in 1989

the yield of switchgrass in 1990 was observed by involving check treatments. Plots assigned to check treatments were harvested in the previous year only once at the end of the season.

Canopy characterization of Pathfinder switchgrass in 1989 quantified by measuring yield, light level, leafiness (blade-nonblade ratio), specific leaf weight (SLW), and leaf area index (LAI) measurements at various height levels. Measurements for percent light interception, leafiness, SLW, and LAI were made according to the methods of Wolf et al.[19,20]. Tillers from a square shaped area of 0.37 m^2 were hand harvested for yield measurements of various height levels. Tiller characterization of Pathfinder switchgrass in the growing season of 1989 was made by measuring the weight and percentage of tillers in various height categories. A handfull of tillers were cut at ground level as a sample before harvests. Tillers were separated into height catagories, counted, oven dried in 70°C for 24 hours, and weighed. Axillary and basal tillers were separated within height categories.

Blackwell, Cave-in-rock (Experiment 2) Cave-in-rock and Blackwell switchgrass were involved in the experiment during 1990. Old stands of these cultivars without harvest in the previous year were located on the same soil as Pathfinder switchgrass, on the same Research Farm. Thirty two plots of Cave-in-rock switchgrass (with a size of 1.8 by 6 m) and 28 plots of Blackwell switchgrass (with a size of 1.8 by 5.5 m) were used in the experiment. Simazine was applied at 2.2 kg/ha as weed control two weeks after early tiller emergence. At the same time when simazine was applied, plants were fertilized with 95 kg/ha N. During the growing season of 1990 stands stayed weeed free, and mechanical weed control was not necessary. According to soil test, fertility of soil was maintained at a high level.

Seven and eight cutting treatments were randomly assigned within four replicates of Blackwell and Cave-in-rock switchgrass, respectively. Yield of these cultivars was investigated as influenced by four dates of first cut, one date of second cut, and two cutting heights (Table 3. 2).

Pathfinder, Blackwell, Cave-in-rock (Experiment 1, 2) Plots subjected to treatments with a cutting height of 20 cm were harvested with a rotary mower from 0.5 by 3.7 m strip down the center of the plots. Plots subjected to treatments with a cutting height of 30 cm were harvested with a sickle bar mower from 0.9 by 3.7 m strip down the center of the plots. Harvested fresh yield was dried in a forced - air oven at 60°C for 36 to 48 hours and weighed.

Data were analysed using general linear models procedure [22] and for comparision least significance difference was calculated at 0.05 probability level.

Table 3.2: Treatments imposed on 'Blackwell' and 'Cave in rock' switchgrass in 1990 to investigate the influence of several dates of first harvest with different cutting heights. †

Date of first cut	Date of second cut	Cutting heights
		cm
June 2	June 28	20
		30
June 11	July 10	20
		30
June 21	July 18	20
		30
July 4	Aug. 1	20
		30

† Some plots remain uncut all season to be used in the second year as a comparison of decreased vigor.

Results and Discussion

Pathfinder (Experiment 1)

Yield of first harvest in the first growing season. Date of first harvest and cutting height influenced the yield of first harvest of Pathfinder switchgrass independently of each other in 1989 (Table 3. 3). Delaying the date of first harvest,as expected, increased yield at both cutting heights. At all dates of first harvest yield from plots cut at 20 cm was significantly higher than yield from plots harvested at 30 cm. The difference between yields harvested at different cutting heights shows the amount of tissue developed between 20 and 30 cm height levels. By delaying the date of first harvest this difference increased.

Regrowth in the first growing season. Yield of regrowth was affected independently by the date of first cut and cutting heights. Date of first harvest influenced the yield of second cut via removal of growing points. Researchers emphasize that clipping management, which removes most of the growing points is harmful for switchgrass [13,5,17]. Before the first harvest on June 10, 70% of tillers had growing points below 20 cm, 25% of tillers had growing points between 20 and 30 cm, and 5% of tillers had growing points above 30 cm. This means that cutting at 20 cm on June 10 removed 30% of growing points, while cutting at 30 cm removed only 5% of growing points. Therefore 25% more growing points remained on the plots harvested at 30 cm than on the plots harvested at 20 cm. This is the reason why we obtained higher regrowth by 120% when tillers were first cut at 30 cm than when tillers were first cut at 20 cm. Delaying the second harvest by two weeks resulted in significantly higher second yield.

Before the first harvest on June 21, 44% of tillers had growing points below 20 cm, 39% of tillers had growing points between 20 and 30 cm, and 17% of tillers had

Table 3.3: Yield of 'Pathfinder' switchgrass harvested in 1989 at 20 or 30 cm on different dates for the first cut and after 3 or 5 weeks of regrowth for the second cut.

Harvest number	Date of cut	Height of cutting (cm) 20	30
		– – –– gm^{-2} – – – –	
		First harvest	
1	June 10	166	106
2	June 21	586	240
3	July 3	-	400
LSD @ $\alpha = 0.05$ for means of 12 is 28			
		Regrowth	
1	July 3	49	110
	July 14	70	149
2	July 14	16	15
	July 26	11	58
3	Aug. 8	–	164
LSD @ $\alpha = 0.05$ for means of 4 is 23			

†Values are means of four observations

growing points above 30 cm. This means that cutting at 20 cm removed 56% of growing points, while cutting at 30 cm removed only 17% of growing points. By delaying date of first harvest more growing points were removed at both cutting heights, therefore yield of regrowth was significantly lower when plants were first cut on June 21 than when plants were first cut on June 10. Although less growing point were removed at the first harvest on June 21 when plants were cut at 30 cm than when plants were cut at 20 cm, the difference in regrowth was observable only after five weeks regrowth. Removal of 56% of growing points with harvesting at 20 cm on June 21 did not allow increase of regrowth between the third and fifth weeks after harvest.

Before the first harvest on July 3, 23% of tillers had growing points below 20 cm, 24% of tillers had growing points between 20 and 30 cm, and 53% of tillers had growing points above 30 cm. On this day plants were cut only at 30 cm therefore 53% of growing points was removed. After five weeks of regrowth significantly higher yield was harvested from these plots than from plots with first cut on June 21. This high yield after the first cut on July 3 could be explained by the beneficial influence of defoliation during the dryest summer days. As it is reported by Wolf and Parrish [21] partial defoliation during moisture deficiency improves performance of tillers, because defoliation reduces leaf area for transpiration therefore reducing water-stress on the plants. Plants harvested on July 3 had reduced leaf area during the dryest days of summer, therefore they were able to survive drought better than plants harvested on June 21. Moreover, switchgrass tillers possibly experienced successive moisture deficiency cycles during June. According to growth chamber studies, succesive water-stress cycles induced osmotic adjustment in switchgrass and improved performance of switchgrass during drought (Chapter 2). The increased regrowth after the first harvest on July 3 could be attributed to the beneficial influence of osmotic adjustment or defoliation.

The main purpose of the experiment was to find the best cutting management for switchgrass, which provides the highest regrowth during the summer slump, in the first half of July, when other forage grasses are in shortage. According to these results, in the middle of July the best yield can be obtained if plants are harvested in early June at high, approximately 30 cm cutting height. Considering the height of growing points, switchgrass can give high yield in the dry mid - summer days if harvested in early June removing only 5% of growing points. Very high yields can be harvested if switchgrass is first cut at the begining of July. However George and Obermann [8] reported that in vitro digestable dry matter concentration of both stems and leaves of switchgrass declined quickly during June. In a later study George et al. [10] found that not only in vitro digestable dry matter but crude protein concentration decreased with maturity and with decreasing blade-nonblade ratio.

Yield of first harvest in the second growing season. In the second growing season not only the influence of date of first harvest and cutting height but the influence of treatments from the previous year were evaluated (Table 3.4). Yield of plots which were not harvested in the previous year tended to have higher yields than plots, which were harvested in the previous year. Delaying date of first harvest significantly increased first yields of check treatments. Influence of cutting height and treatments of the previous year on the yield of first harvest counteracted each other. When plots were harvested in the previous year there was no difference in yield between plots cut at 20 cm and plots cut at 30 cm. Although less yield was expected from plots harvested at 30 cm than from plots harvested at 20 cm, cutting at 20 cm in the previous year decreased the vigor of plants so much that clipping at 20 cm in the second season could not give significntly higher yield than clipping at

Table 3.4: Yield of 'Pathfinder' switchgrass harvested in 1990 at 20 or 30 cm on different dates for the first cut and after 4 weeks of regrowth for the second cut. Check plots were not harvested in the previous year.

Date of cut	Number of harvests in 1989	Height of cutting (cm)	
		20	30
		– – –– gm^{-2} – – – –	
		First harvest	
June 6	2	82[†](72)[‡]	37(62)
	1	97(85)	50(83)
	0	114(100)	60(100)
June 19	2	118(49)	144(87)
	1	113(47)	173(104)
	0	239(100)	166(100)
LSD @ $\alpha = 0.05$ for means of 4 is 64, (SEM=2045)			
July 3	1	–	532(126)
	0	521	421(100)
LSD @ $\alpha = 0.05$ for means of 4 is 157, (SEM=12332)			
		Regrowth harvest	
July 3	2	213	292
	0	200	–
July 17	2	100	84
	0	82	–
LSD @ $\alpha = 0.05$ for means of 4 is 56			

[†] Values are means of four observations

[‡] Values in parenthesis are percentages of check plots which were not cut in 1989 and used as a reference to indicate vigor loss.

30 cm. However check treatments, plots not harvested in 1989, showed that without vigor reduction Pathfinder switchgrass produces significantly higher yield when cut at 20 cm than when cut at 30 cm.

Regrowth in the second growing season. There was no influence of treatments from the previous year on the regrowth. Plots harvested in 1989 gave statistically the same yield as plots not harvested in 1989. Influence of treatments from the previous year on the regrowth was overwritten by the influence of date and cutting height of first harvest from the same year. Delaying the date of first harvest reduced regrowth at both cutting heights. Plots harvested at 20 cm gave lower regrowth than plots harvested at 30 cm, because when plants were cut at 20 cm more growing point was removed and regrowth capability of plants decreased more than when plants were cut at 30 cm.

Tiller characteristics. Proportion of basal and axillary tillers of Pathfinder switchgrass in 1989 changed after first harvest (Table 3.5). On both dates of first harvest 100% of tillers was basal tiller. When plants were cut at 20 cm on June 10 which removed 30% of growing points, three weeks later cutting 88% of tillers were basal and 12% of tillers were axillary. This ratio of different tiller types did not change five weeks after cutting. On the other hand when plants were cut on the same date at 30 cm of height which removed only 5% of growing points, no change occured in the ratio of basal and axillary tillers. Three and five weeks after harvest 100% of tillers were basal. When plants were harvested on June 21 growing points were higher than on June 10. Cutting at 20 cm removed 56% of growing points; therefore, three weeks after harvest only 81% of tillers were basal and 19% of tillers were axillary. However, when tillers were cut at 30 cm on June 21, 17% of growing points were removed, which caused the same changes in proportion of tiller types during three weeks than cutting at 20 cm. During the following five weeks

Table 3.5: Percentage of basal and axillary tillers in the canopy of 'Pathfinder' switchgrass as influenced by two dates of first harvest and two cutting heights.

Weeks between harvest and sampling	Type of tiller	Date of first harvest: June 10, Cutting height (cm) 20	June 10, 30	June 21, Cutting height (cm) 20	June 21, 30
		– – – – – –	– – – – – – %	– – – – – –	– – – – – –
0†	Basal	100	100	100	100
	Axillary	0	0	0	0
3	Basal	88(5)‡	100	81(17)	81(2)
	Axillary	12(5)	0	19(17)	19(2)
5	Basal	91(5)	100	—	—
	Axillary	9(5)	0	—	—
8	Basal	—	—	96(3)	77(10)
	Axillary	—	—	4(3)	23(10)

† Data are based on tillers before cutting to 20 or 30 cm.

‡ Values in parenthesis are standard deviations of the means of 4 observations.

this proportion did not change, although 71% of basal tillers dried out.

Before harvests, when stands contained only basal tillers, percentage of tillers in different height categories was investigated (Table 3. 6). At the begining of June half of the tillers (54%) were in the height category from 0 to 40 cm. Ten days later the majority of tillers was found at 60 cm, while the percentage of tillers in that category decreased. Tillers became more uniformly distributed over the profile of the canopy. At the end of June no tillers were in the height category from 0 to 20 cm and the canopy was closed. Investigation of percent of tillers in height categories continued after cutting (Table 3. 7). Average weight and number of tillers in height categories were established three and five weeks after the harvest on June 10, and three weeks after the harvest on June 21. When plants were harvested on June 21, three weeks of regrowth resulted in a smaller canopy with maximal number of tillers in a lower height category than when plants were harvested on June 10. Three weeks of regrowth after cutting on June 10 produced not only higher but more uniform canopy than three weeks regrowth after cutting on June 21. As number of weeks between harvest and sample taking increased from three weeks to five weeks the same changes of percent of tillers in height categories were observed as before harvesting, on undisturbed canopies. Between three and five weeks, height category where most of the tillers were found increased by 20 cm, while the percentage of tillers in that category decreased. Differences in the influence of height of cutting was smaller when plants were harvested later. After cutting at 30 cm the canopy was always higher than after cutting at 20 cm. The height category where the majority of tillers were found was closer to the top of the canopy when plants were harvested at 30 cm than when plants were harvested at 20 cm on June 10. Average weight of a tiller in increasing height categories increased according to the expectation. Tillers tend to be heavier in every height category when plants were

Table 3.6: Percentage of tillers in various height categories of ‘Pathfinder’ switchgrass canopy in 1989.

Sampling	Tiller height categories (cm)					
date	0 to 20	0 to 40	0 to 60	0 to 80	0 to 100	0 to 120
	– – – – – – – – – – – – – –	– –	%– –	– – – –	– – – –	– – – –
June 1	25(4)[†]	54(5)	21(3)	0	0	0
June 10	14(10)	24(4)	40(4)	22(9)	0	0
June 21	0	21(8)	24(5)	30(4)	20(8)	6(4)

[†] Values in parenthesis are standard deviations from means of 4 observations.

Table 3.7: Tiller characteristics of switchgrass regrowth when first cut on 10 June and 21 June to leave 20 and 30 cm stubble heights.

Weeks of regrowth	Tiller height categories	Date of first cut			
		June 10		June 21	
		20 cm	30 cm	20 cm	30 cm
	——cm——	– – –– Weight of tillers (mg/tiller) – – ––			
3	0 to 20	99[†] (42)[‡]	65 (21)	128 (69)	62 (24)
	0 to 40	196 (30)	170 (50)	215 (44)	215 (25)
	0 to 60	331 (66)	416 (131)	297	332 (70)
	0 to 80	385 (52)	725 (175)	–	742 (217)
	0 to 100	–	1457 (551)	–	–
5	0 to 20	60 (19)	25 (25)	–	–
	0 to 40	170 (43)	128 (44)	–	–
	0 to 60	428 (29)	319 (98)	–	–
	0 to 80	941 (156)	586 (148)	–	–
	0 to 100	1662 (141)	1165 (256)	–	–
	0 to 120	–	1858 (461)	–	–
		– – –– % of tillers – – ––			
3	0 to 20	26	14	55	35
	0 to 40	38	19	41	43
	0 to 60	29	16	4	19
	0 to 80	7	41	–	3
	0 to 100	–	10	–	–
5	0 to 20	17	1	–	–
	0 to 40	27	12	–	–
	0 to 60	38	18	–	–
	0 to 80	15	26	–	–
	0 to 100	3	31	–	–
	0 to 120	–	12	–	–

[†] Values are averages of 4 observations

[‡] Data in parenthesis are standard deviations

harvested at 20 cm than when plants were harvested at 30 cm.

Canopy characteristics. The distribution of yield along the canopy profile became more uniform from the middle of June to the end of June similarly to the distribution change of tillers in height categories (Table 3. 8). On both sampling dates the highest yield was obseved between 0 and 20 cm. Amount of dry matter between 20 and 30 cm was 16% on the second sampling date and 19% on the third sampling date, which increases greatly the yield if harvested at 20 cm instead of 30 cm.

Light penetration to the bottom of profiles was highest on June 1 when total canopy height was low. As height of canopy increased less light could penetrate to the bottom of profiles. However at the end of June, when leaves were distributed uniformly along the tillers and tillers were higher, more light reached the bottom of the profiles than on the previous sampling dates.

Leafiness of tillers increased from ground level to the top of the canopy, where blade-nonblade ratio was maximal. At later sampling dates delayed leafiness of the same height category decreased, until at the end of June leaves were most uniformly distributed on the tiller.

Specific leaf weight (SLW) of leaves at the top of the canopy were higher at each sampling date than SLW in the lower part of the canopy, as Wolf and Blaser reported in their article [18]. Low SLW of lower leaves in the canopy is correlated with the low light intensity close to ground level. Pearce and Lee [16] found that SLW of alfalfa leaves grown under low light was lower than SLW of leaves grown under high light.

47% of leaf area index (LAI) was located in the first profile of the canopy from ground level to 20 cm and 53% of LAI was distributed along the following 50 cm, on June 10. LAI became uniform along canopy profile on June 21 as tiller height

Table 3.8: Characteristics of switchgrass canopy on several dates of sampling before first harvest.

Sampling date	Canopy profiles	Canopy characteristics				
		Yield	Light[†]	Leafiness	SLW	LAI
	cm	$g m^{-2}$	%	$g\,kg^{-1}$	$mg\,cm^{-2}$	
June 1	0 to 20	–	23[‡]	510	4.3	–
	20 to 30	–	61	990	4.7	–
	30 to 50	–	88	1000	4.6	–
June 10	0 to 20	504	5	370	5.1	3.80
	20 to 30	127	12	490	4.6	1.31
	30 to 50	120	22	920	5.0	2.21
	50 to 70	44	72	1000	5.5	0.77
June 21	0 to 20	313	10	180	4.4	1.37
	20 to 30	140	19	330	5.2	0.86
	30 to 50	155	26	540	5.2	1.47
	50 to 70	95	48	860	5.8	1.37
	70 to 90	53	83	1000	5.4	0.98

[†] Percentage of light penetrated to the profile.

[‡] Values are averages of 4 observations.

increased and leafiness became uniform.

Yield distribution along canopy profile shows the influence of growing point removal (Table 3. 9). After June 10 when plants were harvested at 20 cm and 30% of growing points were removed, the majority of yield was located in the first 20 cm above ground level. Maximal height of canopy was 70 cm. As sampling date was delayed proportion of the yield in the first profile of the canopy decreased from 63% to 52%. When plants were harvested at 30 cm on the same date and only 5% of growing points were removed, majority of yield was located in two profiles of the canopy, from ground level to 20 cm and between 30 and 50 cm. Maximal height of canopy was 90 cm. As sampling date was delayed distribution of yield along profile became uniform. The canopy was hurt when harvested on June 21 at 20 cm and 56% of growing points was removed. Even when plants were cut at 30 cm and only 17% of growing points were removed yield was lower and less uniformly distributed than the yield of a canopy harvested at June 10 at 30 cm.

When plants were cut at 30 cm at any of harvesting dates the canopy became higher than when plants were cut at 20 cm, therefore less light penetrated to the lower profiles 3 weeks after cutting at 30 cm than three weeks after cutting at 20 cm. The same result was found when sampling date was delayed. Light penetration measurement also shows the destructive influence of harvesting at 20 cm on June 10. Canopies became loose and thin. Even when plants were cut at 30 cm on June 21 more light could reach the lower profiles, canopy became looser than when plants were cut at 30 cm on June 10.

Leafiness was highest in the upper part of the canopy. As cutting height increased from 20 cm to 30 cm less leaf was found in the lower profiles after both harvest dates and on both sampling dates. Delaying the date of first harvest decreased leafiness along canopy profiles. However when plants were harvested on

Table 3.9: Characteristics of regrowth of switchgrass canopy when first cut on 10 June and 21 June to leave 20 and 30 cm stubble heights.

Weeks of regrowth	Profiles	Date of first cut			
		June 10		June 21	
		20 cm	30 cm	20 cm	30 cm
	——cm——	———— Yield (g/m^2) ————			
3	0 to 20	134[†] (63)[‡]	193 (38)	100 (91)	136 (61)
	20 to 30	44 (21)	98 (19)	10 (9)	54 (24)
	30 to 50	35 (16)	126 (25)	–	20 (9)
	50 to 70	–	93 (18)	–	14 (6)
5	0 to 20	152 (52)	135 (25)	21 (100)	117 (50)
	20 to 30	63 (21)	93 (18)	–	56 (24)
	30 to 50	57 (19)	133 (25)	–	39 (16)
	50 to 70	23 (8)	99 (19)	–	23 (10)
	70 to 90	–	70 (13)	–	–
		——— Light penetration (%) ———			
3	0	31	12	53	33
	20	58	26	86	61
	30	77	36	–	78
	50	–	61	–	92
5	0	20	8	80	44
	20	37	15	–	67
	30	50	15	–	84
	50	80	23	–	85
	70	–	64	–	–
		————— Leafiness (g/kg) —————			
3	0 to 20	250	100	210	160
	20 to 30	410	310	770	180
	30 to 50	870	540	–	560
	50 to 70	–	930	–	860
5	0 to 20	240	90	570	250
	20 to 30	470	200	–	410
	30 to 50	760	380	–	710
	50 to 70	840	630	–	710
	70 to 90	–	860	–	–

[†] Values are averages of 4 observations

[‡] Data in parenthesis are percentages of total profile

Table 3.9: Continued

Weeks of regrowth	Profiles	Date of first cut			
		June 10		June 21	
		20 cm	30 cm	20 cm	30 cm
	——cm——	—————— SLW (mg/cm^2) ——————			
3	0 to 20	5.1[†]	5.3	3.8	3.3
	20 to 30	5.9	5.6	5.2	4.3
	30 to 50	6.7	6.9	–	4.9
	50 to 70	–	7.2	–	5.7
	avg.	5.5	6.0	3.9	3.7
5	0 to 20	3.6	4.8	5.3	4.0
	20 to 30	3.8	4.4	–	4.3
	30 to 50	4.3	5.1	–	5.3
	50 to 70	5.5	5.2	–	6.4
	70 to 90	–	6.1	–	–
	avg.	3.9	5.0	5.3	4.4
		————————— LAI —————————			
3	0 to 20	0.66 (44)[‡]	0.35 (11)	0.55 (79)	0.63 (48)
	20 to 30	0.33 (22)	0.53 (17)	0.15 (21)	0.23 (18)
	30 to 50	0.51 (34)	0.98 (32)	–	0.23 (18)
	50 to 70	–	1.21 (40)	–	0.21 (16)
	Total	1.50 (100)	3.07 (100)	0.70 (100)	1.30 (100)
5	0 to 20	1.00 (33)	0.25 (6)	0.22 (100)	0.72 (35)
	20 to 30	0.73 (23)	0.40 (10)	–	0.52 (26)
	30 to 50	0.97 (32)	1.05 (27)	–	0.52 (26)
	50 to 70	0.37 (12)	1.23 (32)	–	0.26 (13)
	70 to 90	–	0.96 (25)	–	–
	Total	3.07 (100)	3.89 (100)	0.22 (100)	2.02 (100)

[†] Values are averages of 4 observations

[‡] Data in parenthesis are percentages of total profile

June 21, light penetration to the lower profiles increased, canopy became looser, leafiness at ground level increased as sampling date was delayed.

Specific leaf weight at the top of the canopy was always higher than on the bottom of the canopy. Increase of SLW from the lower profiles toward the higher profiles was smallest, density of leaves along profiles was most uniform three weeks after cutting when plants were harvested on June 10 at 30 cm. Delaying date of first harvest decreased density of leaves three and five weeks after cutting. When plants were cut at 30 cm on June 10 density of leaves was higher than when plants were cut at 20 cm on the same date. SLW of leaves in the loose canopy, which was the result of 20 cm cutting on June 21 was high 5 weeks after cutting. High SLW of tillers can be caused by high light penetration to the thin canopy.

Distribution of LAI among profiles became uniform as sampling date was delayed. When plants were harvested on June 10 LAI was higher than LAI of plants harvested on June 21 for both cutting heights. When plants were harvested on June 10 at 20 cm, 30% of growing points were removed, or on June 21 at both cutting heights, 56% and 17% of growing points were removed respectively, LAI was the highest close to ground level, between 0 and 20 cm. However when plants were harvested on June 10 at 30 cm and only 5% of growing points were removed, maximal LAI was found in the profile between 50 and 70 cm. Despite the fact that height of canopy increased by 20 cm between the third and fifth weeks after harvest profile of maximal LAI did not change.

Blackwell, Cave-in-rock (Experiment 2)

Yield of first harvest. Influence of date of first harvest and cutting height was investigated on Blackwell and Cave-in-rock switchgrass also in 1990 (Table 3.10). Date of first harvest and cutting heights affected the first and second yield of both cultivars independently of each other. First yield of both cultivars increased as date

Table 3.10: Yield of 'Blackwell' and 'Cave in rock' switchgrass in 1990 harvested at 20 or 30 cm on different dates for the first cut and after 4 weeks of regrowth for the second cut.

Cultivars	Cutting height	Date of first harvest				avg.
		June 2	June 11	June 21	July 4	
	—cm—	g/m^2				
Blackwell		First harvest				
	20	209[†]	411	646	–	–
	30	99	291	483	683	389
	avg.	154	351	564	–	
	LSD @$\alpha = 0.05$ for means of 8, 16 are 34, 24 respectively					
		Regrowth harvest				
	20	435	194	36	–	–
	30	400	204	50	11	218
	avg.	418	199	43	–	
	LSD @$\alpha = 0.05$ for means of 8, 16 are 38, 27 respectively					
Cave in rock		First harvest				
	20	215	451	698	1237	679
	30	118	356	498	1039	503
	avg.	160	403	598	1138	
	LSD @$\alpha = 0.05$ for means of 8, 16 are 62, 44 respectively					
		Regrowth harvest				
	20	473	172	46	10	193
	30	388	178	37	7	153
	avg.	435	175	42	9	
	LSD @$\alpha = 0.05$ for means of 8, 16 are 47, 33 respectively					

[†] Values are means of 4 observations.

of first harvest was delayed and cutting height decreased. The difference between harvested dry matter from 20 and 30 cm increased as date of first harvest was delayed.

Regrowth. Regrowth of Blackwell switchgrass decreased as date of first harvest was delayed. The later Blackwell was cut first and the tillers were more mature, the more growing point was removed reducing the capacity of regrowth of tillers. Dominant growing point height on June 10 was 33 cm, on June 21 was 41 cm, on July 4 was 51 cm, which suggests that delaying the first cut increased the amount of removed growing points. Therefore the later Blackwell switchgrass was harvested the lower the regrowth. However, dominant growing points always were above 20 and 30 cm therefore cutting height did not cause any difference in regrowth. The same influence of date of first harvest and cutting height on regrowth was found in case of Cave-in-rock switchgrass. Dominant growing point heights were higher for Cave in rock than for than for Blackwell. Dominant growing point of Cave in rock on June 10 was 38 cm, on June 21 was 46 cm, on July 4 was 56 cm. As first harvest was delayed height of growing points increased for Cave in rock, therefore capacity of regrowth and second yield decreased. However there was no difference when plants were cut at 20 or 30 cm because dominant growing points always were above 20 cm.

Conclusion

Investigation of the influence of dates of first harvest and cutting heights on the yield of Pathfinder, Blackwell, and Cave-in-rock switchgrass suggested that the highest regrowth can be achived if plants are cut first at the begining of June while being carefull not to remove growing points. Delaying the date of first harvest increased first yield but decreased regrowth. Harvest at 20 cm resulted in higher yield than harvest at 30 cm in the first year. A cutting height of 20 cm decreased vigor of switchgrass in the second year especially if plants were harvested at the end of June. First yield in the second growing season was decreased by any harvest in the first season when compared with no harvest in the first growing season.

Tillers of undisturbed canopies were uniformly distributed in height categories at the end of June. In regrowth after first harvest, height and uniformity of canopy and height category where majority of tillers were located decreased as date of first harvest was delayed and cutting height decreased. From the investigation of canopy characteristics I can conclude that a harvest on June 21 at 20 cm harmed switchgrass, since regrowth after cutting reduced. As an influence of light penetration to the bottom of the canopy leafiness and SLW increased between sampling dates. As date of first harvest was delayed yield became less uniformly distributed, more light penetrated to the bottom of the canopy, SLW, and LAI decreased. When plants were cut at 30-cm, regrowth was more uniformly distributed among canopy profiles, light penetration to the bottom profile decreased, leafiness at lower height levels decreased, LAI increased as compared with 20-cm cutting height.

Switchgrass regrowth can be utilized best for substitution of cool-season grasses if first cut in the begining of June with a cutting height, which does not remove growing points. Harvests at the end of June destroyed the structure of canopy and reduced yields severely. This was especially true if cutting height was 20-cm.

Early June harvest results in sufficient regrowth of switchgrass which can supply forage for animal production during the summer slump. Moreover, canopy characteristics after early June harvest suggest that regrowth will have good quality which improves acceptance of switchgrass by animals. After early June harvest, light penetration to the bottom of the canopy will be minimal which will cause slow weed development.

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