Multi-species Cover Crop Biomass Evaluation Using a Hand-held Normalized Difference Vegetation Index (NDVI) Sensor and Photosynthetically Active Radiation (PAR) Sensor

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Abstract. Cover crops are essential in agricultural management and especially in organic farming for protecting the soil from erosion, competing with weeds, preventing evaporative losses and improving soil quality and fertility. The choice of cover crop species is crucial in achieving the highest level of weed suppression and soil fertility enhancement. Cover crop systems with rye or mixtures of legumes and grasses were set up in a randomized complete block design in Northern Greece. A hand held sensor was used to measure Normalized Difference Vegetation Index (NDVI) of the cover crop plots with parallel measurements of light interception with a PAR sensor, and destructive biomass determination. Weed biomass was also determined for each cover crop mixture. Multi-species cover crops produced higher total biomass than single-species cover crop systems. All cover crop systems evaluated were able to suppress weeds. Remote sensing results showed that NDVI could be used to estimate the total biomass of single cover crops but not cover crop mixtures.

Keywords: cover crops, biomass, weed suppression, NDVI (Normalized Difference Vegetation Index), light interception, PAR, organic agriculture.

1 Introduction

A key issue in organic agriculture is weed suppression to prevent competition with cultivated crops. The use of chemical herbicides is not allowed in organic agriculture, creating a great need to enlist cultural or mechanical methods to control weeds. Mechanical methods include plowing and frequent use of hoeing, disking, harrowing or cultivating (Liebman and Davis, 2009). Mechanical disturbance of the soil increases the risk of soil erosion and exposes lower soil layers to increased oxidation resulting in loss of CO_2 (Rodale Institute, 2012). Cultural weed control methods include intercropping, crop rotations and the use of cover crops (Liebman and Davis,

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2009). Cover crops are crops planted with the sole purpose of protecting the soil, competing with weeds and improving soil quality and fertility (Clark (ed.), 2007). Cover crops provide a wide range of benefits. They help reduce soil erosion, improve soil quality, control weeds, assist with biological control and enhance soil fertility (Dabney *et al*., 2001; Worsham, 1991). Single species or multi-species cover crop mixtures can be used depending on the agroecological zone and the type of farming system used (Wortman *et al*., 2012). The choice of cover crop species is crucial for the achieving the highest level of weed suppression and soil fertility enhancement. Multi-species cover crop mixtures containing both legume and grass cover crops have been shown to have increased productivity and resilience compared to single species cover crops (Wortman *et al*., 2012). This effect appears to depend on the type of cover crop mixtures used and the farming system and in some cases, no enhanced weed suppression or increased productivity of the subsequent crop was observed in multi-species cover crop mixtures when compared to single cover crops (Smith *et al*., 2014).

A cover crop trial was set up where individual species or multi-species cover crops were compared for their ability to suppress weeds and enhance soil fertility. The effect of each cover crop system on weed species was monitored and the biomass and diversity of weed species in each cover crop system was measured. To avoid the need to use destructive methods of biomass estimation, a hand held NDVI sensor was used. Remote sensing with NDVI sensors shows high correlation with biomass in grasses (Serrano *et al*., 2000).

Total crop biomass was measured by collecting crop samples and the relationship between normalized difference vegetation index (NDVI) from a hand-held sensor and the estimated crop biomass was evaluated. The objective of the study was to assess the ability to monitor the development of cover crop mixtures and be able to estimate final crop biomass through the use of non-destructive NDVI sensors. Partial results are reported in this paper.

2 Materials & Methods

2.1 Experimental Design

The cover crop trial was set up at Zannas Farm owned by the American Farm School, which is located in Chalkidona, Greece, with annual precipitation of 450 mm. The experimental design was a Complete Randomized Block Design (CRBD) with four blocks and six treatments within each block. The size of each plot was 30 x 9 m.

Five cover crop systems were used; a) AVEX + Rye, b) TRITIMIX, c) Vetch + Oats, d) Rye, e) Lollium, and f) a non-cultivated fallow as a control. The crop composition of each multi-species mixture is listed in Table 1. The two crop mixtures AVEX and TRITIMIX were provided by the seed company Fertiprado in Portugal. The field was cultivated and planted in mid-January. The establishment of the cover crops was originally planned for late October, but due to unusual wet weather in

Northern Greece during the months of October to December we were not able to prepare the fields and plant before January.

Table 1. Composition of cover crop mixtures

Cover crop misture	Original cover crop species	Added species
AVEX + Rye	*Avena strigosa, Lollium multiflorum Vicia vilosa, Vicia Sativa, trifolium suaveolens, trifolium squarrosum, trifolium bersim*	12.5% rye (*Secale cereale)*
TRITIMIX	*Triticum secale, Lollium multiflorum, Vicia vilosa, Vicia sativa, Trifolium suaveolens, Trifolium squarrosum, Trifolium bersim*	
Vetch + oats	*Vicia sativa* (80%)	20% oats (*Avena sativa*)

The seeding rate used listed in Table 2. There was no fertilizer added to the plots.

Table 2. Seeding rate of cover crops

Cover crop mixture	Kg/ ha, primary mixture	Kg/ha, added crop
AVEX + Rye	61	9
TRITIMIX	70	–
Vetch + Oats	56	14
Rye	70	–
Lollium	70	–

2.2 NDVI and incident Photosynthetically Active Radiation (PAR) light monitoring

NDVI monitoring was performed using an NDVI hand-held sensor. PAR light above and below the cover crop canopy was measured with a canopy analysis system (Delta-T Devices SunScan SS1) and the percent of PAR light intercepted (Li %) was calculated using equation 1.

$$Li\ (\%) = \left\{1 - \left(\frac{PAR_t}{PAR_b}\right)\right\} * 100\ . \qquad (1)$$

Where Li = PAR light intercepted, PAR_t *= PAR transmitted through the canopy,* PAR_b *= PAR beam incident upon the canopy.*

2.3 Field biomass sampling

In early May, at the full flowering stage for most crops, three samples from each plot were harvested using a 0.5m*0.5m square frame. The weeds were separated and the samples were dried at 60°C to a constant dry weight.

2.4 Statistical analysis

Statistical analysis was performed using JMP Pro v.11.0, SAS Institute Inc.

3 Results & Discussion

All five cover crop systems evaluated were able to suppress weed growth in most experimental plots. The cover crop with the highest biomass was TRITIMIX, which was significantly higher than the single-species cover crops Lollium and Rye, with an estimated biomass of 12,470 kg/ha (Table 3.). AVEX+Rye and Vetch+Oats had the second largest biomass, but they were not significantly different from Lollium or Rye (Table 3).

a
b
c

Fig. 1. The three photos illustrate the experimental plots with cover crops (a, b) and the non-cultivated fallow plot (c).

Light interception by the cover crops ranged from 92.5% for Vetch+Oats to 38.3% for Rye (Table 3). Even though Rye allowed more radiation to penetrate its canopy, there were no weeds detected in the Rye plots, possibly due to the allelopathic properties of Rye.

One possible explanation for the small differences detected is that the cover crops were planted late. This prevented the legumes in the multi-species cover crops from optimal development, while the grass species were better able to develop in the colder temperatures of January. Legumes in the multi-species cover crops did not perform as well as grass species and contributed less than their full potential in total biomass (data not shown).

Table 3. Biomass, NDVI and % Li of cover crops before termination.

Cover crop	Biomass (kg/ha)		Weed Biomass (kg/ha)	NDVI		Intercepted PAR (Li %)	
TRITIMIX	12,470	a	ND*	0.63	b	64.9	a,b
AVEX + Rye	10,335	a,b	ND*	0.69	a	74.9	a,b
Vetch+Oats	9,910	a,b	ND*	0.71	a	92.5	a
Lollium	7,105	b,c	ND*	0.69	a	60.6	a,b
Rye	5,950	b,c	ND*	0.61	b	38.3	b,c
Fallow	2,630	c	-	0.36	c	20.9	c

Levels not connected by the same letter are significantly different (LSD at the 5% level)
*ND = weeds not detected

Using a regression analysis of the relationship of NDVI with crop biomass found that it was not statistically significant, when analyzing all field plots (Fig. 2).

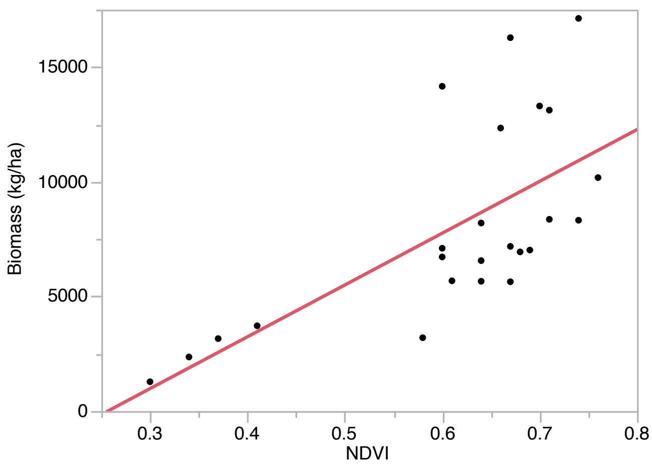

Fig. 2. Regression analysis of biomass vs. NDVI of all cover crops.

When single cover crop systems were analyzed though, the relationship of NDVI and crop biomass was statistically significant for the single cover crop species plots

(Table 3.). A strong regression relationship was found for Lollium (R^2=0.94) and for Rye (R^2=0.81). A similar relationship was found in the fallow plots, which were not cultivated and only weeds were grown. The inability to obtain a good regression relationship between NDVI and crop biomass can be attributed to the complex canopy structure of densely planted cover crop mixtures, which contain grasses and legumes. Grains, such as rye and oats grow taller, while some of the trifolium species of legumes remain lower in the canopy. As leaf area index increases, the regression relationship becomes weaker and NDVI cannot be used to predict biomass reliably (Serrano *et al.*, 2000).

Table 3. Results of the regression analysis of biomass vs. NDVI for individual cover crops.

Parameter	R^2
All field plots Biomass vs. NDVI	0.45*
Lollium biomass vs. NDVI	0.94*
Rye biomass vs. NDVI	0.81 ns
Tritimix biomass vs. NDVI	0.34 ns
Vetch-oats biomass vs. NDVI	0.42 ns
Avex+Rye biomass vs. NDVI	0.47 ns
Fallow biomass vs. NDVI	0.99*

* Significant at the 0.05 probability level.

4 Conclusions

All cover crop systems studied performed well in producing sufficient biomass and suppressing weed development in the experimental plots. Multi-species cover crops were more productive and demonstrated the potential to provide higher biomass and very satisfactory weed suppression. In terms of using remote sensing to monitor cover crop development, the complex canopy structure of a densely planted multi-species cover crop, presents a greater challenge in using an NDVI sensor as a monitoring device. Further studies will be required to determine a method of using NDVI sensors in the ground and/or aerial measurements to estimate biomass in multi-species cover crops. The handheld NDVI sensor along with the canopy analysis system (PAR and Li) can be used successfully in estimating very efficiently the biomass in single cover crops systems.

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