Quantifying the Effects of Temperature and Nitrogen on Switchgrass Growth and Development

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Introduction and Background

- **Switchgrass** (*Panicum virgatum*) is one of the dominant grass species with C4 syndrome.
- Highly productive, 9 to 14 Mg ha\(^{-1}\) across a range of growing conditions.
- Ecologically and energetically important and valuable plant species.
- Temperature- and nitrogen-specific functional relationships will be useful to improve the current models.
Objectives:

• To investigate the effects of temperature and nitrogen nutrition on switchgrass growth and development.

• To provide temperature- and nitrogen-dependent functional algorithms for switchgrass growth, development and physiology for modeling.
Approach:

➤ Experiment I was designed to generate functional algorithms between temperature and switchgrass growth and development in the SPAR Units.

www.spar.msstate.edu
Materials and Methods

Experiment I: Temperature study:

— Cultivar, Alamo.

— All plants were grown in the SPAR chambers from sowing to 34 days after sowing at 28/20 °C and 400 ppm [CO$_2$].

— Temperature treatments were imposed at 34 days after sowing on established plants for 69 days (103 days of sowing).

— Optimum water and nutrient conditions were provided throughout the experiment.
**Materials and Methods**

**Experiment I: Temperature study:**

<table>
<thead>
<tr>
<th>Day/Night temperature, °C</th>
<th>Average temperature, °C</th>
<th>SPAR Chamber [CO₂], ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/14</td>
<td>18.4</td>
<td>400</td>
</tr>
<tr>
<td>28/20</td>
<td>23.7</td>
<td>400</td>
</tr>
<tr>
<td>34/26</td>
<td>29.0</td>
<td>400</td>
</tr>
<tr>
<td>40/32</td>
<td>34.7</td>
<td>400</td>
</tr>
</tbody>
</table>
Materials and Methods

Experiment I: Measurements:

— Measured plant height and leaf numbers weekly.

— Panicle appearance was recorded when 50% of the plants showed panicles on the first tiller in each plant.

— Destructive leaf area and dry weights measurements were done three times.

   — 55 DAS and 21 DAT - 6 rows of 10 plants per row
   — 76 DAS and 42 DAT – 2 rows of 10 plants per row
   — 103 DAS and 69 DAT – 3 rows of 10 plants per row

— Monitored photosynthesis twice during the growing season.
Temperature & Switchgrass Growth and Development

Photosynthesis

Photosynthesis rate (µmole CO₂ m⁻² s⁻¹)

Temperature (°C)

1500 µmol m⁻² s⁻¹ PAR
Temperature & Switchgrass Growth and Development

Stem length

![Graph showing the effect of different temperatures on switchgrass growth. The x-axis represents days after sowing, and the y-axis represents plant height in cm. The graph includes lines for temperatures of 20/14 °C, 28/20 °C, 34/26 °C, and 40/32 °C, each with error bars indicating variability. The lines show a positive correlation between days after sowing and plant height, with higher temperatures resulting in greater growth.]
Temperature & Switchgrass Growth and Development

Leaf developmental rates

Days after sowing

Leaves (no. plant$^{-1}$)

Days after sowing

20/14 °C

28/20 °C

34/26 °C

40/32 °C
Temperature & Switchgrass Growth and Development

Stem elongation rate

\[ Y = -3.0688 + 0.2607X - 0.00391X^2; \, r^2 = 0.99 \]
Temperature & Switchgrass Growth and Development

Leaf addition rate

\[ Y = 0.00956 + 0.004094 \times X; \quad r^2 = 0.97 \]
Temperature & Switchgrass Growth and Development

Tiller development

![Graph showing the relationship between temperature (°C) and tillers (no. plant⁻¹) for different dates (21 DAT, 42 DAT, 69 DAT). The graph illustrates a positive correlation between temperature and tiller development.]
Temperature & Switchgrass Growth and Development

Whole plant leaf area development

![Graph showing the relationship between temperature and whole plant leaf area development for different days after treatment (DAT). The graph plots temperature (°C) on the x-axis and leaf area (cm² plant⁻¹) on the y-axis. Three lines represent different DAT: 21 DAT, 42 DAT, and 69 DAT. Each line indicates the average leaf area across different temperatures with error bars for variability. The graph includes letters indicating significant differences at each temperature.]
Temperature & Switchgrass Growth and Development

Plant biomass

![Graph showing the effect of temperature on plant biomass growth at different days after treatment (DAT). The graph plots total dry weight (g plant⁻¹) against temperature (°C) for 21, 42, and 69 DAT. Different letters indicate statistically significant differences between treatments.]
## Temperature & Switchgrass Growth and Development

### Flowering or Panicle initiation

<table>
<thead>
<tr>
<th>Day/night and average temperature, °C</th>
<th>Time to 50% panicle formation, days</th>
</tr>
</thead>
<tbody>
<tr>
<td>22/14 = 18.4</td>
<td>0.0</td>
</tr>
<tr>
<td>28/20 = 23.7</td>
<td>96 ± 3.2</td>
</tr>
<tr>
<td>34/26 = 29.0</td>
<td>80 ± 2.6</td>
</tr>
<tr>
<td>40/32 = 34.7</td>
<td>87 ± 2.0</td>
</tr>
</tbody>
</table>
### Temperature & Switchgrass Growth and Development

**Reproductive development – 103 days after sowing**

<table>
<thead>
<tr>
<th>Day/night and average temperature, °C</th>
<th>Panicles, no. plant(^{-1})</th>
<th>Panicle weight, g plant(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>22/14 = 18.4</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>28/20 = 23.7</td>
<td>3.0 ± 0.60</td>
<td>0.80 ± 0.3</td>
</tr>
<tr>
<td>34/26 = 29.0</td>
<td>7.7 ± 0.46</td>
<td>2.94 ± 0.6</td>
</tr>
<tr>
<td>40/32 = 34.7</td>
<td>6.0 ± 0.60</td>
<td>1.90 ± 0.4</td>
</tr>
</tbody>
</table>
Summary and Conclusions

- Developmental rates such as leaf addition and tiller numbers increased linearly from 15 to 35 °C.

- Time to 50% panicle initiation, however, took 7 additional days at 35°C than at 29°C. Plants grown at 23.4 °C took 96 d, and plants grown at the lowest temperature didn’t initiate panicles during a 103-days period.

- Rates of stems, leaf area development, and biomass accumulation increased linearly from 15 to 29 °C, but unaltered or slightly decreased at 35 °C.
Summary and Conclusions

• Photosynthetic rates followed similar trends with that of biomass and leaf area developmental trends in response to temperature.

• Functional algorithms can be developed from these database, and if incorporated into simulation models might improve the predictability of the models in the real-world situations.
Experiment II was conducted to investigate switchgrass growth and development as affected by nitrogen grown in large pots outdoors.

Approach:
Materials and Methods

Crop husbandry

- Out-door, pot –culture facility (PVC pots with 12-L capacity).
- Row spacing 1 m and 10 plants per pot.
- 120 pots, 40 pots for each treatment, 4 replications per treatment.
- Irrigation - Full strength Hoagland's nutrient solution from emergence to 45 DAS.
Materials and Methods

Nitrogen treatments

• From 45 to 90 days of sowing, the following treatments were imposed:

  ➢ Treatment 1: Continued with Hoagland’s solution (100% N)
  ➢ Treatment 2: 20% of Treatment 1 (20% N)
  ➢ Treatment 3: 0% of Treatment 1 (0% N)

• Well-watered (3-times a day) and all other nutrients supplied.
Materials and Methods

Growth and Physiological Measurements

- Growth measurements, photosynthesis and pigments were collected at 4-day interval.

- Leaf samples were also collected for nitrogen determination at 4-day interval.

- Biomass was collected at 90 days after sowing.
Nitrogen Switchgrass Growth and Development

End of the season growth parameters
90 days after sowing or 45 days after treatment

<table>
<thead>
<tr>
<th>Nitrogen Treatment</th>
<th>Total biomass, g pot⁻¹</th>
<th>Tillers, no. pot⁻¹</th>
<th>Leaf area, m² pot⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% N</td>
<td>317 ± 28</td>
<td>91 ± 6</td>
<td>1.5 ± 0.09</td>
</tr>
<tr>
<td>20% N</td>
<td>276 ± 16</td>
<td>77 ± 2</td>
<td>1.2 ± 0.04</td>
</tr>
<tr>
<td>0 % N</td>
<td>219 ± 7</td>
<td>54 ± 6</td>
<td>0.7 ± 0.02</td>
</tr>
</tbody>
</table>
Leaf Nitrogen and Photosynthesis

Switchgrass – Temporal Trends in leaf Nitrogen

- 100% N - $Y = 2.67 - 0.05622X + 0.001171X^2; r^2 = 0.78$
- 20% N - $Y = 2.75 - 0.06962X + 0.001087X^2; r^2 = 0.93$
- 0% N - $Y = 2.62 - 0.09239X + 0.001407X^2; r^2 = 0.95$

Leaf Nitrogen, g m$^{-2}$

Days after treatment
Leaf Nitrogen and Photosynthesis

Switchgrass Photosynthesis and Leaf Nitrogen

![Graph showing the relationship between temperature (°C) and transpiration (mmol m⁻² s⁻¹). The graph depicts a positive correlation between temperature and transpiration.]
Leaf Nitrogen and Photosynthesis

Switchgrass Photosynthesis and Leaf Nitrogen

\[ Y = 6.75 + 12.98 \times X; r^2 = 0.69 \]
Leaf Nitrogen and Photosynthesis

Functional Groups

Leaf photosynthesis

Environmental Productivity Indices

Leaf N, g m⁻² leaf area

Cotton - C3
Corn - C4
Leaf Nitrogen and Photosynthesis

N and Photosynthesis – Several Crops

Leaf photosynthesis

Environmental Productivity Indices vs. Leaf N, g m\(^{-2}\) leaf area

- Cotton - C3
- Castor - C3
- Corn - C4
Leaf Nitrogen and Photosynthesis

N and Photosynthesis – Several Crops

Leaf photosynthesis

Environmental Productivity Indices

Leaf N, g m\(^{-2}\) leaf area
Leaf Nitrogen and Crop Growth and Development

N and Several Crops – Stem Elongation Rates
Leaf Nitrogen and Crop Growth and Development

N and Several Crops – Leaf Area Expansion Rates

![Graph showing the relationship between Leaf Area Expansion Rate and Leaf N, g m\(^{-2}\) leaf area for Cotton - C3, Castor - C3, Switchgrass - C4, and Corn - C4.](image)
Summary and Conclusions

Nitrogen Responses across Species and Processes

- Functional algorithms varied among crop species and even among crop species within the functional physiological group such as C$_3$ and C$_4$ species.

- Functional algorithms also varied among crop processes in a given species.

- Among the growth, developmental and physiological processes, leaf growth was more responsive to leaf N in all crops.

- The N-specific functional algorithms will be useful in developing models for various crops.
Acknowledgements

This project is funded by Sustainable Energy Research Center at MSU through Department of Energy.

http://www.serc.msstate.edu/
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Questions or Comments?