Developing diagnostic tools for nitrogen management in potatoes

Anne M. Smith
Agriculture and Agri-Food Canada
Research Centre
5403 1st Avenue South
Lethbridge
Alberta
T1J 4B1

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1.0 Background

Nitrogen (N) fertilization in potatoes, as in most annual crops, is key to maximizing yield and quality. Potatoes are high users of N, and optimization of N application can offer economic and environmental advantages. Excessive N can lead to delayed tuber set, increased incidence of deformed tubers, hollow heart, low specific gravity of the tubers, and physiologically immature tubers all of which can result in economic loss. In addition, over fertilization can potentially have a high environmental cost as a result of contamination of both surface and groundwater resources. The majority of potatoes are grown on coarse-textured soils and excessive irrigation or rainfall can result in N leaching. In contrast, too little N leads to stunted growth, premature death of the vines, increased susceptibility to diseases such as early blight or *Verticillium* and consequently reduced yields and economic return (Waterer and Heard, 2005).

Although N fertilizer is applied in the seeding preparations, in-season N fertilizer may also be required to maximize yield. Whether additional N is applied through fertigation, banding or top-dressing, it is usually initiated following nitrate (NO_3-N) analyses of petiole samples (Zhang et al. 1996, Waterer and Heard 2005). Guidelines for petiole NO_3-N levels, which vary with the age of the crop, are available (Figure 1) and currently undergoing review[1]. Although

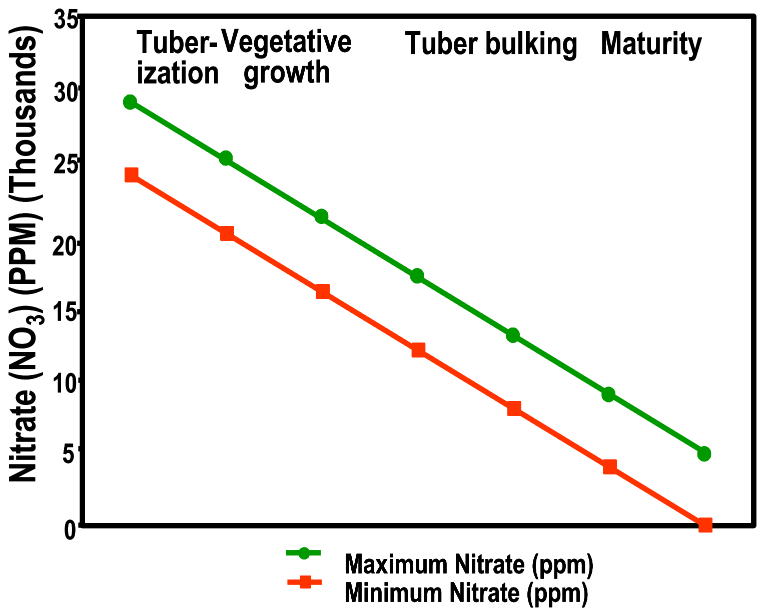

Figure 1: Target range for petiole NO3-N in potato petioles (Source: Waterer and Heard 2005).

petiole sampling is the "standard" for in-season monitoring of N levels in potato, there are some disadvantages to this technique. The NO_3-N levels can vary with the experience of the sampler, the time of day of sampling, the method of sampling, and the laboratory assay

[1] PGA Funded project. Woods S.A. Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta.

methods employed. There is also a delay between petiole sampling and obtaining the necessary information for management decisions.

In recent years, there had been considerable interest in the use of alternative "real-time" methods for estimating N levels in a variety of crops. These methods include the use of the Greenseeker, chlorophyll meter (SPAD-502 or Hydro-N Tester), and Dualex hand-held instruments (Figure 2). Depending on the crop, cost savings have been estimated at $10 to $20 per acres using in-season fertilization (Anon 2005).

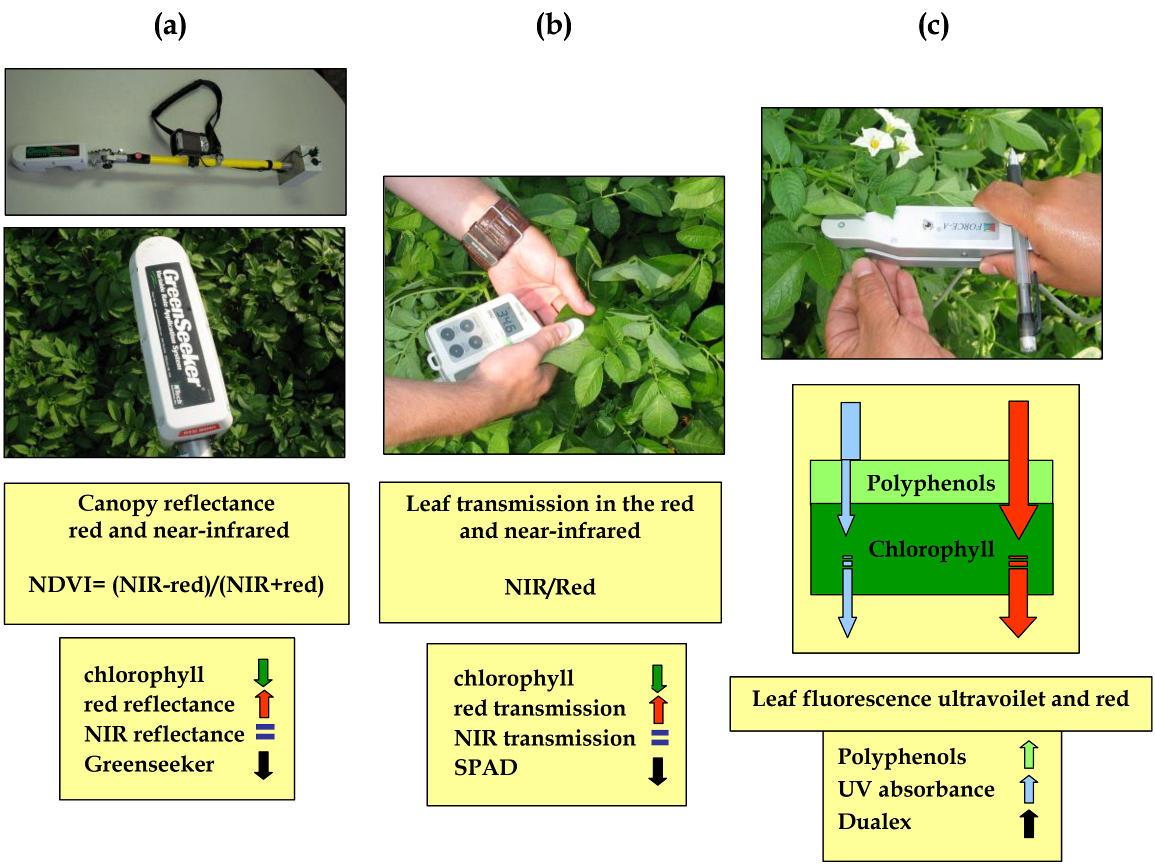

Figure 2: Greenseeker, SPAD 502 and Dualex pinciples of operation.

Research has been conducted on the use of the Greenseeker for improving N management in primarily wheat, forages and corn (Anon 2005). The Greenseeker consists of two diodes which emit energy in 671 and 780 nm wavelengths. The light reflected back from the crop is measured by a photodiode and the normalized difference vegetation index (NDVI) is computed ($[R_{780}-R_{671}]/[R_{780}+R_{671}]$). The principle is that NDVI relates to biomass and greenness (i.e. chlorophyll levels) and thus N management (Figure 2(a)). Studies suggest that the use of the Greenseeker may enable growers to optimize N use (Raun et al. 2001) and be useful in predicting in-season N requirements in potatoes (Bowen et al. 2005).

The chlorophyll meter is a hand held instrument which provides a simple, fast and non-destructive method for estimating relative amounts of chlorophyll. The chlorphyll meter measures transmittance of leaves in two wavelengths (650 and 940 nm) which are differentially absorbed by chlorophyll (Figure 2(b)). The chlorophyll meter readings can be related to chlorophyll levels and then indirectly to N management (Schepers et al. 1992, Varvel et al. 1997). This instrument has been widely used in N management research in a variety of crops (Wood et al. 1992, Follet et al. 1992, Sing et al. 2002) including potatoes (Vos and Bom 1993, Minotti et al. 1994, Denuit et al. 2002, Rodrigues 2004). A study in Belgium, involving field level production, indicated the potential use of a chlorophyll meter to monitor potato plant N status and aid in split applications of N fertilizer (Olivier et al. 2006).

More recently, investigations into the use of fluorescence excitation and the Dualex field portable instrument for N management have appeared in the literature (Cartelat et al. 2005). The Dualex (dual excitation) which measures leaf levels of polyphenolics and chlorophyll, operates in full daylight with an UV beam at 375 nm and a red reference beam at 650 nm (Figure 2(c)). Under conditions of N stress the concentration of polyphenolic compounds in leaves increases while chlorophyll content. The potential of this instrument as a tool for in-season nitrogen management in corn and wheat has recently been shown (Tremblay et al. 2007, Tremblay and Bélec 2006, Cerovic et al. 2005) but to date data for potatoes are very limited.

The use of the newly developed Dualex instrument in combination with a chlorophyll meter may offer even greater potential than either instrument individually to identify N stress due to measurement of both chlorophyll and polyphenolic compounds (Cartelat et al. 2005, Cerovic et al. 2005, Meyer et al. 2006).

Objective

(1) To conduct a second year pilot study to evaluate the use of the Greenseeker, SPAD, and Dualex meters for measuring in-season N deficiency in potatoes.
(2) To determine the relationship amongst the Greenseeker, SPAD and Dualex readings and petiole N values.

2.0 Methods

2.1. Experiment 1 and 2

2.1.1. Study sites

There were two study sites, Brooks (Experiment 1) and Vauxhall (Experiment 2), Alberta. The study sites were established and maintained by Dr. Michele Konschuh and were part of an on-going study into the effects of urea as opposed to ESN (slow release fertilizer) applications on potato productivity. There were 10 treatments in each trial of which only the five urea treatments were sampled (Tables 1 and 2, Figure X). The residual soil N level at both Brooks and Vauxhall resulted in a higher than anticipated N level in the check treatment. At Vauxhall, the residual N level was such that planned lowest N application of 115 kg/ha was not possible and the treatment was replaced by 123 kg/ha residue soil N. There were 5 replicates per treatments. Each plot consisted of two rows containing 20 Russett Burbank tubers per row (40 tubers per plot). The potato tubers were planted on May 13 at Vauxhall and May 14 at Brooks. Management of the plots is described in Konschuh (2009).

Table 1: Differential nitrogen fertilizer application (kg/ha N) in the five treatments at Brooks.

Trt #	Residual Soil N (top 60 cm)	Urea (Pre-plant)	Urea (Top-dressed)	Total N	% of STD
1*	92	0	0	92	71%
2	92	133	0	225	100%
3	92	78	0	170	75%
4	92	23	0	115	50%
10**	92	88	65	245	109%

* No N added, residual N in the soil from soil testing.
** Standard treatment

Table 2: Differential nitrogen fertilizer application (kg/ha N) in the five treatments at Vauxhall.

Trt #	Residual Soil N	Urea (Pre-plant)	Urea (Top-dressed)	Total N	% of STD
1*	123	0	0	123	54%
2	123	102	0	225	100%
3	123	47	0	170	75%
4	123	0	0	115	50%
10**	123	90	65	278	124%

* No N added, residual N in the soil from soil testing.
** Standard treatment

2.1.2. Petiole sampling

Petiole samples were taken three times during the 2008 season to determine NO_3-N. At Brooks samples were taken 44 (June 26), 66 (July 18) and 86 (August 8) days after planting (DAP) while at Vauxhall sampling was conducted 46 (June 27), 71 (July 22) and 85 (August 6) DAP. The July sampling at Vauxhall was delayed one week due to a hailstorm. The protocol used is described in Konschuh (2009).

2.1.3. Greenseeker, SPAD and Dualex measurements

Greenseeker, SPAD and Dualex measurements were taken 44 (June 26), 64 (July 16) and 87 (August 7) DAP at CDC South, Brooks and 44 (June 25), 64 (July 15), 71 (July 24) and 85 (August 5) DAP at Vauxhall. As there was a hail storm at Vauxhall 64 DAP (July 15) the plots were re-sampled 73 DAP (July 24) to provide closer sampling to the petiole NO_3-N measurements.

The Greenseeker NDVI measurements were taken over the area that included the 4th, 10th and 16th plant in each row. Particular attention was paid to keeping the sensor height in relation to the top of the crop canopy the same on each date. Six NDVI readings were recorded per plot to provide a measure of in-plot variability as well as between plot variability.

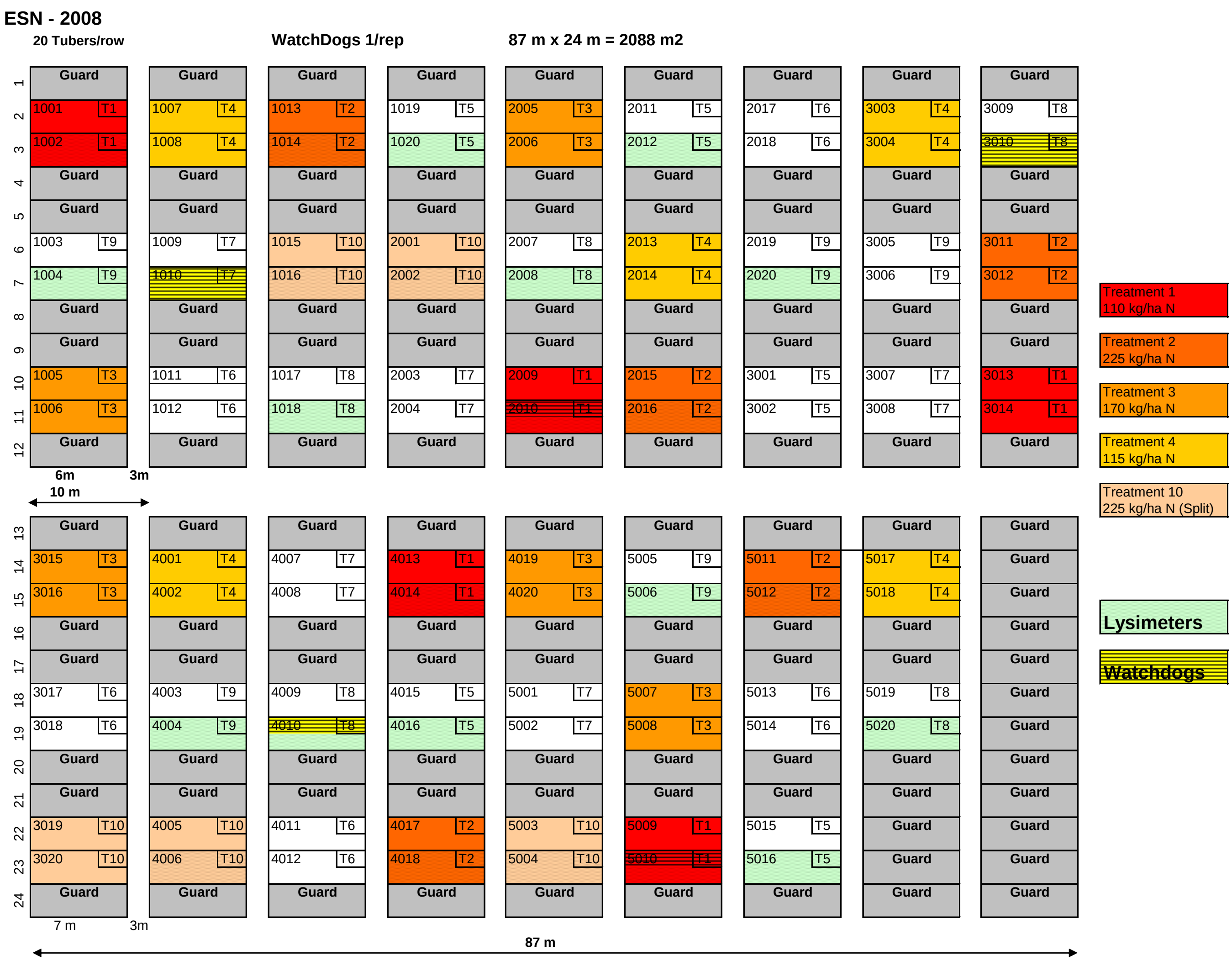

Figure 3: Plot layout at Brooks and Vauxhall.

Consistent with the Greenseeker measurements the SPAD and Dualex readings were taken at the midpoint of the terminal three leaflets on the 4th fully expanded compound leaf of the 4th, 10th and 16th plant of each row within a plot (Figure 4). The SPAD readings were taken on the upper surface of the leaflets while the Dualex readings were taken on both the upper and lower surface of the leaflets. The three SPAD and the six Dualex readings per plant were averaged as were the readings from the six plants per plot to provide a mean value per plot. In order that the SPAD and Dualex readings could be compared and used to create a SPAD/Dualex ratio, the measurements were always made in the same order (i.e. the 1st, followed by the 2nd followed by the 3rd leaflets).

Due to variations in the soil, water supply, growth stage, sampling protocols, variety, seasonal environmental conditions, and variations amongst the machines themselves, it is generally accepted that absolute values for Greenseeker, SPAD and Dualex are unsuitable. Accordingly, it is generally accepted that the values measured with these instruments are ratioed to those obtained from plants within a nutrient rich reference area (Tremblay and Bélec 2006). The results for the Greenseeker, SPAD and Dualex measurements are expressed as a ratio where the denominator is the mean value obtained in the 245 and 278 kg/ha split N application treatment at Brooks and Vauxhall respectively, as these treatments were deemed to be nutrient rich.

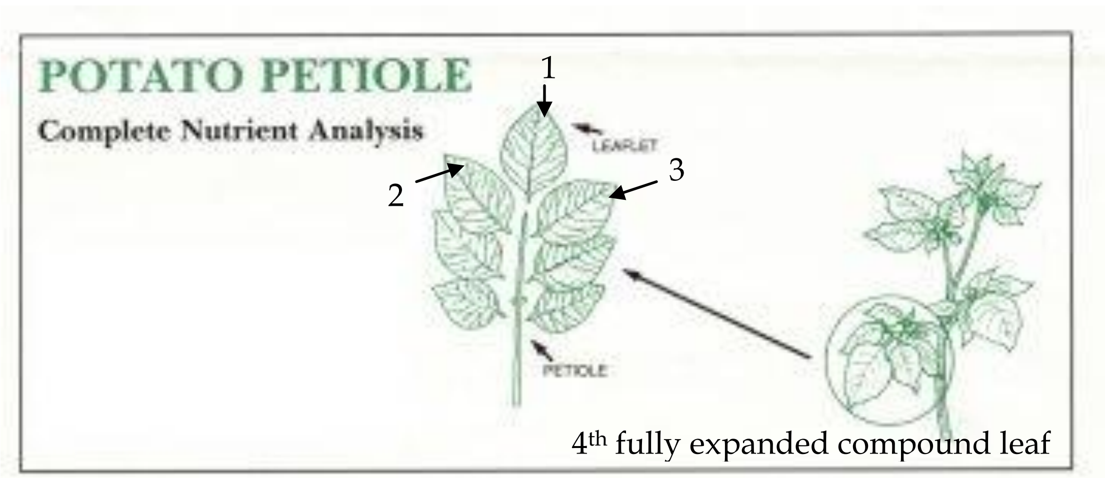

Figure 4: Diagram of petiole and sampling sites.

2.2. Experiment 3.

2.2.1. Study site

The third experiment was conducted in an irrigated commercial potato field. Pre-plant N was applied based upon initial soil tests and with the exception of two areas in the field (Figure 5) in-season N was applied based upon petiole sampling. In the two areas set aside, based upon petiole sampling, 0 and 50% of the in-season required N rate was applied. To achieve these treatments, fertigation was withheld in the 0% treatment and occurred only every second time in the 50% rate.

2.2.2. Greenseeker, SPAD, Dualex and petiole sampling

Three areas were identified and flagged in each of the fertility treatments. At each location, 10 Greenseeker measurements were taken as described above. The measurements were taken in a random pattern around the flags but ensuring that there was a minimum of 10 paces (approx 7.5 meters) between samples. Thus, a total of 30 measurements were made in each fertility treatment.

SPAD and Dualex measurements were taken as described previously. There were 10 plants per sample flag for a total of 30 plants and 180 individual measurements per treatment. The same plants were sampled on each date. Measurements are taken at the same time as the petiole sampling. Typically this occured between 7:30 and 9:30 AM. Petiole samples and hand held instrument measurements were taken weekly over the growing season (June 28, July 5, 12, 18 and 25, and August 2, 9, 16 and 23).

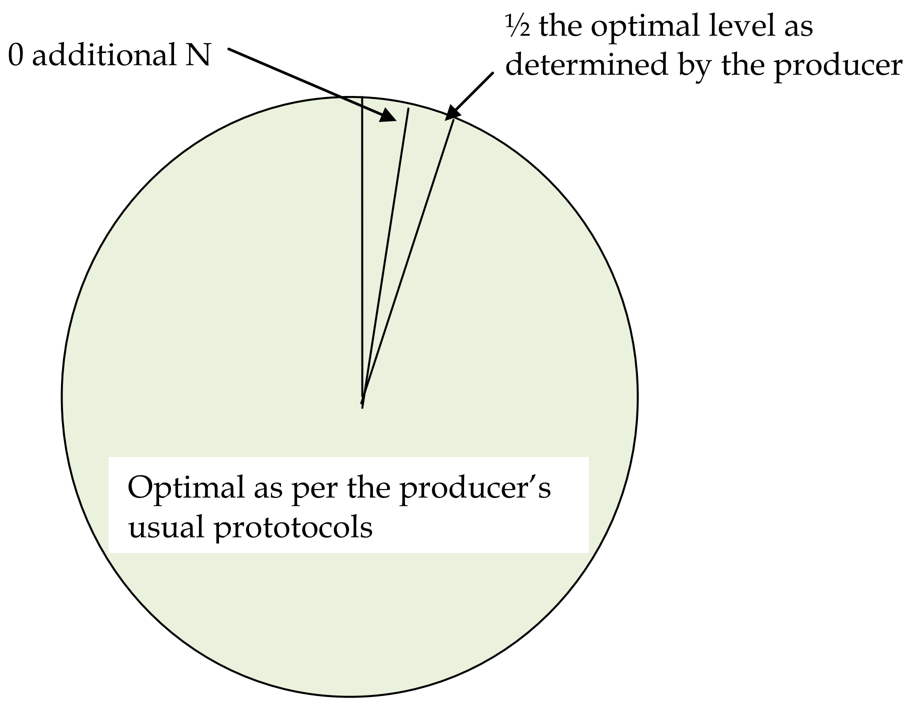

Figure 5: Experimental set-up in the commerical potato field.

3.0 Results

3.1. Experiment 1 and 2

3.1.1. Yield

At Brooks there was no significant difference in marketable yield amongst the various N treatments. However, total potato yield, when compared to the standard 245 kg/ha N split application, was significantly greater in the 170 kg/ha treatment which could be attributed to the greater yield of large potatoes. The yield of small and medium potatoes, compared to the standard 245 kg/ha split N application was unaffected by the various N treatments (Figure 6).

A hailstorm at Vauxhall on 64 DAP resulted in damage to the aboveground plant material and likely contributed to the lower yields at Vauxhall compared to Brooks. Total, marketable and medium sized potato yields were unaffected by N treatment at Vauxhall. However, compared to the standard 278 kg/ha split application of N, large tuber yield was significantly lower and small tuber yield significantly greater in the 123 and 170 kg/ha N treatments (Figure 7).

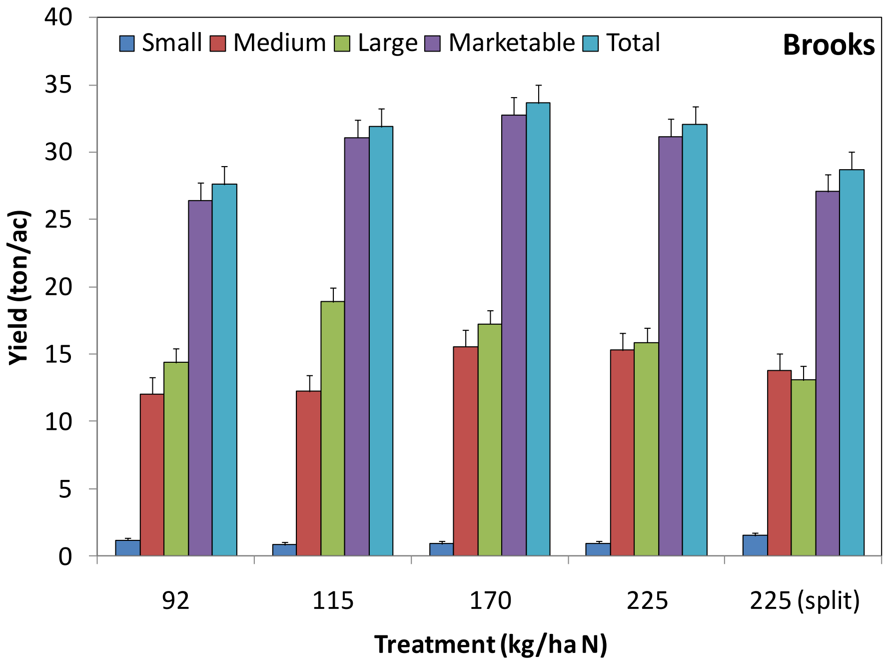

Figure 6: The effect of varying N application rates on potato yield at Brooks, AB**.**

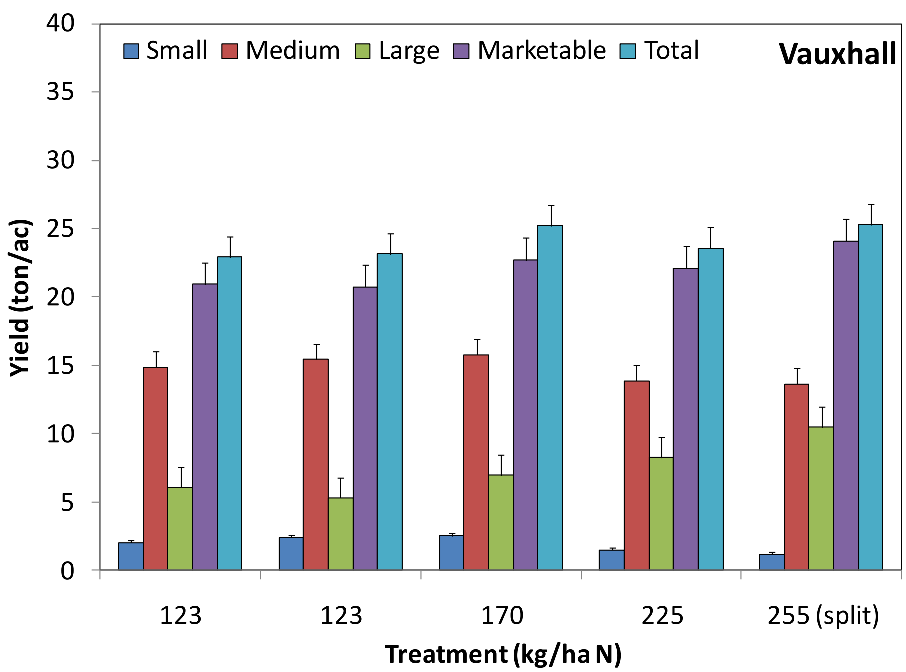

Figure 7: The effect of varying N application rates on potato yield at Vauxhall.

3.1.2. Petiole NO_3-N

Petiole NO_3-N levels decreased over the season at Brooks. With the exception of the single pre-plant 225 kg/ha N application 44 DAP, the 225 kg/ha split N treatment showed significantly higher petiole NO_3-N levels compared to the other treatments. 44 and 64 DAP, the reduction in petiole NO_3-N level increased with decreasing N application rate but 86 DAP there was no significant difference in the petiole NO_3-N levels amongst the single N application treatments. With the exception of the 225 kg/ha split application of N 44 DAP, the petiole NO_3-N was below the lower recommended level (Woods et al. 2008).

Petiole NO_3-N levels at Vauxhall were highest 44 DAP but lowest 71 DAP rather than 87 DAP (Figure X). This latter observation may be attributed to the effects of the hailstorm on July 15th which set back potato growth. With the exception of 44 DAP, the petiole NO_3-N levels in the 225 kg/ha split and single pre-plant applications were not significantly different from each other. The 123 and 170 kg/ha N applications rates resulted in a significant reduction in petiole NO_3-N levels, the level of reduction tending to increase with decreasing N application rate. It was noted that the petiole NO_3-N levels were below the lower limit of the optimal levels suggested by Woods et al. 2008.

3.1.3. Greenseeker

In all treatments at Brooks, the Greenseeker NDVI values increased from 44 to 64 DAP when full canopy closure was achieved. Thereafter the Greenseeker values remained constant. With respect to the various N treatments, the results were variable amongst dates. The Greenseeker value for the 92 kg/ha treatment was significantly lower than for any other treatment 44 DAP. With time, this difference was reduced and 86 DAP there was no significant difference in the Greenseeker values amongst the various treatments (Figure 10A).

At Vauxhall, in all treatments the Greenseeker NDVI values increased from 44 to 64 DAP when full canopy closure was achieved. With respect to the various N treatments, the results were variable amongst dates. 44 and 85 DAP there was no significant difference amongst treatments while 64 DAP compared to the standard 278 kg/ha split application the Greenseeker values were significantly lower for the other N treatments (Figure 11A). The NDVI values tended to be lower with the lower N rates.

3.1.4. SPAD

At Brooks, in all treatments, the SPAD remained fairly constant through the experimental period. On all measurement days the SPAD readings for the 92 and 115 kg/ha N treatments were significantly lower than for the standard 245 kg/ha split application of N. The 170 kg/ha N application also showed a reduction in SPAD readings 44 and 86 DAP but not 64 DAP (Figure 10B). Generally the level of reduction in SPAD readings increased with decreasing N application rate.

At Vauxhall, in all treatments, the SPAD values decreased with DAP. Early in the season, 44 DAP, compared to the 278 kg/ha split N application, the 123 and 170 kg/ha N treatments showed a significant decrease in the SPAD value, the SPAD value decreased with decreasing N application rate (Figure 11B). However, there was no significant difference in the SPAD values amongst all N treatments 71 and 85 DAP.

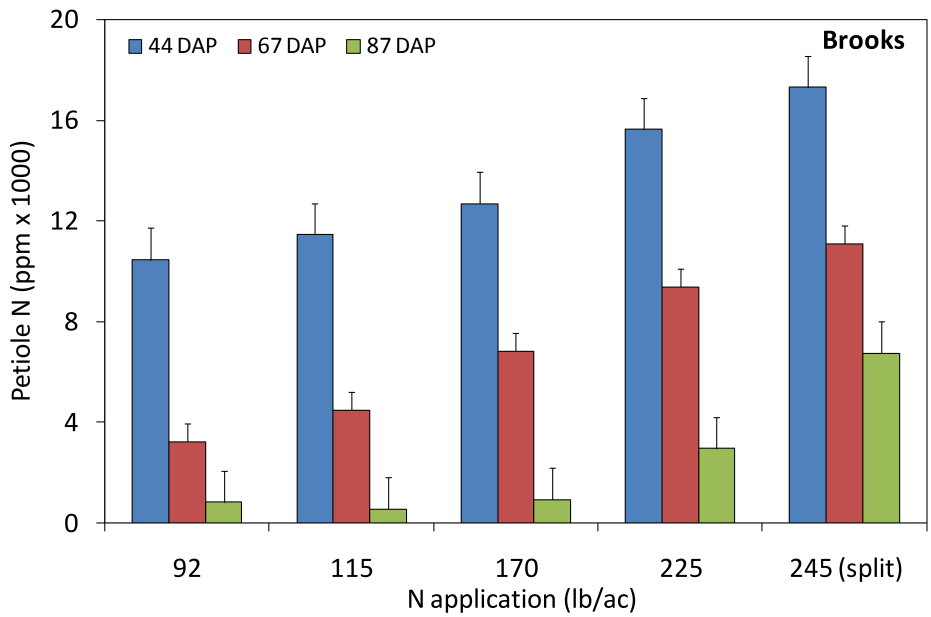

Figure 8: The effect of N application rate on potato petiole NO_3-N levels at Brooks.

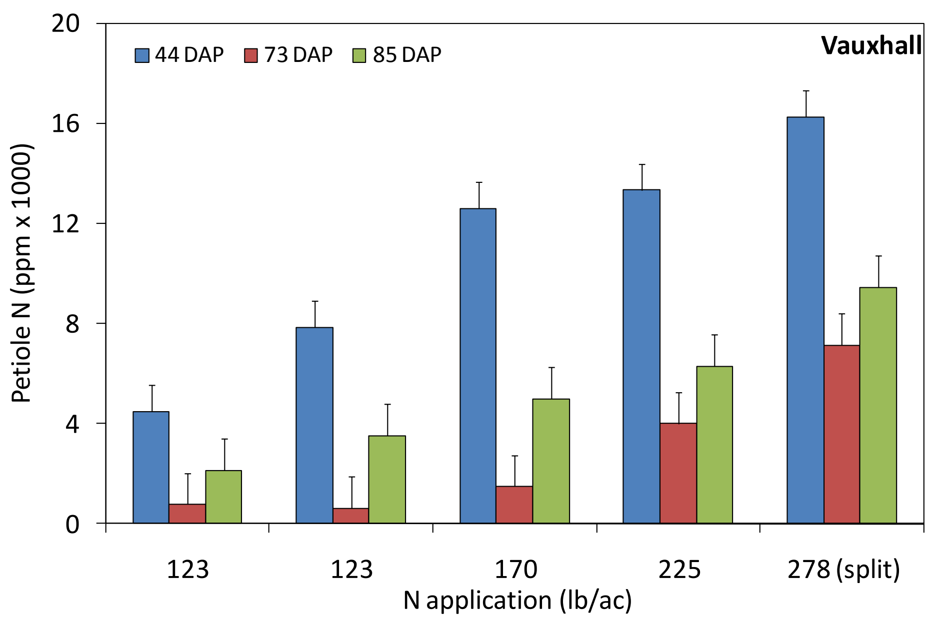

Figure 9: The effect of N application rate on potato petiole NO_3-N levels at Vauxhall.

3.1.5. Dualex

Consistently on each sampling date at Brooks, the two lowest application rates of 92 and 115 kg/ha N showed a significant increase in the potato leaf Dualex values compared to all other N treatments. There was no significant difference in the Dualex values amongst the 170 kg/ha, 225 kg/ha single N treatments and the 245 kg/ha split N application.

Within treatments at Vauxhall, the greatest change in Dualex readings occurred from 44 to 73 DAP when the values increased. From 71 DAP to 85 DAP only a slight increase was observed in the Dualex readings. With the exception of 85 DAP and the 225 kg/ha single N application, relative to the 278 kg/ha split N application, the Dualex readings significantly increased with a decrease in N application rate (Figure 11C). There was no significant difference in the Dualex readings amongst the 123 and 170 kg/ha N treatments.

3.1.6. SPAD/Dualex ratio

At Brooks, the results were similar to those with the Dualex instrument alone with the 92 and 115 kg/ha treatments showing a significant decrease in the SPAD/Dualex ratio compared to all other treatments. There was no significant difference between the SPAD/Dualex ratios in the 92 and 115 kg/ha N treatments. Unlike the Dualex alone, the SPAD/Dualex ratio showed a significant effect for the 170 kg/ha, the value being significantly lower than for the 245 kg/ha N split application treatment (Figure 10D).

In all treatments, the SPAD/Dualex ratio at Vauxhall decreased with DAP. The results were similar to those with the Dualex instrument alone. With the exception of 85 DAP and the 225 kg/ha single N application, relative to the 278 kg/ha split N application, the SPAD/Dualex ratio significantly decreased with a decrease in N application rate (Figure 11D). There was no significant difference in the SPAD/Dualex ratios amongst the 123 and 170 kg/ha N treatments.

3.1.7. Relationship hand held instruments and petiole sampling.

At Brooks there was no relationship between petiole NO_3-N and Greenseeker measurements on any date (Figure 12). The SPAD and SPAD/Dualex showed a strong relationship with petiole NO_3-N both 44 and 64 DAP while the Dualex alone only showed a significant relationship with the petiole NO_3-N 64 DAP. On the last date of measurement 86 DAP there were no significant relationships between petiole NO_3-N and any of the instrument readings. At Vauxhall, on each date a strong relationship was found between the petiole NO_3-N and the Dualex, SPAD/Dualex and Greenseeker measurements but only 44 DAP was a significant relationship observed between petiole NO_3-N and the SPAD measurements (Figure 13).

Overall at Brooks there was a significant relationship between the petiole NO_3-N and all instrument measurements except the SPAD while at Vauxhall a significant relationship was evident between the petiole NO_3-N and all instrument readings (Table 3).

Table 3: The relationship between the hand-held instrument measurements (independent variable) and potato petiole NO_3-N (dependent variable).

Location	Independent variable	Intercept	Slope	R^2	RMSE
Brooks	Dualex	44132	-39067	0.47	3958
	SPAD	-	-	-	-
	SPAD/Dualex	-13416	448	0.37	4324
	Greenseeker	45714	-46370	0.41	4183
Vauxhall	Dualex	-28352	-22733	0.68	2742
	SPAD	-27375	877	0.72	2542
	SPAD/Dualex	-5819	265	0.70	2650
	Greenseeker	37953	-39563	0.33	3941
Vauxhall + Brooks	Dualex	32487	-26805	0.55	2742
	SPAD	-24360	780	0.38	2542
	SPAD/Dualex	-7146	304	0.50	2650
	Greenseeker	40181	-40973	0.36	3941

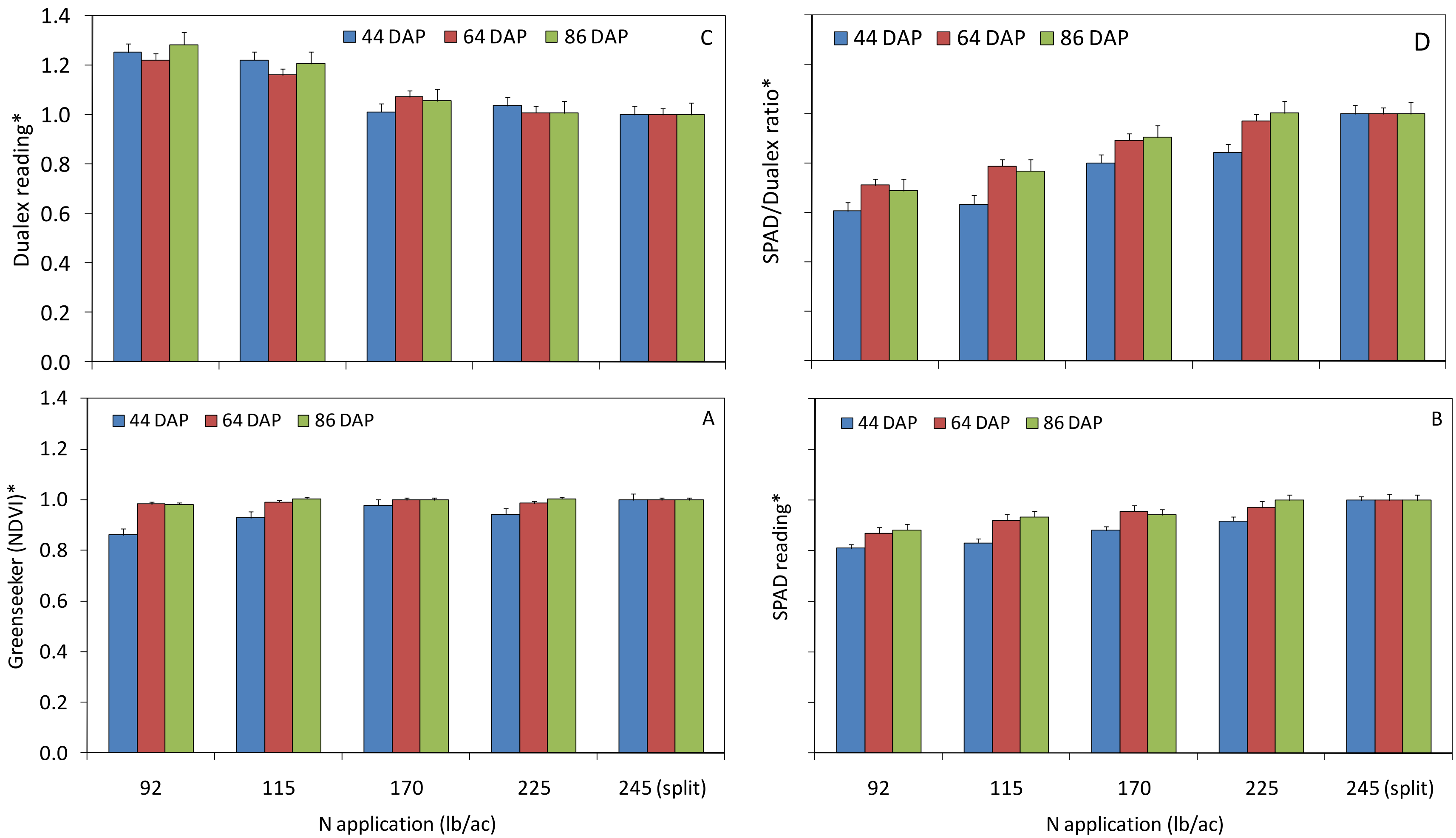

Figure 10: The effect of N application rate on potato canopy Greenseeker (A), potato leaf SPAD (B) and Dualex (C) and SPAD/Dualex ratio (D) values at Brooks.

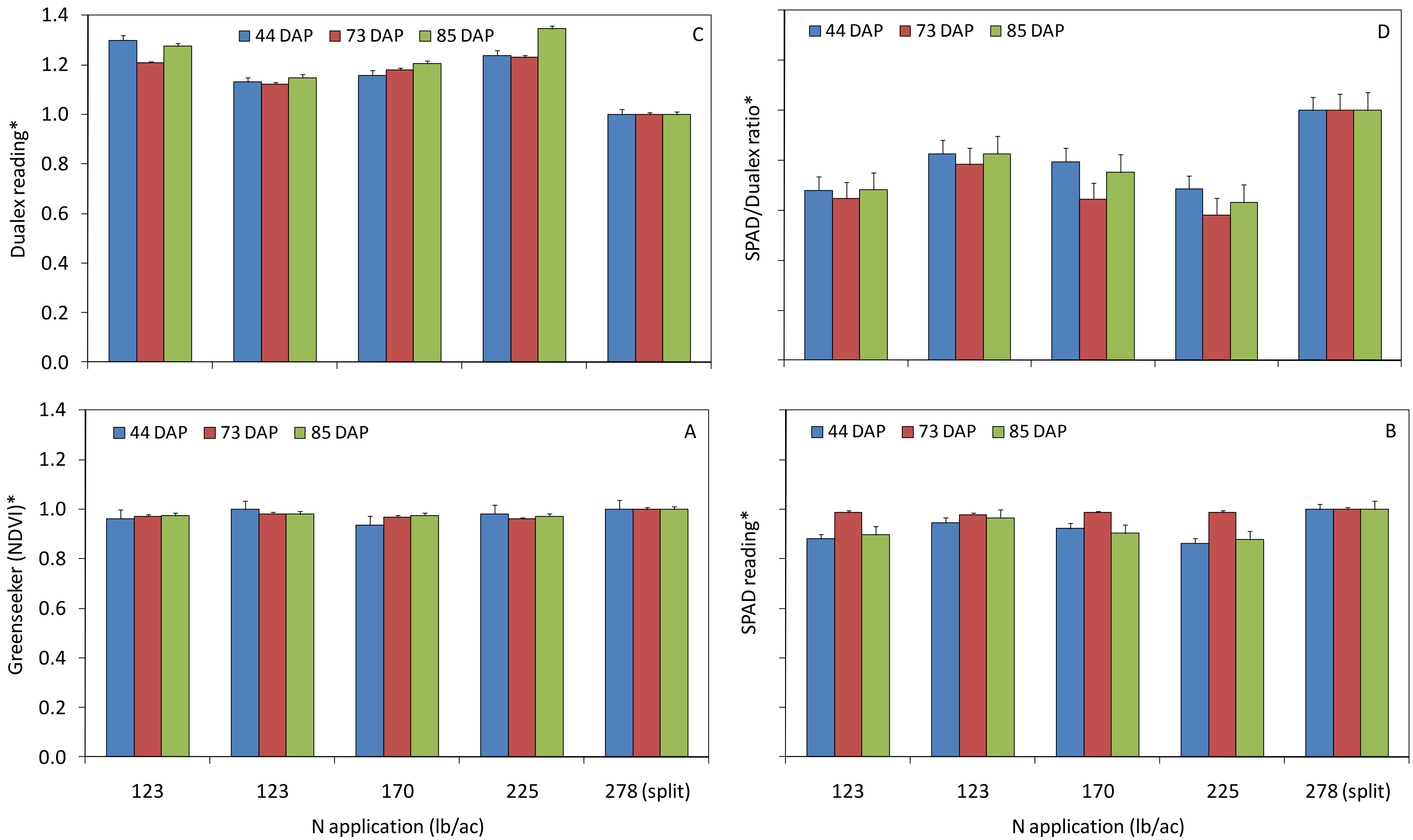

Figure 11: The effect of N application rate on potato canopy Greenseeker (A), potato leaf SPAD (B) and Dualex (C) and SPAD/Dualex ratio (D) values at Vauxhall.

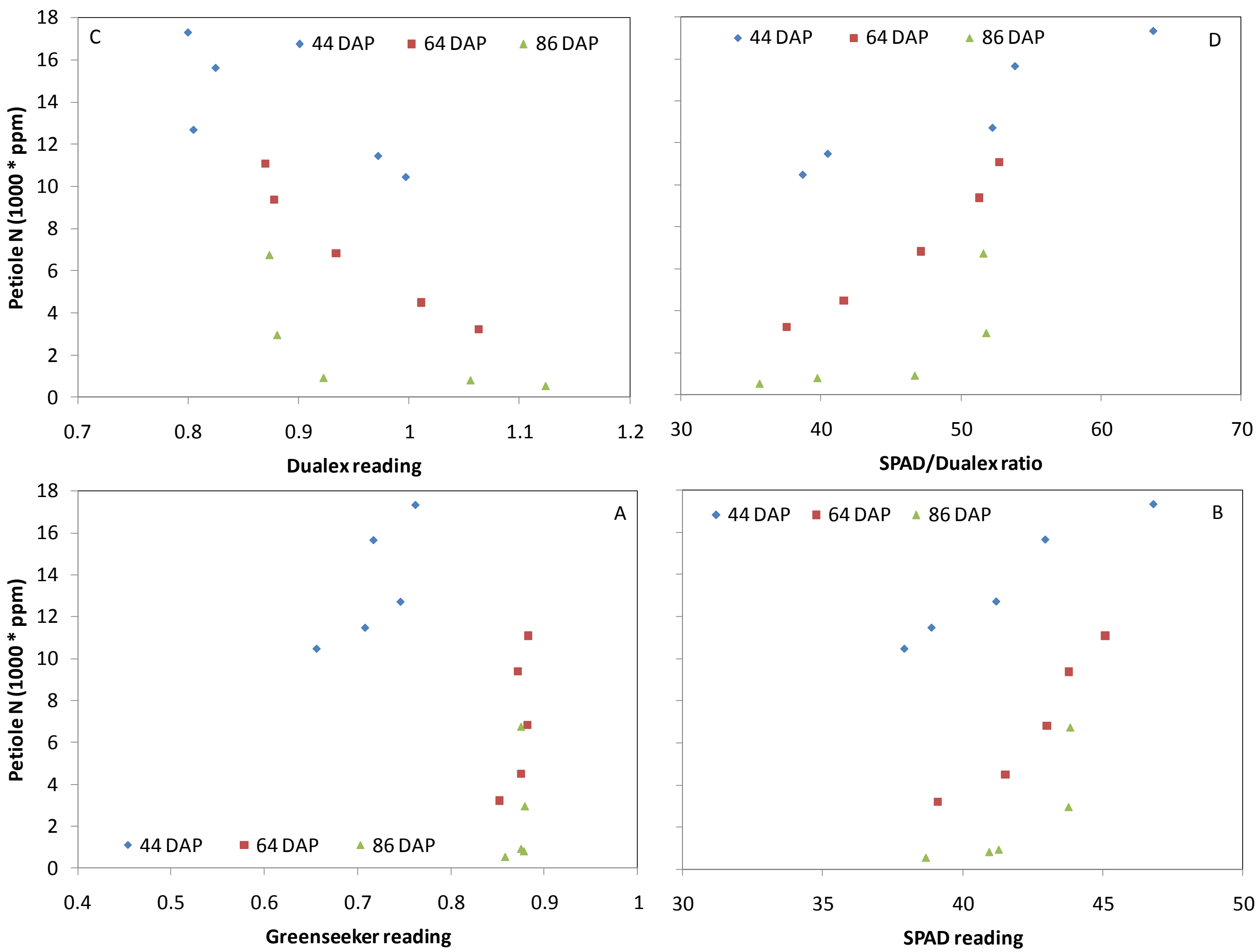

Figure 12: The relationship between the Greenseeker (A), SPAD (B), Dualex (C) and SPAD/Dualex ratio (D) and potato petiole NO_3-N at Brooks in 2008.

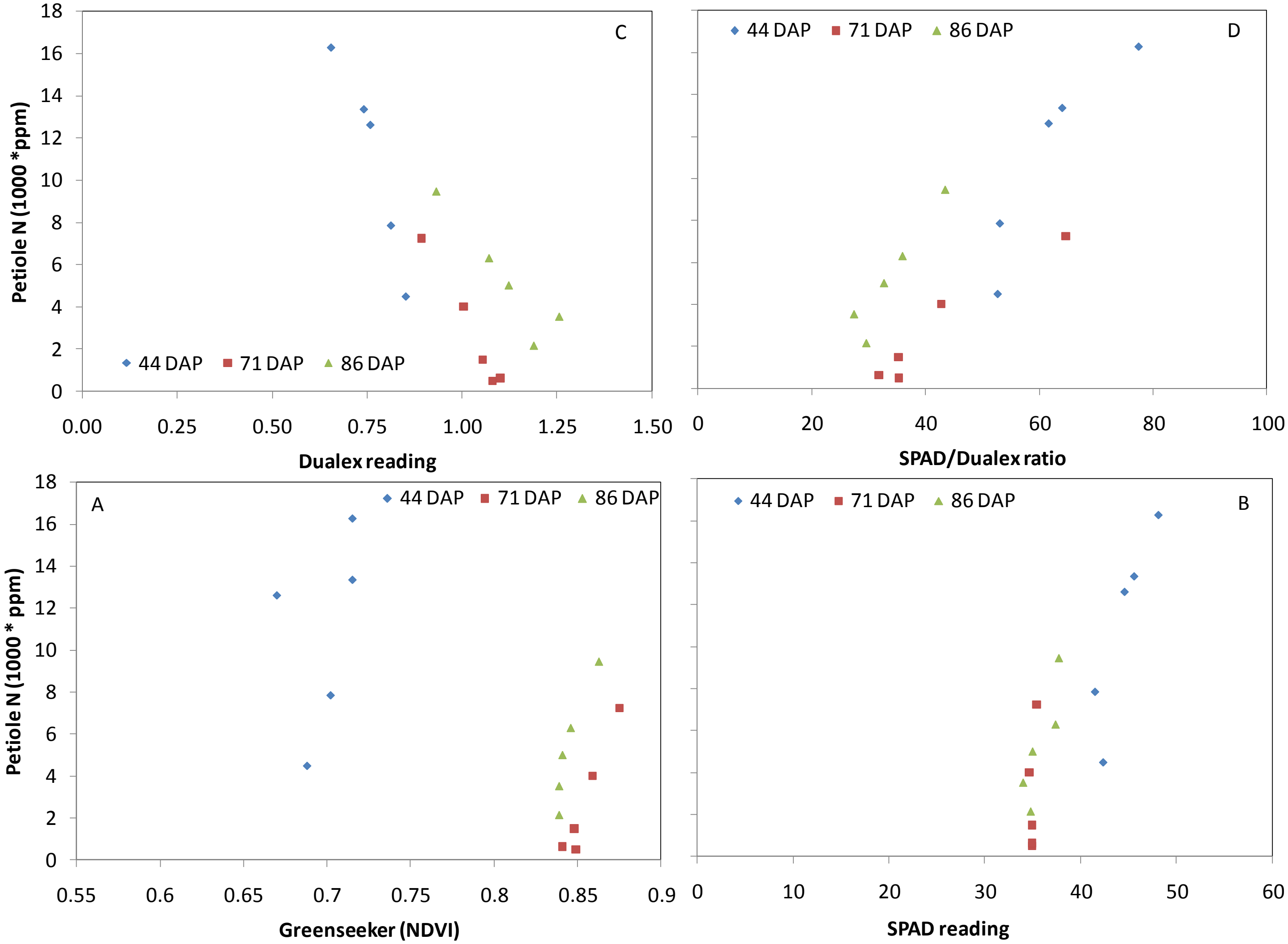

Figure 13: The relationship between the Greenseeker (A), SPAD (B), Dualex (C) and SPAD/Dualex ratio (D) and potato petiole NO_3-N at Vauxhall in 2008.

3.2. Experiment 3.

3.2.1. Yield

The total yield of potatoes in each of the three N treatment levels was similar. Unfortunately, the harvested potatoes were not separated into small, medium, and large tubers so marketable yield could not be determined.

3.2.2. Petiole NO_3-N

The potato petiole NO_3-N levels fluctuated throughout the season for all three treatments, but with few exceptions, the levels were within the optimal target for petiole NO_3-N (Figure 14).

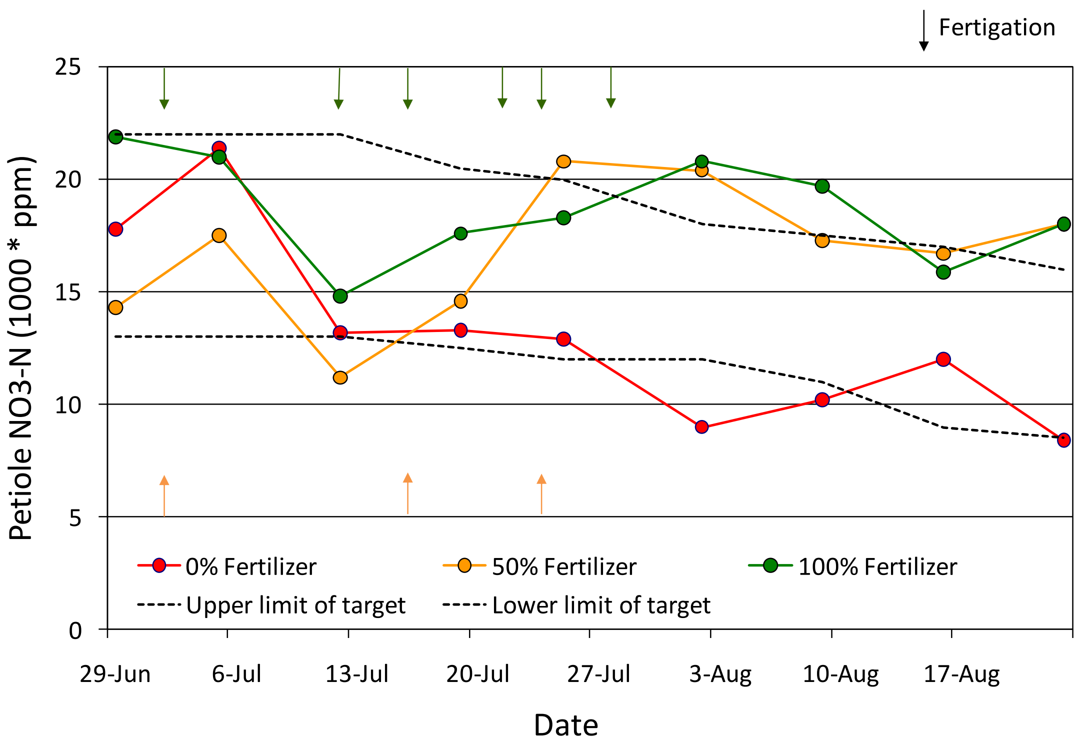

Figure 14: Petiole NO_3-N levels in the 0, 50 and 100% fertility treatments in the commercial field.

3.2.3. Greenseeker, SPAD, Dualex and SPAD/Dualex

With few exceptions the Greeenseeker, SPAD, and Dualex readings and, the SPAD/Dualex ratio values were similar amongst the three fertigation levels (Figure 15).

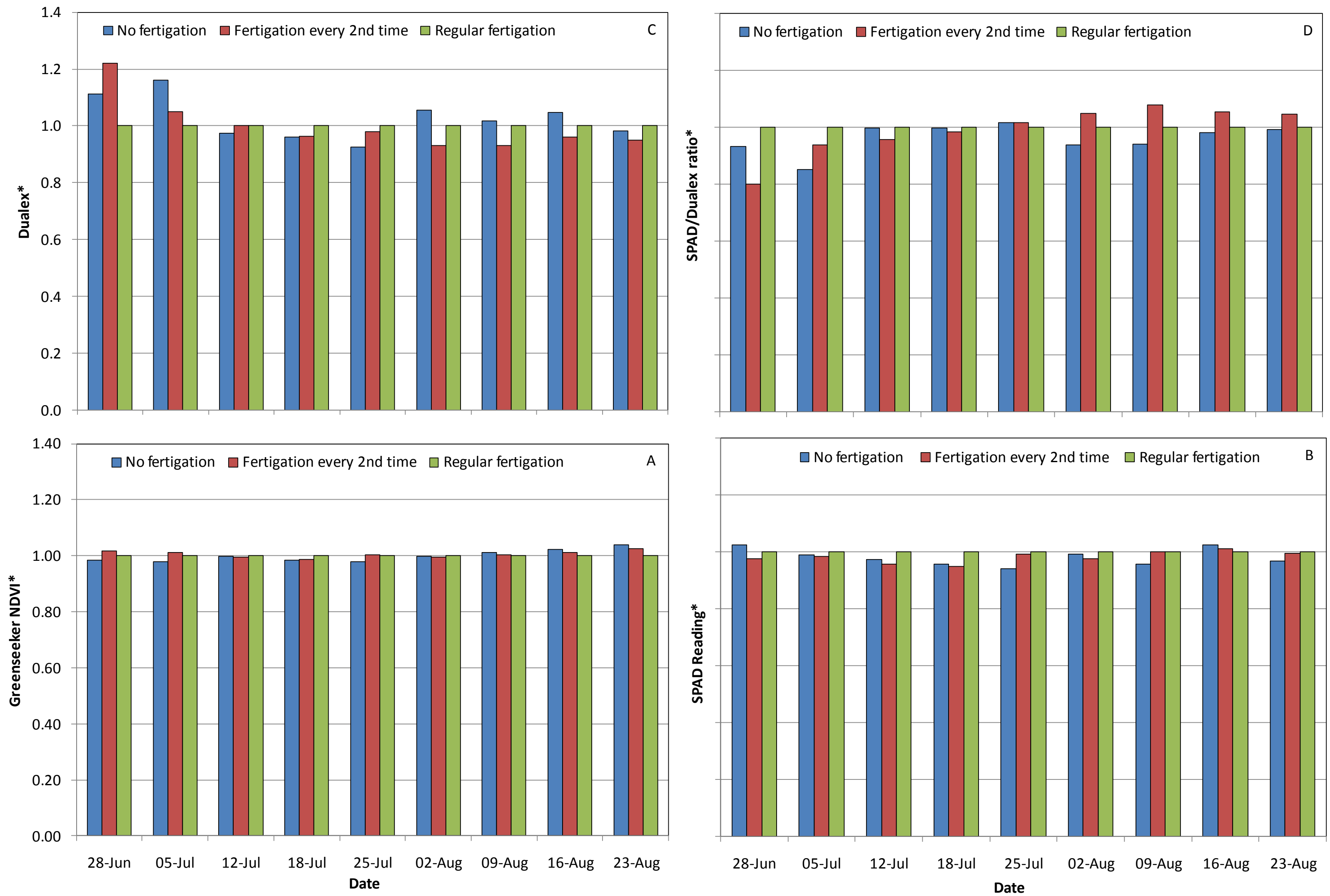

Figure 15: The effect of fertigation treatment on Greenseeker (A), SPAD (B), Dualex (C) and SPAD/Dualex (D) ratio values.

4.0 Discussion

Interestingly, at both Brooks and Vauxhall, although the petiole NO_3-N values were, with few exceptions, well below the acceptable minimum level for target yield (Table 4), the yields were acceptable. In Vauxhall, although the marketable yield of potatoes was unaffected by N treatment, there was the suggestion that the 123 and 170 kg/ha N rates altered yield with the weight of small and large sized tubers increasing and decreasing respectively. This effect on yield was mirrored in a decrease in petiole NO_3-N and SPAD/Dualex ratio values and an increase in Dualex values in plants subjected to 123 and 170 lb/ac N.

At Brooks, yield was unaffected by the various N treatments, yet the petiole NO_3-N results showed differences with respect to the differential N rates. The trends in the results for the Dualex and SPAD/Dualex combination were similar to those for petiole sampling and suggest the potential of these instruments to replace destructive sampling. This is further exemplified by the reasonable relationship observed between the petiole NO_3-N levels and both the Dualex readings and the SPAD/Dualex ratio at Vauxhall and Brooks. With respect to the SPAD and the Greenseeker, the trend in the results with respect to yields and petiole NO_3-N were not consistent over time and site. The Greenseeker readings are a measure of greenness which is a function not only of the colour of the canopy but also the amount of vegetation present. The presence of bare soil in the field of view of the instrument influences the Greenseeker readings which is not the case for the SPAD and the Dualex leaf level instruments.

Table 4: Optimal petiole NO3-N levels for Russet Burbank potatoes in southern Alberta (from Woods et al. 2008).

Days after planting	Optimal NO3-N levels (ppm)	
	Upper limit	Lower limit
44	26040	17640
46	25460	17060
67	19370	10970
71	18210	9810
86	20172	12772
87	19928	12528

Calibration of the hand-held instruments is an issue. In previous studies involving other crops an over fertilised reference strip is used to develop a sufficiency index approach to N requirement. The reference strip eliminates the influence of environment and cultivar differences in the results. In the case of potatoes, petiole NO_3-N curves have been developed for a number of cultivars which are regularly used by producers to manage in-season applications of N. It may be possible to calibrate the hand held instrument readings based upon the petiole NO_3-N levels to derive sufficiency indices.

5.0 Recommendations and potential impact of the study

The results of the two years of this study require to be integrated. However, as in 2007, the Dualex and SPAD/Dualex readings appeared to mirror trends in yield and in petiole NO_3-N levels. The Dualex and SPAD/Dualex ratio show a good correlation with petiole NO_3-N levels despite the fact that the handheld instruments provide a measure of cumulative N levels while the petiole NO_3-N provides a measure of N available at the time of measurement. The Dualex and SPAD/Dualex may be less susceptible to time of day, hydration of the plant etc.
The results suggest that research into the use of the Dualex instrument should be continued and data gathered to relate Dualex readings to N deficiency and N requirements in potatoes.

6.0 Acknowledgements

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Bibliography

There are no sources in the current document.