Green Canopy Cover Percentage as a Method for Quantifying *Andropogon virginicus* (Broomsedge) Reduction through Fertilizer Applications in a Cool Season Hay Production System

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The XXIV International Grassland Congress / XI International Rangeland Congress (Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods) takes place virtually from October 25 through October 29, 2021.

Proceedings edited by the National Organizing Committee of 2021 IGC/IRC Congress

Published by the Kenya Agricultural and Livestock Research Organization

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Key words: remote sensing; soil fertility; canopy cover; Canopeo]

Abstract
Remote sensing has been used to measure green canopy cover for a variety of agronomic purposes. This study explores the use of digital imagery as a method to quantify warm and cool season grasses in a hay production system. Due to alternate growth periods, cool and warm season grasses show greener color in different seasons. These seasonal color shifts provide an opportunity to measure their respective percentages when growing together in a system. This study was conducted in a hay field that was originally dominated by cool season grasses including tall fescue (*Festuca arundinacea*) and Kentucky bluegrass (*Poa pratensis*), but had been invaded by broomsedge (*Andropogon virginicus*), a native, warm season grass that is known to be an indicator of poor soil fertility. Soil tests for this field revealed a severe potash deficiency. Plots with high percentages of broomsedge would only be greener during the peak times for warm season grasses, and have a lower percentage of green canopy cover throughout the rest of the year, leading to a lower average green canopy cover percentage for the entire year. Thirteen different fertilizer regimens were applied with four replications each in a randomized complete block design (N-P-K kg/ha: 0-0-0, 0-0-202, 0-0-404, 0-45-0, 0-45-202, 0-45-404, 202-0-0, 202-0-202, 202-0-404, 202-45-0, 202-45-202, 202-45-404, 43-43-43). Images were captured with a Nikon D750 DSLR camera and a DJI Phantom 4 Pro V2.0 drone throughout 2020, and analyzed for green canopy cover percentage using the Canopeo application in MATLABR2020b.The two fertilizer treatments showing the highest yearly averages for green canopy cover were those that contained the highest levels of N, P, and K (202-45-202 kg/ha and 202-45-404 kg/ha). This method of collecting data was both time and labor efficient and yielded adequate and useful data.

Introduction
Broomsedge is a warm season perennial that is known for growing on soils with low fertility, especially low phosphorus (Brakie, 2009). Removing harvested forage from hayfields removes large amounts of nutrients, quickly depleting the soil if the nutrients are not replaced. On average, one ton of fescue hay will remove approximately 16kg of N, 8kg of P, and 23kg of K when harvested ("Lime and Nutrient Recommendations," 2020). Warm season grasses are dormant in the cooler seasons and lose their greener color, while cool season grasses are dormant in the summer and can develop a tan or brown color. In Kentucky, warm season grasses are typically active from June to September, and cool season grasses from April to July, and September to November (Ball, Hoveland, & Lacefield, 2015). Because broomsedge is a warm season grass, it can be detected during the cooler times of the year when it is dormant (brown) and the cool season grasses are still active. Cool season grasses can be quantified using green canopy cover analysis in periods of the year when warm season grasses will be dormant and thus brown.

The Canopeo Software Program (OSU Plant and Soil Sciences Department) detects fractional green canopy cover (FGCC) by classifying pixels in a photo as green or non-green by measuring ratios of red:green and blue:green. The program then exports an image that is completely binary black or white, and then quantifies how many pixels are green (Patrignani & Ochsner, 2015). Digital image analysis has been used to measure canopy cover in turfgrass as an alternative method to time consuming hand sampling techniques, and to eliminate some sources of bias and error (Richardson, Karcher, & Purcell, 2001). Combining soil test information with a rapid and labor efficient method of green canopy cover analysis can provide a method for evaluating the composition of hay fields and pastures, as well as for measuring responses to soil amendments.

Methods and Study Site
This study was conducted between from January to November 2020 in a hayfield in Powell County, Kentucky, USA. The field is approximately 0.3 ha (0.8 ac) with a widespread infestation of broomsedge (*Andropogon virginicus).* The hayfield had been harvested for at least 10 years, with sporadic applications of fertilizer that greatly undersupplied potassium.

Thirteen different treatments of fertilizer (see Table 1) were applied in a randomized complete block design with four replications each. Each plot was approximately 3m x 10m. Fertilizer treatments of nitrogen, phosphorus, and potassium (NPK) were as follows:

Treatment	N* (kg/ha)	P** (kg/ha)	K*** (kg/ha)
1	0	0	0
2	0	0	202
3	0	0	404
4	0	45	0
5	0	45	202
6	0	45	404
7	202	0	0
8	202	0	202
9	202	0	404
10	202	45	0
11	202	45	202
12	202	45	404
13	43	43	43

Table 1: Fertilizer treatments in kg/ha
**N applied in split applications in March, May (after first cutting) and mid-August.*
***P applied in March*
****K applied in March for treatments receiving 202kg/ha, and split between March and August for treatments receiving 404kg/ha*

Photos were taken throughout 2020 in January, April, July, and November. January and April photos were taken using a Nikon D750 Digital Single-Lens Reflex (DSLR) camera with an AF-S NIKKOR 20mm f/1.8G ED Wide-Angle Lens and a ProMaster 77mm UV Haze Ultraviolet Filter (4857), and the remainder of the photos taken with a DJI Phantom Pro V2.0 drone. January photos were taken by suspending the camera from a pole at the top of an 8' step ladder so that the camera pointed straight to the ground. A remote control was used to take the photos. Photos taken in April were done from the ground, simply by holding the camera away from the body at arm's length and taking a photo straight down at the ground. Beginning in July, the drone was used for capturing aerial images. The first set of drone images in July were captured at 200' altitude with 80% overlap of images, and the second set in November captured at 50' with 60% overlap. Occupancy grid data was also collected in November. The occupancy grid results are not included in this paper; however, the timing of the method is included for comparison of time efficiencies between methods.

Drone imagery was stitched using DroneDeploy and then each plot was cropped from the full field photo using Adobe Photoshop. All images (digital camera and drone) were analyzed for green canopy cover using the Canopeo application for MATLAB R2020b. Green canopy cover was compared using Excel and RStudio.

Results

[Green Canopy Cover]

Green canopy cover values for ranged from 3.14-11.66% for January 2020, 30.62-65.67% for April 2020, 92.66-99.77% for July, and 6.06-85.78% for November. Yearly averages for green canopy cover ranged from 35.16-64.99%. The treatment with the highest yearly average for green canopy cover was 202 kg/ha N, 45 kg/ha P, and 404 kg/ha K. The treatment receiving no fertilizer had the lowest yearly average for green canopy cover. The month with the highest average green canopy cover was July (98.49%) and the lowest was January (6.72%).

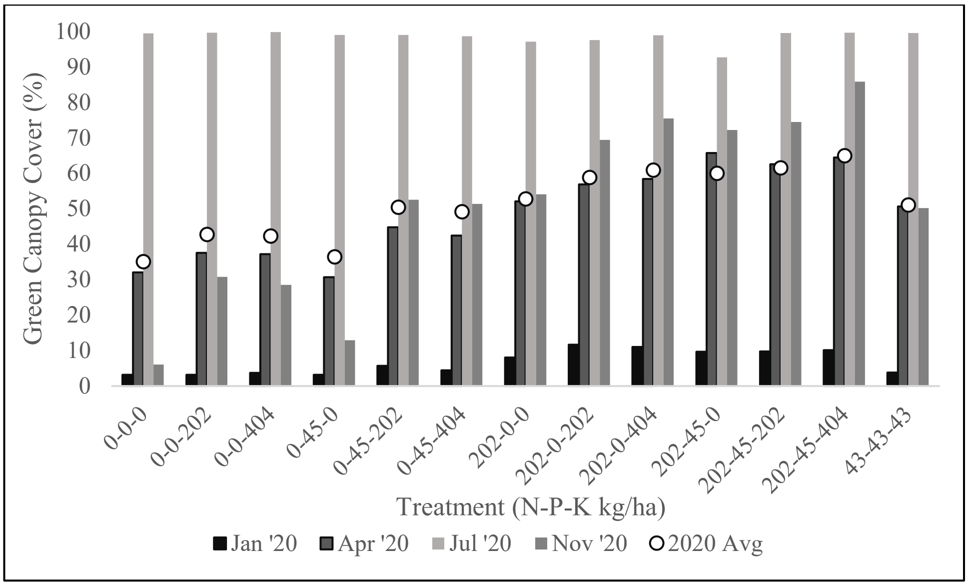

Fig 1: Green canopy cover percentages by treatment for each sampling date and 2020 averages

Collection Method Efficacy

Various methods were used throughout the year, taking different amounts of time to complete. January's images captured with a digital camera took 54 minutes to complete. Drone imagery for July and November took 6 minutes and 9 minutes, respectively, to complete. Occupancy grid data was collected in November by a team of two people, each covering half of the plots and taking approximately 90 minutes to do so.

Discussion

Plots that received complete fertilizer treatments displayed higher green canopy cover measurements during the cooler sampling months of January, April, and November. This would correlate to the larger presence of cool season grasses present in those plots, as compared to the plots that have a smaller proportion of cool season grasses. Plots with a smaller proportion of cool season grasses are those that contain more undesirable warm season grasses such as broomsedge because of poor fertility. Green canopy cover was similar across all treatments during July. This may be due to the cool season grasses in the well fertilized plots retaining their green color, and under fertilized plots appearing green due to the undesirable warm season grasses being active. The large range between the treatments in November is noteworthy, showing that proper fertilization can keep a stand of grass productive late into the season.

The most time efficient method for collecting visual imagery to process for green canopy cover was certainly the drone, however this was also the most expensive method. This method also requires training in order to fly the drone, as well as to process the images in different software programs. The digital camera used in this study was also expensive, however many digital cameras exist on the market at more affordable prices. A digital camera or smartphone camera is likely more accessible to most farmers, and these images can be directly imported to Canopeo either on a computer or directly through the smartphone application. The time and skill involved to complete processing and analysis of the data as collected by the different methods for the layperson requires further investigation. Either the drone or digital camera are still far more time efficient than occupancy grid sampling, and the precision and accuracy of these methods is still yet to be compared.

Acknowledgements

The authors would like to thank the University of Kentucky College of Agriculture, Food and Environment for supporting this research, as well as Dacha Farm for allowing us to conduct this experiment on their land.

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