A new rainfall adjusted nitrogen nutrition index is promising to assess the risk of achieving desired key performance indicators for wheat production in Western Australia

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Abstract
In-season nitrogen (N) applications are an important farm management tool to influence crop profitability in Western Australia (WA). Agronomic benchmarking tools have been developed to guide such N decisions, but these often lack evaluation. This study compared and tested a new nitrogen nutrition index (NNI) with a CSBP plant N status (NUlogic®). It introduced a new NNI for wheat, developed for water limited regions like WA, on the basis of minimum N concentration (Nc) needed in shoots to achieve maximum shoot growth. It then adjusted that critical N curve using the rainfall and nitrate variable to best correlate with relative yield. The NUlogic method was directly calibrated on grain yield, using an N dilution curve derived from shoot Nc versus grain yield. Data from thirty-two WA field trials on N were used in this study. Both approaches were equally suited to predict N deficiencies, identify yield gaps and inform about N- (NUE) and water-use efficiency (WUE) in-season. However, the NNI method had to be adjusted for lower rainfall, indicating that targeting maximum shoot growth without rainfall adjustment would over-estimate N deficiency. An adjusted NNI $\geq$ 1 was likely to close yield and protein gaps. The maximum WUE increased up to a NNI of 1.5. Thereafter NUE declined sharply unlike the WUE. A "sufficient" or higher NUlogic N status behaved similar to a NNI $\geq$ 1. While this is work in progress, both tools look promising to assess the risk of these key performance indicators to guide profitable N applications in-season.

Keywords
Plant nitrogen status, Decision Support System, benchmarking, risk management.

Introduction
Plant sampling as a diagnostic and/or monitoring tool has been utilised to some extent to identify N deficiency and to guide N fertiliser applications, but more confidence in the tools is needed to increase usage and thereby NUE and on-farm profitability. Explaining the approaches for a nitrogen nutirition index (NNI) and CSBP plant nutrient status (NUlogic®) as well as demonstrating their value to correct N deficiency will increase the users understanding and interpretation skills. This can lead to more effective N recommendations to reduce yield gaps in-season.

The NNI and NUlogic approach have strengths and weaknesses. The traditional NNI approach examines plant growth per area. It uses a critical N dilution curve (Nd) from the declining shoot Nc in relation to increasing shoot biomass (in t/ha) as a reference point to the actual measured shoot Nc (Greenwood et al. 1990; Lemaire et al. 2008; Sadras and Lemaire 2014). Initially a universal Nd for C3 plants has been proposed by Greenwood et al. (1990), which they derived from data collected in high rainfall/irrigated environments where plant growth and yield are usually positively and, up to a point, linearly correlated. This relationship, however, does not apply to wheat grown in semiarid climates if wheat experiences drought stress during grain filling (Van Herwaarden et al. 1998). Also, while soil water deficit negatively affects plant growth, soil N supply can alter the response to leaf and stem growth differently under these conditions (Ratjen et al. 2016). This will affect total shoot Nc. Furthermore, breeding for higher yielding varieties in semi-arid climates has caused selection of varieties with high water-soluble carbohydrates in shoots thereby diluting shoot Nc (Hoogmoed and Sadras 2016). Thus the NNI concept is tested here for low rainfall environments and compared with the NUlogic plant N status, an index that has been calibrated directly on grain yield (rather than on biomass). A drawback of the NUlogic method is that the relative grain yield is correlated to Nd using individual shoot weight and its Nc. Plant density, which is an important yield component, is not considered.

The hypotheses of this study are (1) that the risk of achieving agronomic key performance indicators can be predicted in-season using those two plant physiological approaches and (2) that the traditional N-growth calibration, NNI, can be adjusted for WA climates, assuming that the Nd for C3 plants, proposed by Greenwood et al. (1990), is overestimating N deficiency for WA.

Methods

Adjusted NNI and NUlogic plant N status

The NNI methodology described by Greenwood et al. (1990) is modified here to include early sampling and lower rainfall. Unlike trials used by Greenwood et al. (1990) and Justes et al. (1994), trials in WA have shown early biomass (when < 1 t/ha) responses to N fertiliser, suggesting non-assimilated N (NO_3) to be important at early plant stages (Elliott et al. 1987). Hence, critical Nc and nitrate concentration (NO_3c) for each sampling date was calculated for different N fertiliser treatments. Biomass was estimated from individual shoot dry weight and estimated plant density according to seeding rate, thousand grain weight and germination rate. Biomass dry weight was compared among the N treatments, using one-way-ANOVA. Statistically significant results ($P < 0.05$) were used for the critical Nd and NO_3 dilution curve, NO_3d (Figure 1). Non-statistically significant results were displayed as additional data. The largest, statistically significant biomass determined critical Nc and NO_3c. If two or more treatments resulted in the same highest biomass, then the one with the lowest N was selected as the critical N and NO_3 at that critical biomass. A Nd and NO_3d was plotted through those data points using a power function. The Nd was further adjusted by a rainfall coefficient (SR = Summer Rain, GSR = Growing Season Rain), improving the relative yield-NNI correlation by 25% (Figure 2). The adjusted NNI (equation 1-3) is a ratio of the measured N, and at early plant stages also NO_3, to the Nd and NO_3d. An adjusted NNI of 1 stands for optimal N nutrition, a NNI < 1 is regarded as N deficient and a NNI > 1 is representing a N luxury consumption.

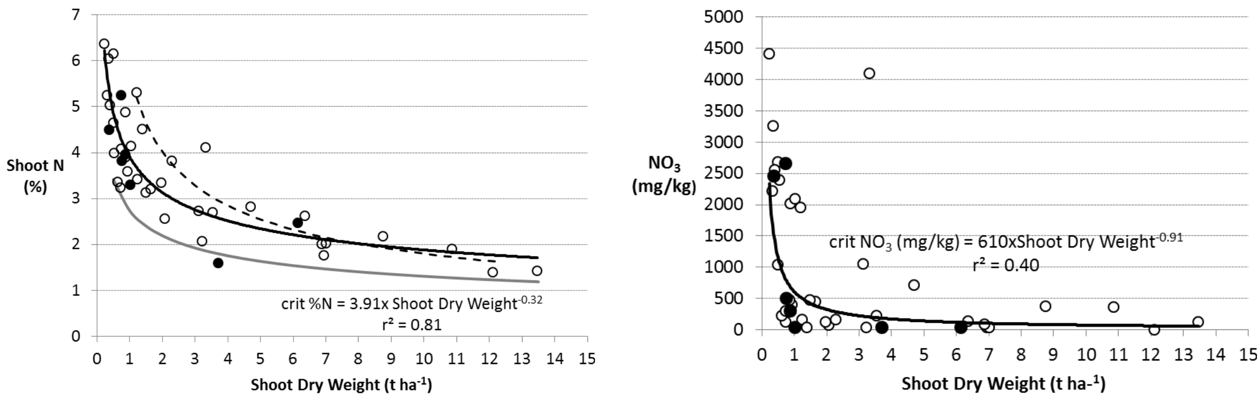

Figure 1. Statistically significant data (filled circles) were used to fit black lines as the critical Nd (left) and NO_3d (right) for areas with > 400mm rainfall. The grey line for Nd (left) gave the best fit for data < 400 mm rainfall. Blank circles show non-significant data. Dotted line is the critical Nd by Greenwood et al. (1990) for C3 plants.

$$\mathbf{NNI}_{(SR+GSR>400\ mm\ \&\ Biomass\ <\ 1t/ha)} = ((N(\%) / (3.91*biomass^{-0.32})) + (NO_3(mg/kg) / (610*biomass^{-0.91}))) / 2) \quad (1)$$

$$\mathbf{NNI}_{(Biomass\ >\ 1\ t/ha)} = N(\%) / (3.91*biomass^{-0.32}) \quad (2)$$

$$\mathbf{NNI}_{(SR+GSR\ <\ 400mm)} = N(\%) / ((3.91*biomass^{-0.32}) * 0.7) \quad (3)$$

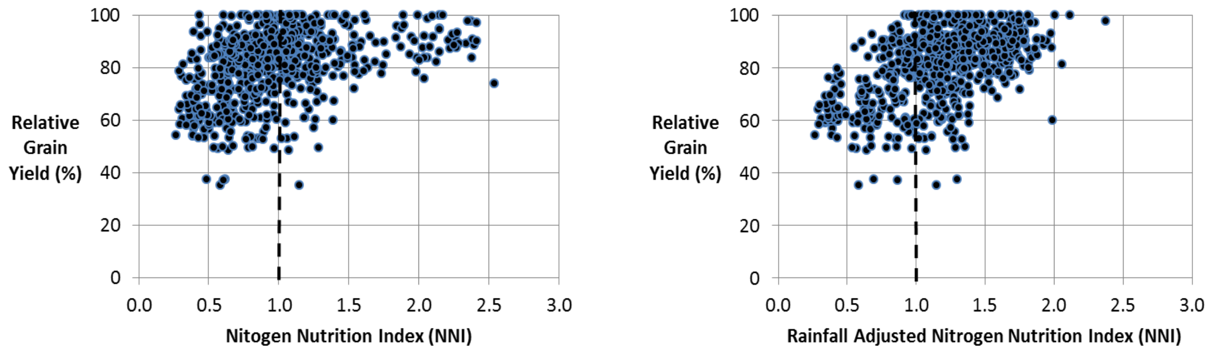

Figure 2. The NNI-yield correlation using total N and NO_3 (left) was further improved for the adjusted NNI using rainfall data (right) to justify equation 1-3.

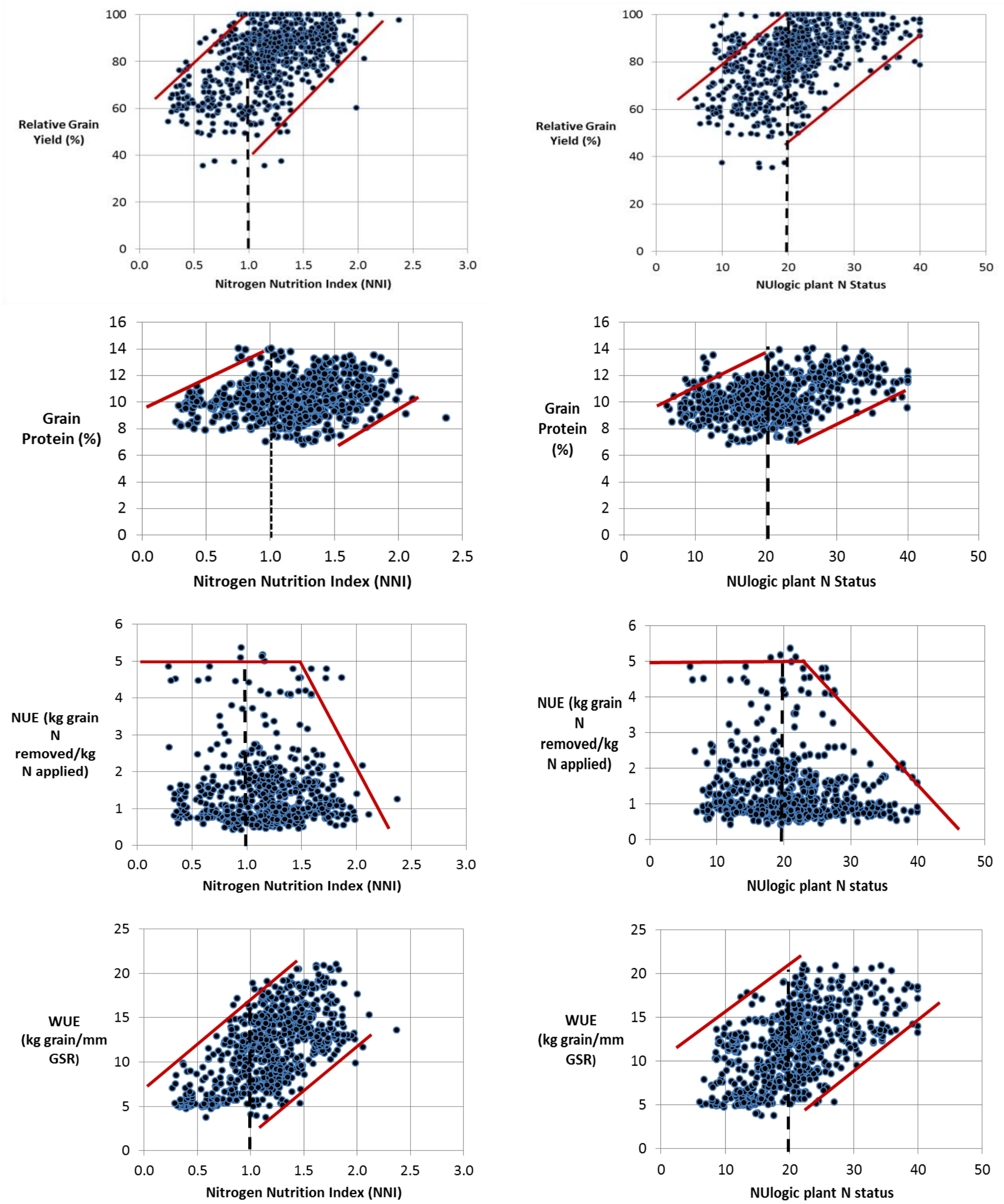

Figure 3. The adjusted NNI (left) and NUlogic plant N status (right) show the closing of a yield gap or estimating loss of yield potential and expectancy of lower yield potential (top), of reaching the target protein (2nd from top) and of evaluating NUE (2nd from bottom) and WUE (bottom) in-season. The scale for the NUlogic N status refers to the categories "low" (0-10), "marginal" (10-20), "sufficient" (20-30) and "high" (30-40). Red lines in graphs indicate (visually assessed) boundary lines for maximum and/or minimum limits.

The NUlogic model has been developed from regression analysis of N-responsive CSBP field trial data using a combination of decision tree and multi factorial regression analysis of normalised data, which had optimised coefficients using a squared error function. Input factors are N (%), NO_3 (mg/kg), shoot dry weight (g), plant age (days) and target yield (t/ha). The Nd and NO_3d, based on individual shoot dry weight, are calibrated on relative yield (not maximum shoot growth), and then adjusted to absolute yield: "Low" indicating 0-60%, "Marginal" 60-80%, "Sufficient" 80-90% and "High" 90-100% of the target yield.

Data

CSBP Data were taken from 32 WA field trials, using different wheat varieties and locations from 2002 to 2016, yielding between 1-7 t/ha. Grain protein varied between 7-14%, decreasing with higher shoot N:S ratio. That ratio fluctuated between 9-16, declining with plant age. Plant sampling occurred from early tillering to late stem elongation. Only N trials with no other nutrient deficiency and only plant samples that did not receive any fertiliser after sampling were included in the data analysis. All samples were analysed at the CSBP soil and plant laboratory. Summer rain (Dec-Mar/Apr) and growing season rain (May-Sep/Oct) were taken from the nearest weather station recorded by the Bureau of Meteorology.

Results

This study confirmed both hypotheses. The risk of achieving desired agronomic end-of season parameters, such as relative yield, grain protein, NUE and WUE, can be assessed by in-season variables. The adjusted NNI, which can be used as such an in-season intermediate variable (Cui et al. 2002), gave similar results when compared with the NUlogic plant N status (Figure 3).

An adjusted NNI < 1 or a NUlogic plant N status < 20 ("sufficient") drastically reduced yield potential. Values above that threshold tended to increase minimum yield, reduced variability and thus the risk of closing that yield gap. Despite the variation, which may be due to mineralisation potentials during the season, upper and lower trend lines could indicate also suboptimal protein, NUE and WUE. The adjusted critical Nd was below the proposed curve by Greenwood et al. (1990), especially when NO_3 and rainfall was considered (Figures 1 and 2). Canopy management in low rainfall environments, a shift in leaf:stem ratio, higher carbohydrate content and irregular N uptake due to climate variability may cause lower critical Nc at the same biomass than what has been measured in higher rainfall areas. In low rainfall areas of WA it appears to be beneficial to control plant growth with suboptimal N, reducing the amount of transpiring leaf mass so that more water will be available at grain filling (Van Herwaarden et al. 1998). In summary, the adjusted NNI or NUlogic N status may be suitable to assess the risk of achieving the investigated key performance indicators. However, care needs to be taken to rule out any interference from non-nutritional and other nutritional problems apart from N.

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