



Effects of Nitrogen Deficiency on Plant Growth, Leaf Photosynthesis, and Hyperspectral Reflectance Properties in Castor (*Ricinus communis*)

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Rationale and Objectives

- Castor (*Ricinus communis*) is a C₃ oil seed crop that has the potential to be used as a source of bioenergy in the southern United States.
- Castor responds well to management practices, particularly, nitrogen because of its rapid and indeterminate growth habit.
- Early detection of N-deficiency helps crop managers in correcting the nitrogen nutrition deficiency which impacts growth and seed yield.
- Traditional methods of detecting leaf nitrogen status involve destructive sampling and laborious laboratory methods.
- Remote sensing of canopy and leaf reflectance is a timely and inexpensive method for estimating plant growth and leaf N status.
- Hyperspectral remote sensing has been used to detect leaf nitrogen status in several crop species such as cotton, corn and several forage species.
- The influence of nitrogen nutrition on growth, development and physiology of many bioenergy crops including castor has not been fully investigated. In addition, N-specific spectral algorithms are also not investigated in castor.

Objectives:

- To investigate changes in leaf nitrogen, physiology, growth and canopy reflectance of castor grown under various rates of nitrogen nutrition.
- To develop functional relationships between leaf N and growth and developmental rates.
- To detect and to establish functional relationships between canopy reflectance and leaf N and chlorophyll pigments.
- Identify best wavebands to be used for N management in castor production.

Methodology and Measurements

The experiment was conducted in out-door, pot culture conditions at the Mississippi State University's Plant Science Research Center, Mississippi State, MS, during the 2006 growing season. Plants were grown in 12-L PVC pots (0.65 m X 0.15 m) filled with fine sand as growing medium.

Treatments:

- All plants were irrigated with half-strength Hoagland's nutrient solution, three times a day, from emergence to 34 days after sowing.
- Thereafter, one set of 80 plants with four replications (20 plants per replication) continued with standard Hoagland's solution while the other two treatments (80 plants with 4 replications each) received 20% N (20% N) and 0% N (0% N) of control from 34 to 66 days after sowing.

Measurements:

- Growth measurements, photosynthesis and pigments were collected from all treatments at 4-day interval throughout the treatment period.
- Samples for leaf nitrogen were also collected at 4-day interval and the leaf N content was determined using micro-Kjeldahl procedure.
- Biomass was collected at 66 days of sowing and 32 days of treatment.
- Leaf hyperspectral reflectance measurements (350–2500 nm) were obtained using a backpack ASD (Analytical Spectral Device, Inc.) spectroradiometer and a supplemental light source (ML-902, Makita corporation, Aichi, Japan).
- Spectra (5 per replication) were collected from each treatment at 4-day interval throughout the treatment period.

Spectral Analysis:

- From the time-series measurements of leaf N, and plant growth and photosynthesis measurements, functional relationships were calculated.
- Five spectra from each of the four replications were first averaged and again averaged over the replications.
- Then, the data were averaged over 10-nm intervals to decrease the amount of data for analysis.
- Thereafter, spectral reflectance values were regressed against leaf nitrogen and chlorophyll amounts, and coefficients of determination (R²) were calculated.
- The reflectance value at given waveband with greatest R² was used to divide the rest wavebands to calculate reflectance ratios. Further, the first derivatives of reflectance were also calculated.
- First derivatives of reflectance, normalized values of reflectance and reflectance ratios with best wavebands, were calculated and regressed against leaf N and pigments to find best R² values.

Growth and Development

- Nitrogen deficiency affected castor growth and development significantly (Fig. 1 & Table 1).
- Leaf N concentrations declined with decreased nitrogen supply throughout the growing period, the decrease was much steeper in the 0 and 20% N treatments than the control (Fig. 2).
- Leaf and stem growth rates were more sensitive to leaf N than node addition rates (Fig. 1 & 3).
- Total plant weight of the 0% and 20% N treatments were about half and one third of the control plants, respectively, 66 DAS.
- Leaf dry weight decreased to a larger extent when compared with stem and root dry weights at the end of the season (Table 1).
- N deficiency caused significant decline in pigment concentrations (data not shown) and rate of photosynthesis (Fig. 3).

Fig. 1. Effect of nitrogen on plant height and leaf area development in castor.

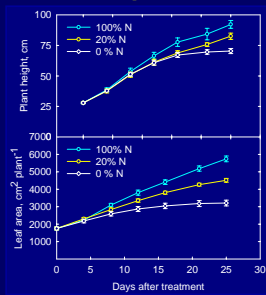


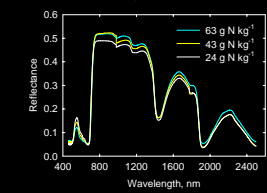
Table 1. Effects of N deficiency on growth and dry matter accumulation, measured at 66 days after sowing.

Treatment	Height, cm	Leaf area, cm ² plant ⁻¹	Dry weights, g plant ⁻¹			Total
			Stem	Leaf	Root	
100% N	111.7±1.6	0.93±0.03	46.1±2.1	70.5±4.3	23.6±2.4	199.8±21.0
20% N	58.37±2.11	0.49±0.03	24.6±1.91	33.15±3.59	20.0±3.8	133.9±5.22
0% N	69.62±6.63	0.23±0.01	10.86±0.41	30.15±1.76	20.09±2.4	69.43±1.93

Remote Sensing and Physiology

- The three N treatments imposed resulted in a wide range of leaf N concentrations (2 to 7%, Fig. 2) and pigment concentrations allowing to develop reflectance algorithms.
- N deficiency increased leaf reflectance at R555 and R 715 nm, and caused a red-edge shift to a shorter wavelengths (Fig. 4).
- Leaf reflectance in the blue and green regions (450–600 nm) and 700–750 nm range are most responsive to changes in N and pigment concentrations in castor.

Fig 4. Plot showing typical spectra of castor plants grown at 3 levels of N nutrition, 22 days after N treatment.



Results

- First derivatives of reflectance and reflectance ratios yielded best correlations for both chlorophyll and leaf N concentrations than single wavebands (Fig. 5).
- Reflectance ratios, however, yielded better correlations with leaf N and pigment concentrations than with the first derivatives (Fig. 5).
- The N concentrations based on area basis (g/m²) and weight basis (g/kg) were positively correlated with leaf reflectance at R455/R585 and R455/R595, respectively (Fig. 5).
- First derivatives of reflectance at R525 nm were negatively correlated with leaf N concentrations based on weight band area basis, and first derivative at R705 was positively correlated with leaf pigments (Fig. 5).
- Best wavebands responsive to N and pigments are presented in Table 2.

Fig 5. Relationship between best reflectance ratios, first derivative of reflectance and Leaf N and chlorophyll content of castor leaves.

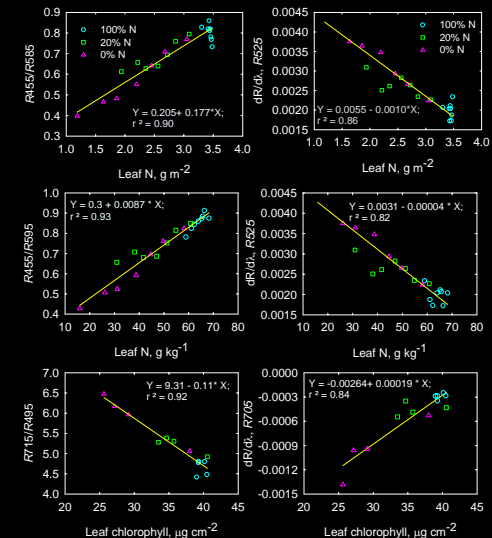


Table 2. Best wavebands for predicting leaf nitrogen and chlorophyll content in castor plants

Parameter	Best bands	Equation	R ²
Nitrogen (g m ⁻²)	455, 585	Y = 0.20 + 0.177 * (R ₄₅₅ + R ₅₈₅)	0.90
Nitrogen (g kg ⁻¹ dry wt)	455, 585	Y = 0.30 + 0.087 * (R ₄₅₅ + R ₅₈₅)	0.93
Chlorophyll (µg cm ⁻²)	715, 495	Y = 9.31 - 0.11 * (R ₇₁₅ + R ₄₉₅)	0.92

Summary and Conclusions

- Castor responds very well to N nutrition due its indeterminate growth habit.
- N deficiency caused severe reductions in castor growth and development.
- Among the plant processes, leaf expansion rate was more sensitive to N deprivation followed by stem elongation, node addition, and photosynthesis.
- Nitrogen deficiency also affected partition of biomass; partition to leaves was decreased most compared to other plant components such as stems and roots.
- Nitrogen stress increased reflectance of castor leaves in the region of 500 – 700 nm.
- Reflectance ratios were found to be the best method in estimating castor leaf N and pigments.
- Nitrogen estimated on percent dry weight basis yielded better correlation than with estimations based on area basis.
- The wavebands identified (Table 2) in this study can be used to estimate castor leaf N and pigments and thus may be used to manage N requirements during the growing season.