Modelling critical NDVI curves in perennial ryegrass

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Abstract

The use of optical sensors to measure canopy reflectance and calculate crop index as e.g. normalized difference vegetation index (NDVI) is widely used in agricultural crops, but has so far not been implemented in herbage seed production. The present study has the purpose to develop a critical NDVI curve where the critical NDVI, defined as the minimum NDVI obtained to achieve a high seed yield, will be modelled during the growing season. NDVI measurements were made at different growing degree days (GDD) in a three year field experiment where different N application rates were applied. There was a clear maximum in the correlation coefficient between seed yield and NDVI in the period from approximately 700 to 900 GDD. At this time there was an exponential relationship between NDVI and seed yield where highest seed yield were at NDVI ~0.9. Theoretically the farmers should aim for an NDVI of 0.9 and intervene in case of a lower NDVI, which means to apply more nitrogen (N). However, this might be impossible in some years. From a practical point of view aims are therefore to obtain the highest NDVI as late as possible in the growing season and if NDVI has to increase this is done by an additional N application at a time where the crop is able to take up and utilise the applied N.

Introduction

Critical nitrogen (N) dilution curves (CNC) are defined as the critical plant N concentration at different shoot biomasses levels (Lemaire & Gastal, 1997). If CNC can be linked to seed yield by defining the minimum plant N concentration at different biomasses to give maximum yield suggests that N is the limiting factor to obtain a high seed yield. It is very appealing to introduce CNC in practical seed production as discussed by Gislum and Boelt (2009a). Besides a situation where N is not the only limiting factor to obtain a high seed yield the use of CNC is not for practical agriculture in its present form. However, the concept of monitoring the crop during the growing season and intervene according to the result of the monitoring to achieve a high seed yield is great.

The use of optical sensors measuring canopy reflectance and influx of light to calculate a crop index e.g. normalized difference vegetation index (NDVI), to predict final yield or for variable-rate N fertilization is well known within agricultural. Raun et al. (2005) showed the possibility to use an optical sensor-based algorithm for N fertilization in winter wheat and discussed both the effects on yield and the possibilities to decrease environmental contamination due to excessive N fertilization. The environmental effects of using optical sensors to adjust N fertilization was further discussed by Roberts et al. (2010), who supported the environmental benefits from using optical sensors in corn to adjust N fertilization, but on the precondition that the sensor information can be processed by a decision-rule algorithm into an N rate that approximates the optimal N rate. Not only the possibility to increase yield by a higher utilization of N applied but also the environmental benefits from using optical sensors was a great inspiration for us when we developed a partial least square regression model to predict seed yield in perennial ryegrass (Gislum & Boelt, 2009b). Even though the number of publications on optical sensors, N and yield in agriculture is enormous the concept has not been implemented in practical seed production around the world.

If optical sensors are going to be part of practical seed production it is critical that the method has to be cheap to buy and run, and easy and robust to use and most important be economically profitable for the seed grower. The technical part of this we will leave for the engineers to solve, but the agronomic part is left for us to solve. Based on our agronomic knowledge from several field experiments with different N application rates and N application strategies we are aware that things change during the growing season and N is seldom the only limiting factor for a high seed yield. Based on this it would be obvious to use the concept of CNC and monitor the crop during the growing season. The obvious solution to make CNC more applicable in agriculture would of course be to use optical sensors in combination with the concept behind CNC.

The purpose of this experiment was therefore to develop a critical NDVI curve where the critical NDVI, defined as the minimum NDVI obtained to achieve a high seed yield, was modelled during the growing season.

Materials and Methods

Field experiments with perennial ryegrass were established at Roskilde (1996 and 1998) and at Flakkebjerg (1999) in Denmark. The cultivars used in 1996 were Borvi (diploid) and Grasslands Nui (diploid) but in 1998 and 1999 Grasslands Nui was replaced by Tivoli (tetraploid). For all years and for both locations the purpose of the experiments was to evaluate the effect of different N application rates and application strategies on seed yield. The N application rates were: (spring) 0, 50, 100, autumn/spring 30/120 and 60/140 kg N ha^{-1}. The experimental design was a factoral design with four replicates where N application rate was the main factor.

Canopy reflectance was measured at different times during the growing seasons with a hand-held spectroradiometer (Skye SKR 1800, Skye Instruments Ltd., UK). Solar radiation and canopy reflectance were measured at 640-660 nm (red) and at 790-810 nm (infrared). Five separate measurements were made each covering 1.5 m^2 within each plot. Accumulated growing degree-days (GDD) at base temperature 0^oC were calculated from January 1 in each year.

The five spectral reflectance measurements in each plot at each sampling date were averaged after outlier detection and the mean values were used in the analysis. The total number of canopy reflectance measurements was 1140. From the canopy reflectance data normalized difference vegetation index (NDVI) were calculated using NDVI=($R_{infrared}$-R_{red})/($R_{infrared}$+R_{red}) where $R_{infrared}$ represent canopy reflectance in the infrared and R_{red} represent canopy reflectance in the red regions, respectively. At each measurement of canopy reflectance, the linear correlation coefficient (R^2) between NDVI and seed yield was calculated. All analyses were performed using the procedures PROC GLM and PROC NLIN module within the Statistical Analysis System version 8, software package (SAS, 1999).

Results

Analysis of the correlation coefficients between NDVI and seed yield at the different GDD revealed a large variation ranging from negative correlation coefficients, correlation coefficients close to zero and very high correlation coefficients (figure 1 left). The maximum correlation coefficient was from approximately 700 to 900 GDD.

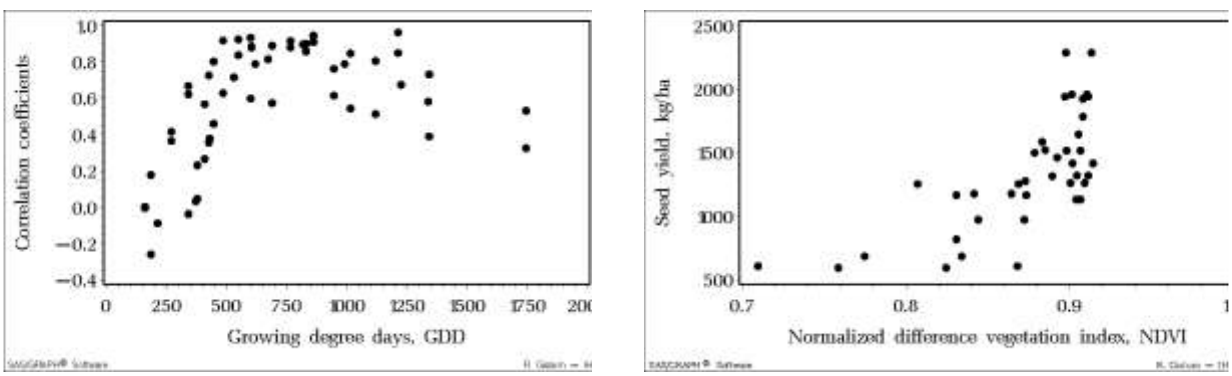

Figure 1. Left: accumulated growing degree days (GDD) plotted against correlation coefficients (R^2). The total number of data points is 55. Right: Normalized difference vegetation index (NDVI) plotted against seed yield (kg/ha) in the period from 700 to 900 GDD.

The relationship between NDVI measurements from 700 to 900 GDD and the seed yield showed an exponential relationship where it was not possible to define maximum NDVI to obtain highest seed yield (figure 1 right).

Discussion

The purpose of modelling a critical NDVI curve during the growing season was determined to be too optimistic due to no significance difference in NDVI at the first period of growth in the spring. During this period there was also a very low or even no correlation between NDVI and seed yield, which will make a critical NDVI curve of no value. Focus was therefore moved to the narrow time period (700 to 900 GDD) where the correlation coefficient is at a maximum. This period is almost identical to the period shown by Gislum and Boelt (2009b). During the 700 to

900 GDD period it is possible to replace a critical NDVI curve by a NDVI value to obtain a high seed yield. During this period the goal should be to obtain an NDVI value as high as possible, which is ~0.9. Results from a similar study showed that the most important spectral information used to describe seed yield is information from (rainfall or soil moisture) and N (Gislum and Boelt, 2009b). Unfortunately the period from 700 to 900 GDD is during the period before and at heading and during this time N application is not recommended in all years. The decision should be made each year.

With the purpose to make the present results applicable in herbage seed production the conclusion is that aims should be to reach an NDVI value at approximately 0.9 at 700 to 900 GDD. The best possible way to increase NDVI is to apply more N and the time for measuring NDVI would therefore have to be adjusted according to the time where N application will still have an effect on the seed yield.

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