Nitrogen partitioning in spring and winter wheat at various N rates

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Abstract

Nitrogen partitioning can determine crop productivity. This study assessed N partitioning in wheat (*Triticum aestivum* L.) as affected by varying N fertiliser rates and planting dates. Dry matter (DM) accumulation and N concentration were quantified in stem, leaves, chaff and grain at anthesis and harvest. The effects of planting dates (5 May (winter) versus 5 August (spring)) and N rates (0, 50, 100 and 200 kg urea-N ha^{-1}) were evaluated using split plot designs with three replicates under both rainfed and irrigated conditions at Lincoln, New Zealand. For all assessed management systems, the treatment combination means for the fraction of N allocated into harvested grain (i.e., N harvest index (NHI)) ranged from 0.74 to 0.91, while aboveground whole plant N accumulation at harvest (N uptake) varied from 51 to 244 kg N ha^{-1}. Log-analyses of these data indicated that 75% of variation in N allocated to grain can be attributed to fluctuations in N uptake, whereas NHI changes explained on average only 25% of this variability. Overall, this assessment identified limited management effects on N partitioning but only under rainfed conditions. Of the NHI-associated variability under rainfed conditions, 42% and 34% were attributable to planting date (spring (0.82) > winter wheat (0.87)) and to a significant interaction between planting date and N rate, respectively ($P<0.05$). Increased N partitioning was observed for rainfed spring wheat at both 0 and 50 kg urea-N ha^{-1} (0.91 and 0.87, respectively) as compared to lower NHI values for rainfed winter wheat at the same N rates (0.79 and 0.80, respectively). These findings can inform modeling efforts of rainfed wheat production.

Additional keywords: N utilisation, N uptake, harvest index

Introduction

The world population is projected to increase by from 7000 to 9000 million in the next five decades (US Census Bureau, 2011). Under a global scenario of increased food and energy demands by this increasing population and also because arable land is limited, sustainable resource management and enhanced crop production efficiency are critically needed. In cereals, crop productivity is partly driven by the proportion of plant dry matter (DM) allocated into grain (Anderson, 1985; Hernandez-Ramirez *et al*., 2011), and therefore, major research efforts have been dedicated to examine DM partitioning. However, less information is available about crop N partitioning (Ehdaie and Waines, 2001; Ferrise *et al*., 2010). As a numerical indicator, N partitioning integrates information from N status in grain and plant residue as well as from DM partitioning in a single parameter (Dordas, 2009; Hernandez-Ramirez *et al.*, 2011). Moreover, as a concept, N partitioning has been directly associated with plant productivity (Cassman *et al.*, 1992; Ehdaie and Waines, 2001).

In New Zealand, the Canterbury plains are the most important area for intensive cultivation of cereal crops such as wheat. Therefore, it is relevant to examine the potential responses of wheat N partitioning to various management systems (Cassman *et al.*, 1992; Xu *et al.*, 2005). Thus, this study was conducted to assess N partitioning parameters and associated yield response in wheat as affected by varying N fertiliser rates and planting dates under both rainfed and irrigated conditions.

Materials and Methods

This study was conducted in Lincoln, Canterbury (l43°38'S; 172°30'E). The soil is a deep (>1.6m) Templeton (Udic Ustochrept) sandy loam. Normal precipitation is 635 mm year^{-1} (50 year data). Daily weather patterns during the experimental period are shown in Figure 1.

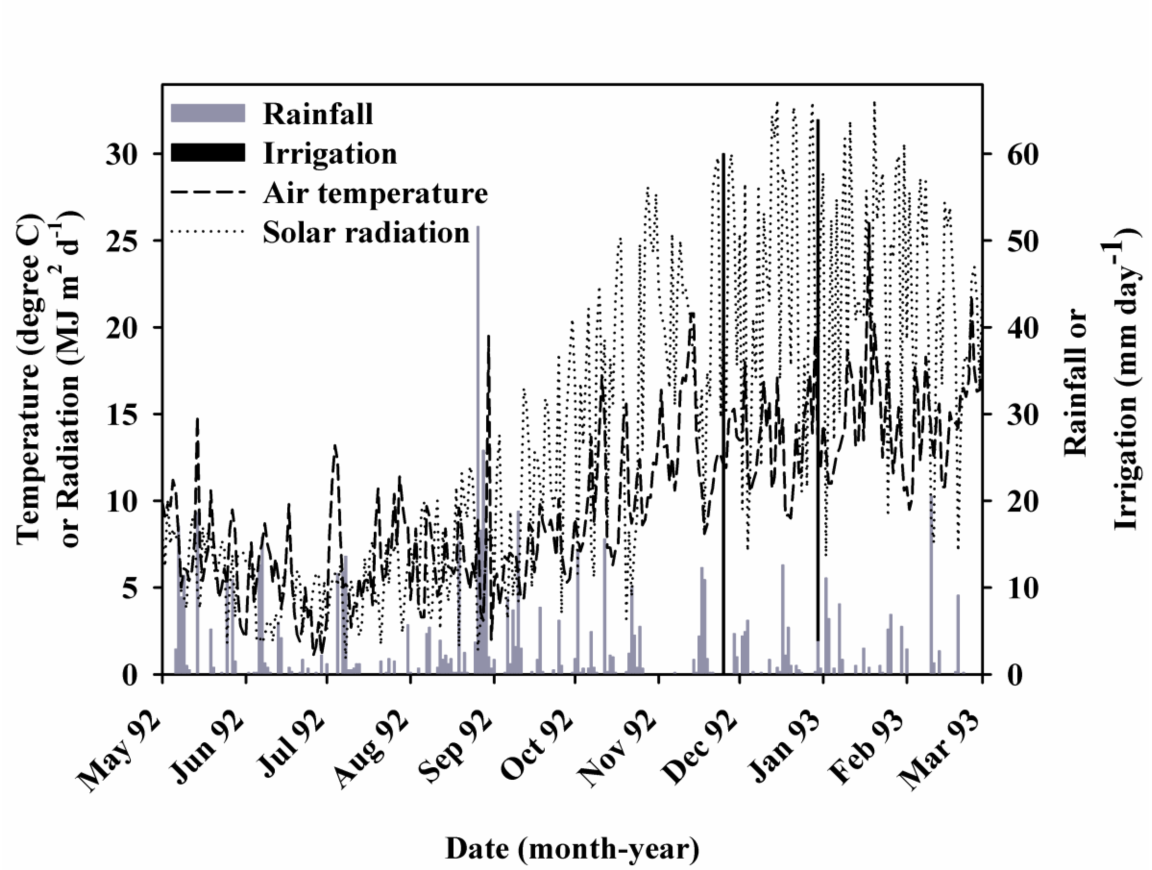

Figure 1:. Solar radiation, air temperature, rainfall and irrigation water during the period of the experiment. Values shown are daily means for air temperature, solar radiation and daily cumulative for rainfall plus irrigated water.

Two separate experiments were arranged in split plot designs with three replicates. Subplot area was 35 m^2. One experiment was under rainfed conditions and the other was irrigated. These two experiments were neighbouring and simultaneous, and therefore, both were conducted under similar soil and weather conditions. The whole (or main) plot factor was planting date (winter (5 May 1992) versus spring (5 August 1992)). The split plot factor was N rate (0, 50, 100 and 200 kg N ha^{-1}) using broadcast urea. Plots receiving 50 kg N ha^{-1} rate were fertilised in a single dose on 5 August for winter wheat and on 1 October for spring wheat. The 100 and 200 kg N ha^{-1} fertiliser rates were added as split applications. The 100 kg N ha^{-1} rate was evenly split for both winter (5 August and 1 October) and spring wheat (1 October and 20 October), while the 200 kg N ha^{-1} rate was split across three dates for both winter (50 kg on 5 August, 100 kg on 1 October and 50 kg on 20 October) and spring wheat (100 kg on 1 October, 50 kg on 20 October and 50 kg on 25 November). Existing mineral N (nitrate plus ammonium) within the top 30 cm of soil prior to N fertilisation was 27 kg N ha^{-1}. Triple superphosphate (135 kg P_2O_5 ha^{-1}) was applied at planting for both winter and spring wheat. Following conventional tillage practices, the wheat cultivar Batten was sown at a planting density of approximately 312 seeds m^{-2}. Weed management was done on 24 August for winter planting and on 6 October for spring planting using commercial herbicides as chlorsulfuron (15 g ha^{-1}), clopyralid amide (300 g ha^{-1}), pirimicarb (100 g ha^{-1}) and triadimenol (125 g ha^{-1}). Irrigated plots received two water additions of 60 mm each on 25 November and 30 December (Figure 1). Anthesis was observed on 23 November for winter wheat and on 12 December for spring wheat. Harvest was carried out on 21 January 1993 for winter wheat and on 3 February 1993 for spring wheat.

Aboveground plant samples were collected at anthesis (0.2 m^2) and at harvest (2.1 m^2). A subsample of a least 10 plants was used for partitioning into stem, leaves, chaff and/or grain. All plant materials were oven-dried at 60°C to determine DM values. Subsamples were taken from the oven-dried plant material and ground for N concentration analysis by Kjeldahl method. The DM values and tissue N concentrations were subsequently used to calculate N masses. Two different harvest indices (HI; dimensionless) were calculated to estimate aboveground partitioning of DM (Equation 1) and N (Equation 2).

$$\mathrm{DMHI} = G_{DM} / AB_{DM} \qquad \text{(Equation 1)}$$

$$\mathrm{NHI} = G_{N} / AB_{N} \qquad \text{(Equation 2)}$$

where G is grain and AB is total aboveground biomass (i.e., grain and straw (stem, leaves, chaff)) at harvest.

The relative contributions of aboveground N partitioning (NHI) and aboveground plant N uptake (Nuptake) to N utilisation were estimated using equation 3 (Hernandez-Ramirez *et al.*, 2011).

$$\mathrm{NHI}_{\mathrm{contribution}} = \frac{\ln\left(\dfrac{100\times|\mathrm{NHI}_1 - \mathrm{NHI}_0|}{\mathrm{NHI}_0}\right)}{\ln\left(\dfrac{100\times|\mathrm{Nuptake}_1 - \mathrm{Nuptake}_0|}{\mathrm{Nuptake}_0}\right) + \ln\left(\dfrac{100\times|\mathrm{NHI}_1 - \mathrm{NHI}_0|}{\mathrm{NHI}_0}\right)} \times 100 \qquad \text{(Equation 3)}$$

where the subscripts 0 and 1 indicate incremental change for each variable at lower and higher values, respectively. Fractional aboveground plant N uptake contribution (fNuptake) was calculated directly (Equation 4).

$$\text{Nuptake}_{\text{contribution}} = 100 - \text{NHI}_{\text{contribution}} \qquad \text{(Equation 4)}$$

All variables were statistically assessed for influential points, homogeneity of variance and normality by Cook's distance, Bartlett and Shapiro-Wilk test, respectively. Subsequently, Box-Cox transformations were applied as needed. The relationships among variables were examined by Pearson product moment correlations (*r*). Split plot analyses were done to assess treatment effects using analyses of variance (ANOVA) with general linear models including block as a random factor, planting date and N rate as a fixed factors, planting date by N rate as an interaction, planting date by block interaction as a whole (or main) plot error and both N rate by block and planting date by N rate by block were pooled as a split plot error. Coefficients of variation (CV) and determination (R^2) were attained from ANOVA models. Subsequently, Tukey honest significant distance (HSD) tests were performed for multiple treatment mean comparison. Estimations and significance statistics were processed at α=0.05. Statistical analyses were performed using Minitab 14 (Minitab Inc., State College, PA).

Results

Within both rainfed and irrigated experiments, N rate showed significant effects for DM and N accumulation and partitioning, while the effects of planting date were minimal (Table 1). In addition, interaction effects of planting date and N rate on both DMHI and NHI were significant only under rainfed conditions (Table 1, Figure 2). A separate ANOVA with factor combinations (after removing whole plot and split plot factors and their interaction) revealed planting date and N rate interaction effects on NHI only under rainfed conditions (Figure 2a). Partitioning of N into grain was consistently greater for spring versus winter wheat; however, these differences were more obvious at the two lower N rates (0 and 50 kg N ha^{-1}) (Tukey's HSD test, $P<0.05$). Whereas winter wheat at 0 and 50 N rates resulted in an NHI of 0.79 and 0.80, respectively, spring wheat at 0 and 50 N were 0.91 and 0.87, respectively (Figure 2a). It is noteworthy that this difference in N partitioning across planting dates was not present at the higher N rates (100 and 200 N, Figure 2a). Another ANOVA with factor combinations done on DMHI under rainfed conditions partly supports this finding (Figure 2b). This interaction effect of planting date and N rate on DMHI revealed only one overall significant difference. Treatment combinations of spring wheat at both 0 N and 200 N, and winter wheat at 200 N substantially increased DMHI means (0.47, 0.48 and 0.46, respectively) compared with winter wheat at 0 N had a relatively low DMHI (0.33), (Figure 2b, Tukey's HSD test, $P<0.05$).

Grain and straw N concentrations at harvest (data not shown) were affected only by varying N fertiliser rate under both rainfed and irrigated conditions (ANOVA and Tukey's HSD tests, $P<0.05$). As expected, grain N concentrations increased from approximately 17.0 to 23.5 g N kg^{-1} DM for the lowest versus highest N rate, respectively, while straw N concentrations fluctuated from 2.1 to 3.8 g N kg^{-1} DM for the same comparison. These increases in tissue N concentrations in conjunction with associated increases in DM translated into enhanced N masses for both whole plant and grain as a direct function of increasing N fertiliser rate regardless of planting date (Table 1).

Table 1: Wheat aboveground dry matter (DM) and nitrogen (N) accumulation and partitioning (harvest index, HI) for spring and winter plantings and varying N fertiliser rates at anthesis and harvest stages for rainfed and irrigated experiments. (n=3).

Treatment or statistic	DM Accumulation			DMHI	N Accumulation			NHI
	Whole plant		Grain		Whole plant		Grain	
	Anthesis	Harvest			Anthesis	Harvest		
	—— Mg DM ha^{-1} ——				—— kg N ha^{-1} ——			
Rainfed experiment								
Planting date (SW)								
Spring	10.2	12.6	5.7	0.45	131	132	114	0.87^{a}
Winter	12.5	15.8	6.5	0.40	147	144	119	0.82^{b}
N rate, kg N ha^{-1}								
0	7.5^{b†}	8.2^{b}	3.2^{c}	0.41	69^{c}	65^{c}	56^{c}	0.85
50	12.1^{a}	15.3^{a}	6.3^{b}	0.41	123^{bc}	121^{b}	101^{b}	0.83
100	12.7^{a}	16.1^{a}	6.8^{b}	0.42	157^{ab}	143^{b}	120^{b}	0.84
200	13.1^{a}	17.2^{a}	7.9^{a}	0.46	208^{a}	224^{a}	190^{a}	0.85
Mean	11.3	14.2	6.1	0.43	139	138	117	0.84
Source of variation								
SW	NS	NS	NS	NS	NS	NS	NS	*
N	**	***	***	NS	***	***	***	NS
SW x N	NS	NS	NS	*	NS	NS	NS	**
R^{2}	0.79	0.95	0.95	0.79	0.85	0.97	0.96	0.84
CV, %	19	9	11	8	25	12	12	3
Irrigated experiment								
Planting date (SW)								
Spring	9.9	12.7	5.9	0.46	121	130	112	0.86
Winter	11.4	13.3	4.9	0.37	119	113	89	0.78
N rate, kg N ha^{-1}								
0	5.8^{c}	6.8^{c}	2.7^{c}	0.40	44^{c}	56^{d}	45^{c}	0.81
50	10.7^{b}	12.9^{b}	5.2^{b}	0.40	95^{b}	97^{c}	81^{b}	0.83
100	12.9^{ab}	16.2^{a}	6.7^{ab}	0.41	153^{a}	136^{b}	111^{b}	0.81
200	13.3^{a}	16.2^{a}	7.1^{a}	0.44	189^{a}	196^{a}	162^{a}	0.82
Mean	10.7	13.0	5.4	0.41	120	121	100	0.82
Source of variation								
SW	NS	NS	NS	NS	NS	NS	NS	NS
N	**	***	***	NS	***	***	***	NS
SW x N	NS	NS	NS	NS	NS	NS	NS	NS
R^{2}	0.92	0.91	0.89	0.90	0.89	0.95	0.92	0.78
CV, %	12	13	17	7	23	15	19	5

*,**,*** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

[†] within columns, means followed by the same letter do not differ (Tukey HSD test).

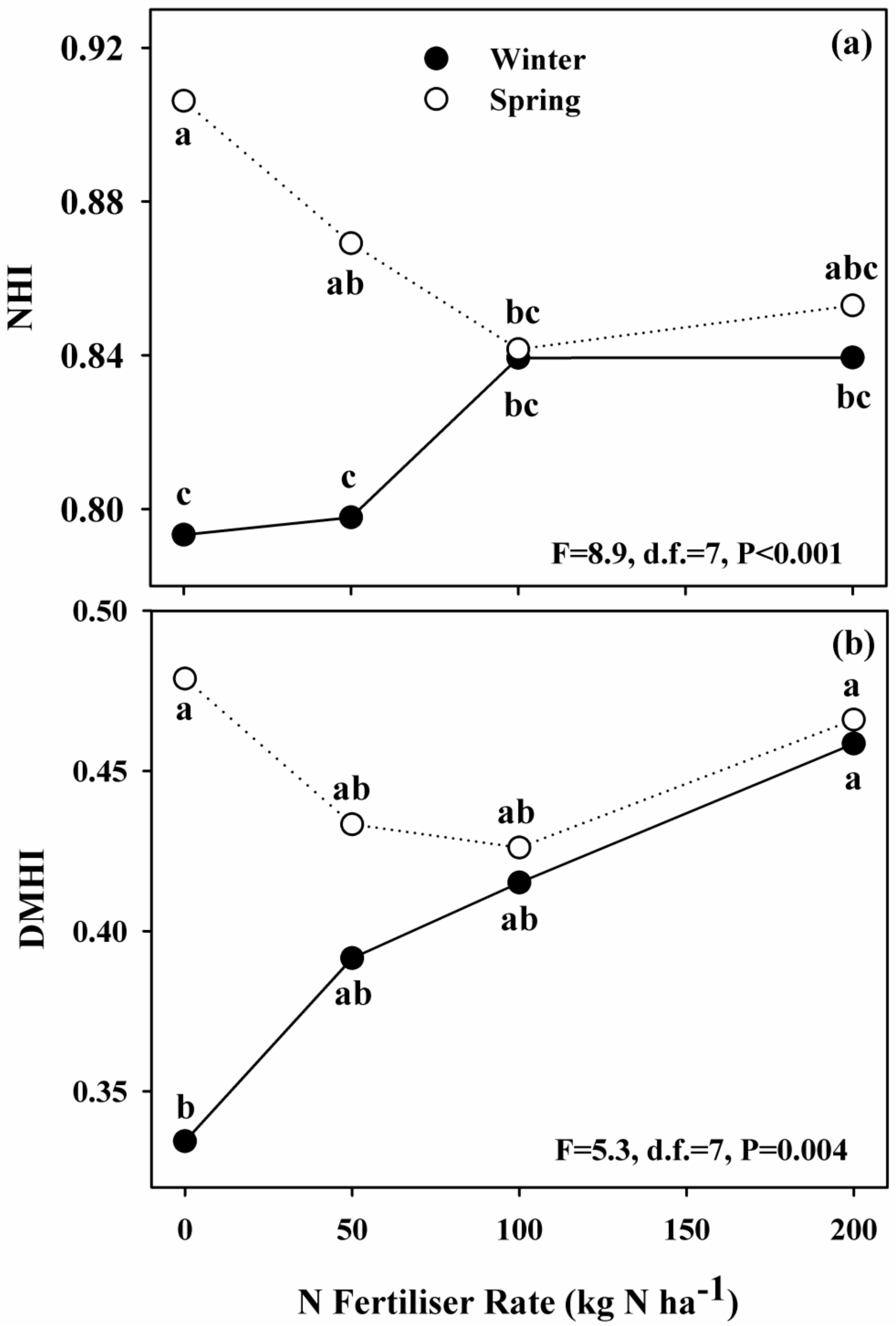

Figure 2: Significant interactions for (a) nitrogen and (b) dry matter (DM) partitionings at harvest time (expressed as harvest indices (HI)) for rainfed wheat as a simultaneous function of both planting date (spring versus winter) and four N fertiliser rates. Treatment combination means (fertiliser rates x planting times) with the same letter are not significantly different according to the Tukey HSD test (α= 0.05) after corresponding ANOVA models. (n= 3).

Discussion

Grain and whole plant DM productivity increased when N fertiliser was added and for all treatments, except whole plants in the rainfed experiment, increased with increasing nitrogen (Table 1). For example, under both rainfed and irrigated conditions, grain productivity approximately doubled when comparing 0 N versus 50 N fertiliser rates. However, irrespective of these observed DM increases, both DM and N partitioning (DMHI and NHI) remained unaffected by varying N rate under both rainfed and irrigated conditions ($P>0.05$). Likewise, although DMHI and NHI values were closely correlated ($r=0.85$, $P<0.05$) (Anderson, 1985; Ehdaie and Waines, 2001), N concentration in grain did not appear to affect these two partitioning indices in this study. Nonetheless, further correlation analyses indicated that N concentration and mass of N allocated into grain at harvest were both clearly associated to whole plant N concentration at anthesis ($r=0.68$ and 0.78, respectively, $P<0.05$). These relationships amongst these variables are to some degree expected because grain N (both concentration and mass) is a major component of whole plant N mass. This observation could support the general premise that grain N is mainly predetermined by tissue N concentration at anthesis (Cassman *et al*., 1992; Xu *et al*., 2005; Ferrise *et al*., 2010). Additionally, the N mass allocated into grain was also directly correlated with straw N mass at harvest ($r=0.77$, $P<0.05$). More importantly, decreases in straw N concentration (data not shown) at harvest were shown to be strongly associated with increased NHI, but only for spring wheat ($r=-0.77$, $P<0.05$). Collectively, these results indicate that the dynamics of plant N partitioning differs between spring and winter wheat cropping systems.

Conceptually, increases in grain N mass can be attributed to either greater plant N uptake or increased partitioning of this uptake N into the grain (NHI), or fractions of both. Under both rainfed and irrigated conditions and across treatment combination means, 75% of the variation in N allocated to the grain can be attributed to fluctuations in whole plant N accumulation at harvest (N uptake), while NHI changes explained on average 25% of the variations in grain N mass in wheat. This outcome is in general agreement with Dordas (2009), who detected no change in NHI as a function of nutrient management in wheat fields and previous analyses by Hernandez-Ramirez *et al*. (2011) for differentiating the relative contributions of NHI and N uptake to grain N mass in corn cropping systems under varying N management. Overall, these results indicate the limited influence of planting date and N fertilisation rates on plant N partitioning although certain interacting effects were identified under the rainfed conditions in this study where NHI for the two lower N rates was greater for spring than for winter wheat as mentioned above (Table 1, Figure 2a). Additional analyses can focus on temporal changes in DM and N partitioning indices and associated plant N uptake and N translocation to the grain across multiple cropping systems.

Conclusion

This field assessment in general identified limited effects of planting date and N managements on N partitioning while N fertiliser addition caused expected productivity responses in wheat cropping systems. In the specific case of N-limited soils under rainfed conditions, spring wheat appears to be relatively more efficient in partitioning whole plant N into grain compared to winter wheat. More research can address this preliminary finding. Also, under both rainfed and irrigated conditions, both DM and N partitioning indices were typically stable across varying N fertiliser rates and planting date. These findings could inform modeling efforts of wheat production systems particularly under rainfed conditions.

References

Anderson, W.K., 1985. Differences in response of winter cereal varieties to applied nitrogen in the field. II. Some factors associated with differences in response. *Field Crops Research* 11: 369-385.

Cassman, K.G., Bryant, D.C., Fulton A. and Jackson, L.F. 1992. Nitrogen supply effects on partitioning of dry matter and grain of irrigated wheat. *Crop Science.* 32: 1251-1258.

Dordas, C. 2009. Dry matter, nitrogen and phosphorus accumulation, partitioning and remobilization as affected by N and P fertilization and source-sink relations. *European Journal of Agronomy* 30: 129-139.

Ehdaie, B. and Waines, J.G. 2001. Sowing date and nitrogen rate effects on dry matter and nitrogen partitioning in bread and durum wheat. *Field Crops Research* 73: 47-61.

Ferrise, R., Triossi, A., Stratonovitch, P., Bindi, M. and Martre, P. 2010. Sowing date and nitrogen fertilisation effects on dry matter and nitrogen dynamics for durum wheat: an experimental and simulation study. *Field Crops Research* 117: 245-257.

Hernandez-Ramirez, G., Brouder, S.M., Smith, D.R. and Van Scoyoc, G.E. 2011. Nitrogen Partitioning and Utilization in Corn Cropping Systems: Rotation, N Source and N Timing. *European Journal of Agronomy* 34: 190-195.

US Census Bureau. 2011. United States Census Bureau International Program (database). Retrieved on 20 September 2011 from http://www.census.gov/population/international/data/

Xu, Z. Z., Yu, Z. W., Wang, D. and Zhang, Y. L. 2005. Nitrogen Accumulation and Translocation for Winter Wheat under Different Irrigation Regimes. *Journal of Agronomy and Crop Science* 191: 439-449.