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# REFLECTANCE MEASUREMENTS, A QUICK AND NON-DESTRUCTIVE TECHNIQUE FOR USE IN AGRICULTURAL RESEARCH

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**Abstract**

Electro-magnetic radiation from the sun is found at wavelengths of 300-3000 nm. Plants and soil absorb part of this radiation; the remainder is reflected into the atmosphere. Interaction between radiation and plants/soil is dependent on wavelength. Information about the physical and physiological state of the plants can be obtained through spectral analysis of incoming and reflected sun-radiation in a crop.

Recently developed portable equipment for use in field experiments was tested to estimate the potential use of the reflectance technique for growth and yield studies in quinoa (*Chenopodium quinoa* Willd.). Relative Vegetation Index RVI, a measure of the relation between reflectance in a small range of the near-infrared (790-810 nm) and the red (640-660 nm) region ($RVI=\rho_{IR}/\rho_R$), was monitored through an entire cropping season.

RVI increased in a seed- and a green-matter-type of quinoa in the first part of the growth season until anthesis, and was responsive to fluctuations in the amount of green vegetation. The index responded earlier to lack of nitrogen than it did for leaf area index (LAI) and for dry-matter production, indicating that the technique can be used to diagnose nitrogen deficiency. RVI was strongly correlated to final seed yield.

These results show that the reflectance technique can be evaluated using portable equipment to obtain information on growth and nitrogen status of quinoa, and for predicting seed yield.

## Introduction

Quinoa *(Chenopodium quinoa* Willd), a native South American plant species with a high level of resistance to several important stress factors, has been cultivated in the Andean region for over 5000 years. Interest in quinoa has recently spread to Europe, where it has been shown to be a promising, environmentally friendly newcomer with minimal requirements for pesticides and inorganic fertilizers (Jacobsen, 1997).

The present study was conducted to facilitate work on the growth and development of quinoa in agronomical and physiological studies. The technique under discussion can replace numerous harvests of total biomass and leaves without resorting to destructive forms of measurement.

## Materials and methods

The experiment was conducted in 1994 in the field at the experimental station Hoejbakkegaard of the Royal Veterinary and Agricultural University, 20 km west of Copenhagen, Denmark. Two quinoa accessions were studied: Olav and KVL 205, which have been selected in Denmark from Chilean material for green matter and seed production, respectively. Soil type was a sandy loam with 4% organic matter and a pH of 6. Sowing took place on 21 April at a sowing depth of 2 cm and a row spacing of 26.8 cm. Sowing rate was 144 plants/$m^2$. Five levels of nitrogen fertilizers were used: 0, 120, 240, 360 and 480 kg N/ha.

Spectral radiation was measured to calculate the spectral reflectance index of the crop. Four sensors (Skye SKR 1800) were used for measuring incoming and reflected radiation: two red sensors covering 640-660 nm range and two near-infrared sensors measuring between 790 and 810 nm. The sensors were connected to a computer. All measurements were taken at an altitude of 255 cm above the soil surface, giving a sample area of 1 $m^2$, between 2 h before and 2 h after solar zenith.

The Relative Vegetation Index (RVI) is a measure of the relation between the reflectance in a small range of the near-infrared (790-810 nm) and the red (640-660 nm) regions. RVI is calculated from the equation $RVI=\rho_{IR}/\rho_R$, which is the reflectance in the infrared divided by the reflectance in the red region. The reflectance in the infrared spectrum can be shown as $\rho_{IR}=R_{IR} / I_{IR}$, where $R_{IR}$ is the reflection in the infrared spectrum and $I_{IR}$ is incoming infrared radiation, and the reflectance in the red spectrum can be shown as $\rho_R= R_R / I_R$, where $R_R$ is the reflection in the red area and $I_R$ is the incoming red radiation. As plants grow, plant cover increases in the plot to be measured, causing an increase in the RVI index due to higher infrared and lower red reflectance**.**

RVI was measured over intervals of 2-3 days throughout the growing season. The RVI values were calculated as the mean of three observations from each measurement, with seven to ten measurements per plot, amounting to approximately 30% of the plot. LAI was measured weekly from 5 to 19 weeks after emergence, where five plants per plot in ten plots per treatment were manually harvested. Total dry matter content DM was measured weekly from 14 to 19 weeks after emergence in one row for each of ten plots per treatment. For the rest of the growing season, DM were measured after whole plots were harvested biweekly.

## Results and discussion

Development of RVI over the growing season is seen in Fig. 1. Each point on the figure represents a mean over two blocks for each treatment. Only one of the genotypes is presented, as there was no significant difference between the two.

Until the end of the vegetative phase, the development of RVI was weak, followed by a period of pronounced increase, attaining a maximum at around 9 weeks. At that point, Olav was in the phenological phase of bud formation, with a bud size of 1 cm; KVL 205 was in the same phase, but with a slightly larger bud attaining pyramid shape (Fig. 1). After a minor decline, RVI increased from the end of the bud formation phase to the onset of anthesis, remaining constant until the deflowering phase, where RVI again declined. Anthesis did not affect the reflectance of quinoa significantly, possibly because flowering in quinoa does not imply a marked color shift (Gandarillas, 1979; Jacobsen and Stølen, 1993). In other crops such as rape, RVI falls due to increased reflection from the yellow flowers (Petersen, 1992; Mogensen et al., 1996), During deflowering the index falls, continuing in seed set where the quinoa inflorescence changes color to yellow in Olav and to red in KVL 205. Simultaneously, with the change of inflorescence color, the plants also lose their green leaves. Both effects of maturing increase reflection in the red part of the spectrum, causing a reduction in RVI.

The curves for the different nitrogen levels were almost parallel over time, with increasing N levels causing higher RVI (Fig. 1). In the vegetative phase there was no difference in RVI for the different N-treatments, but under bud formation the RVI of the 0 N treatment was significantly lower than the others. In anthesis, 120 N had a significantly lower RVI than the rest of the treatments, followed in the deflowering phase by the 240 N treatment.

In the current experiment, increasing N-level had a more distinct and quicker effect on RVI than the other characters measured. This must be due to the fact that nitrogen not only influences leaf expansion rate, but also chlorophyl content and thereby the green color of the leaf, as previously shown for sunflower and pepper (Peñuelas et al., 1994; Thomas and Oerther, 1972). From bud formation, the amount of green vegetation was greater in the fertilized treatments, causing an increase in RVI, which  has been also been demonstrated with barley (Jensen et al., 1990).

The relation between LAI and DM with RVI was studied in three separate periods: the vegetative and bud formation phase; the anthesis and deflowering phases; and the seed set phase. A large increase in LAI and DM was observed at 6 weeks, which was reflected in a similar increase in RVI, reaching a maximum during bud formation, where soil cover was almost complete (Fig. 1).

The development of RVI followed very closely to the development of LAI in the first phase, however, in only one of the genotypes was there a significant correlation between LAI and RVI. The subsequent fall in RVI may be attributed to leaf loss and to the fact that the color of the quinoa bud is lighter than the rest of the plant, which may increase reflection in the red area and decrease RVI. The relationship between LAI and a vegetation index is normally described for a number of crops as curvilinear, both before and after maximum LAI (Wiegand et al., 1990; Boumann, 1992; Petersen, 1992; Thomsen, 1992; Gilabert et al., 1996; Mogensen et al., 1996). This could not be demonstrated in the case of quinoa. There was no effect of N-level on the relation between LAI and RVI early in the growth season, as was demonstrated in barley (Petersen, 1992).

It was possible to show a linear relationship between RVI and DM at small dry-matter values for KVL 205 only in the vegetative and bud formation phases, as research has shown for barley until a value of 2 t/ha (Petersen, 1989). In the genotype Olav, however, the relationship was exponential until the onset of flowering, which was also found for barley in Jensen et al. (1990) and for barley and wheat (Smith et al., 1993).

During flowering and deflowering there was no correlation between RVI and LAI or DM, as RVI developed differently from LAI and DM. In seed set phase, which is relatively long, the correlation between RVI and LAI and DM diminished as the amount of green vegetation decreased, while the amount of DM increased. Similar observations were made by Tucker (1979) in grass and by Ahlrichs and Bauer (1983) in wheat, whereas Jensen et al. (1990) found a curvilinear relation in barley until maturity.

RVI measured six times during the growing season was compared to final grain yield. From anthesis there was a close relationship between RVI and yield.

In conclusion it was shown that the time where RVI was most sensitive to changes in the green vegetation was early in the growing season, thereafter reaching a maximum at the phenological phase where the bud was distinct. In anthesis RVI responded earlier to different nitrogen levels than LAI and DM and was not significantly different between the two genotypes. N-level had no effect on the relation between RVI and LAI or DM. RVI measured in anthesis and deflowering was strongly correlated to yield in both genotypes. Based on the relation between RVI and final yield, and the early response of RVI to N-levels, it should be possible to predict yield at an early date and estimate the amount of fertilizer required, as well as the timing of fertilizer applications needed to produce optimal yields.

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**Fig. 1.** RVI over time for five N-levels in the seed type KVL 205.
The vertical, dotted lines indicate the growth stages: v vegetative, k bud formation, b anthesis, ab deflowering, f seed set.