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RADIATION USE EFFICIENCY IN WINTER CEREALS UNDER SUFFICIENT NITROGEN SUPPLY

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ABSTRACT

In comparison of winter cereals radiation use efficiency in nitrogen fertilizer availability, a factorial experiment in randomized complete block design was conducted during the years 2013/2014 /2015 in Gonbad Kavous region, Iran. Winter cereals were evaluated at zero and optimum nitrogen rates. Results showed LAI varied from 6.08 in triticale to 3.28 in hull less barley in first year while for second year maximum and minimum LAI were obtained in triticale (4.51) and oat (3.38) respectively. In both years, the most accumulation total dry matter was related to triticale. The maximum and minimum K were calculated for bread wheat (0.86) and triticale (0.67) and varied from 0.86 in two rowed barley to 0.56 in hull less barley in first and second years. RUE varied from 2.02 gr Mj−1 in durum to 2.78 gr Mj−1 in triticale and from hull less barley (3.44) to six rowed barley (2.80).

Keywords: Cereal, Extinction coefficient, Nitrogen, Radiation, Wheat.

INTRODUCTION

Wheat, oat, triticale and barley are four groups of winter cereals belonging to the Poaceae family. They are being cultivated throughout different parts of the world where different environmental conditions affect plant growth and yield (Kalaji et al., 2011). Solar radiation is the main source of energy for crops. Several studies have documented that two important factors affect dry matter productions involving solar radiation interception and radiation use efficiency (Li et al., 2009 ; Sandana et al., 2012). A linear relationship was observed between biomass accumulation and the cumulative solar radiation intercepted by crops in the optimum condition. The slope of this relationship is represents as radiation use efficiency (Zhang et al., 2012). RUE, Radiation use efficiency is defined as crop biomass produced per unit of photosynthetically active radiation (PAR) intercepted by the canopy. RUE connected to leaf area index and crop biomass that has a main role in plant production (Miranzadeh et al., 2011).

Beer- Lambert law describes the correlation among PAR, K, and LAI as below equation (Felent et al., 1996):

$$IPAR = PAR \times (1 - \exp(-K \times LAI)) \qquad (1)$$

Where, PAR is photosynthetically active radiation, IPAR is intercepted photosynthetically active radiation, K is the extinction co-efficient for total solar radiation and LAI is leaf area index. Ocanell et al (2004) described that k is the canopy efficiency in radiation interception that depended on radiation orientation; leaf area; canopy structure; plant variety and planting pattern

(O'Connell et al., 2004). 'k' Values that was reported for wheat, oat and barley 0.70, 0.63 and 0.74, respectively and PAR was estimated equal half of daily total radiation (Muurinen and Peltonen-Sainio, 2006). RUE varies in different crops and growth stages (Zahoor et al., 2010).RUE is mainly affected by various abiotic factors likely vapor pressure (Kemanian, and Stockle 2004), drought and water stress, low temperature (Lecoeur, and Ney, 2003) nutrition deficiency (Quanqi et al., 2008) especially nitrogen nutrient availability (Muurinen and Peltonen-Sainio, 2006; Lecoeur and Ney, 2003). RUE varies from 1.46 to 2.93 gr Mj^{-1} for wheat (8), from 1.79 to 2.33 gr Mj^{-1} for barley (O'Connell et al., 2004) and 1.11 to 1.12 gr Mj^{-1} for oat (Muurinen and Peltonen-Sainio, 2006). In an experiment on cereals at 2004, RUE was calculated 3.50 gr Mj^{-1} for wheat and 3.21 gr Mj^{-1} for triticale and the average of RUE for different years and growth stages varied from 1.40 to 1.97 gr Mj^{-1} (Singer et al., 2007). Kavigali and Sadras (2001) in their study on wheat radiation use efficiency in different nitrogen application reported that RUE ranged more at 80 and 120 $kg.ha^{-1}$ than zero nitrogen fertilizer rates (Caviglia and Sadras, 2001). among all of macro and micro nutrients nitrogen is the most essential element which influences RUE by leaf area extended, chlorophyll structure and enzyme activities. Increasing nitrogen application rates correlate to RUE increasing as long as leaf nitrogen content stays under nitrogen saturation point (Salvagiotti and Miralles, 2008).

The present study compared various cereals for the ability to radiation interception, which are related to extension coefficient and nitrogen uptake. Additionally, it described the differences among various cereals species ecophysiological traits correlated to nitrogen rates.

MATERIALS AND METHODS

1. Site and management The experiment was conducted during the growing seasons of 2013/2014 and 2014/2015 on a loamy clay soil with pH 7.7 at experimental research field of Gonbad- e- Kavous University, Gonbad- e- Kavous, Iran (37° 15´ N and 45° 46´ E). The local climate is temperate; summers are hot and dry and winters are mild and rainy. The regional average annual rainfall is over 450 mm and average annual temperature reported about 17.7°C. The experiment carried on a factorial in randomized block design with four replications. Bread wheat (*Triticum aestivum* L.), durum wheat (*Triticum turgidum* L.), barley (*Hordeum vulgare* L.) include two-rowed barley, six-rowed and hull less barley, oat (*Avena sativa* L.) and triticale (*Triticum wittmak* L.) were investigated at two nitrogen fertilizer application rates, zero and optimum, as Urea. Fertilizer P and K were applied according to soil analysis result (table 1). The Optimum nitrogen levels determined 150 kg ha^{-1} for bread wheat and hull less barley, 120 kg ha^{-1} for durum wheat and two rowed barley, 210 kg ha^{-1} for six rowed barley, 240 kg ha^{-1} for triticale and 90 kg ha^{-1} for oat based on the result of soil analysis and the average of recent 10 years yield of each cereals. Plots were sown on 7 December 2013 and 9 December 2014 at seedling rate of 270 per square meter for oat and barley and 350 per square meter for wheat and triticale.

2. Measurements

2.1. Leaf area index (LAI*)* Twenty plants from each plot were selected by random, during the growing season at intervals of 10–15 days at winter and 7 - 10 days at spring (from tillers emergence to physiological maturity stage). The plants divided into leaves, stems and heads. Leaf area was measured with leaf area meter (Delta- T model device). Green leaf area index (LAI) was obtained by exponential model as defined below:

LAI= ((a*exp ((-a)*(dap-b)*c))/ (1+exp((-a))*(dap-b)))2) (2)

Where LAI is leaf area index, dap is days after plant and a, b and c are equation coefficient.

2.2. Dry matter accumulation Each part of plants dried in oven at 70° C for 48 hours and then dry weight recorded. A logistic model used to describe cumulative dry matter where DM_{max} is the maximum cumulative dry matter, a is equation coefficient, b is time (days) to reach 50 percent of total dry matter and dap is days after planting.

)3 ($Y=DM_{max}/(1+exp(-a*(dap-b)))$

2.3.Extinction coefficient (k) and Radiation use efficiency (RUE) photosynthetically active radiation (PAR) was measured above and beneath of canopy with a Sun Scan canopy system (Delta-T Devices). Measurements were taken from three replications, per plot intervals of 5- 7 days from tillering stage to covered canopy between 12 to 14 p.m. The average of extinction coefficient (k) was estimated as the value of the slope of the regression of ln (1 - fi) equation base on leaf area index.

Accumulation radiation was calculated by using the software 9int-PAR. This program is combined leaf area index and extinction coefficient relevant to whether data include in solar hour, daily leaf area index and daily radiation. Radiation use efficiency calculated as the slope of a linear regression of accumulation dry matter versus accumulation PAR.

3.Statistical analysis After testing for the homogeneity of variances, the data collected from these experiments were statistically analyzed with SAS software and the treatments mean was compared by LSD test at 5% level. In addition, Graphs were drawn with Excel 2007.

RESULTS AND DISCUSSION

1. Leaf area index According to results through the years**,** combination coefficient and standard error range of LAI model at zero and optimum nitrogen fertilizer rates showed that nitrogen application had no significant effect on leaf area index. In the first year, leaf area index varied from 6.08 in triticale to 3.28 in hull less barley at 117 days after planting. In the second year, maximum leaf area index was obtained in triticale (4.51) at 115 days after planting and minimum leaf area index was observed in oat (3.38) at 118 days after planting. The result showed that in first year crop canopy was closed earlier in comparison to the second year and triticale had the maximum leaf area index in both years. As it can be seen in Figure 1, Leaf area index pattern is defined as an exponential model in different cereals. The peak of leaf area index of cereals showed synchrony in anthesis advent, and increased gradually and similar among different cereals in order to reach to tillering event. After that, it differed until to physiological maturity. At the first year, by the lower temperature in winter leaf area developed gentler rather than the second year. The significant difference in cereal leaf area index demonstrated in figure 1 (a) and (b).

2. Accumulation dry matter The results showed that effect of nitrogen application on total dry matter had no difference significantly that can by the sufficient soil nitrogen supply for reaching maximum growth and dry matter. The pattern of dry matter accumulation followed a logistic model that showed cereal had no significant difference at initiation dry matter accumulation (figure 2 (a) and (b)). With beginning liner stage of growth and difference in leaf area index, significant variation in crop growth rate began and reached to a peak at pre flowering before maximum leaf area. In both years, the most accumulation total dry matter was observed in triticale (2054.9 gr m^{-2}, 2557.05 gr m^{-2}) that related to more height, node number, leaf area and leaf number in triticale rather than other cereals. The minimum accumulation dry matter was obtained in durum wheat (1528 gr m^{-2}) in the first year and in second year was linked to oat (1836.5 gr m^{-2}). In the second year, durum wheat with 2219.9 gr m^{-2} showed significant increase in accumulation dry matter rather than the first year that can be for increasing plant height, nodes and inter nodes (figure 2). Minimum accumulation dry matter in oat can be explained by lesser tillers number, lower leaf number, leaf area and height.

3. Extension coefficient and radiation use efficiency The year × cereal × nitrogen interaction effect was significant on extension coefficient (k) at 1% level ($P < 0.001$). Year × cereal interaction and year × nitrogen differed significantly at 1 percent level. Results showed that nitrogen application had no significant effect on extension coefficient, but K varied in different cereal significantly. Table 1 shows the k value for crops in 2013-2014 and 2014/2015. The maximum of k value was observed in bread wheat (0.86 ± 0.03) and the minimum was obtained in triticale (0.67± 0.03). Extension coefficient was obtained 0.77 ± 0.03 for durum wheat, 0.79 ± 0.03 for six-rowed barley, 0.80 ± 0.3 for two-rowed barley, 0.74 ± 0.05 for hull less barley and 0.76 ± 0.04 for oat. Combination of k coefficient showed that nitrogen application at zero and optimum rates did not differ significantly.

For 2014-2015 nitrogen, application had no significant effect on extension coefficient, where the maximum of k was 0.86 ± 0.043 in two rowed barley and the minimum that related to hull less barley with 0.56 ± 0.036. K calculated for triticale 0.73 ± 0.03, bread wheat 0.86 ± 0.03, durum wheat 0.83 ± 0.04, six rowed barley 0.66 ± 0.05 and oat 0.82 ± 0.05 (table 1).

Figure 3 shows fractions of intercepted radiation changes by the leaf area index in different cereal in 2013/2014 and 2014/2015. Extension coefficient is strongly depended on leaf structure in canopy, radiation intercepted and leaf area index. There is no significant difference in extension coefficient in same canopy structure and growth pattern in cereals. The relation between total dry matter and accumulation radiation during planting to maturity is described by the strong coefficient that is more than 0.97. Combination of RUE±SE at zero and optimum rates demonstrated that nitrogen application did not have any significant effect on cereal radiation use efficiency (table 2). Sufficient soil nitrogen supply and insignificant difference in cereals leaf area index and extinction coefficient related to radiation intercepted at zero and optimum nitrogen rates describe non-significant difference in RUE. Cereals differed significantly in radiation use efficiency. At the first year, RUE varied from to 2.02 ± 0.07 gr Mj^{-1} in durum wheat to 2.78 ± 0.14 gr Mj^{-1} in triticale. RUE obtained 2.17± 0.048 for oat, 2.42±0.13 for bread wheat, 2.33± 0.09 for two-rowed barley. 2.52 ±0.11 for hull less barley and 2.39± 0.08 for six-rowed barley. in the second year, the maximum RUE was observed in hull less barley (3.44± 0.25) and minimum was obtained in six rowed barley (2.80± 0.12). RUE was obtained 2.17± 0.048 for oat, 2.42±0.13 for bread wheat, 2.33± 0.09 for two-rowed barley, 2.52 ±0.11 for hull less barley and 2.39± 0.08 for six-rowed barley (table 2). Figure 4 (a) and (b) illustrates a linear equation y=ax+b of regression accumulation dry matter to radiation at zero and optimum levels. Slop of this line (a) is known as RUE. As it can be seen in above figures, the slope of triticale is the most and oat has the least in the first year. In the second year, plenty variation in cereal RUE was observed. More slopes indicate more accumulation dry matter in per radiation unit that causes to more assimilate transfer and efficiency while produces biomass further for improving yield (Dipenborek., 2000).

DISCUSSION

1.Leaf area index during years, triticale by its adaptation to warm and drought climate condition; has improved the root system development for more nutrition absorption that increased node number and leaf area index with leaf area development. Lower leaf area index in oat and hull less barley associated to longer each phonological advent and the response to environmental condition and lower leaf number. Koochaki and Sarmadnia (2008) remarked that leaf area index pattern in almost all crops is exponential, therefore leaf area increases gradually in initial growing season and reaches to a peak at anthesis event and then decreases because of leaf senescence and yellowness in the end of growing season. The optimum leaf area index of cereals varies from 3 to 5. Leaf area in all plant types has a main role in accumulation dry matter by radiation interception, in the other words, most of plants reach to maximum radiation interception and accumulation dry matter by reaching optimum leaf area index (Acreche et al., 2009). Murrinen et al (2005) and Ocanell et al (2004) reported the maximum leaf area index in cereal almost being seen at pre anthesis advent.

2.Accumulation dry matter No difference between zero and optimum nitrogen fertilizer effect on accumulation dry matter refers to soil nitrogen supply and different plant ability to nutrient sources take up. Total dry matter in all cereal in the second year of experiment was more than the first year but in oat was observed no significant difference. Triticale showed the maximum total dry matter in both years. Increasing dry matter can explain by increasing plant length, tiller number or leaf length. Yujio et al (2006) in an investigation on triticale documented that by increasing nitrogen fertilizer application up to 145 kg ha^{-1} biological yield raised significantly up to 4.5 ton $ha^{-1.}$ .Ocanell et al (2004) declared lower leaf area index reduces radiation interception and decreases photosynthesis rate and efficiency in per area unit.

3. Extension coefficient and **Radiation use efficiency** Extinction coefficient was various in different cereals in both years of experiment. According to the results, soil nitrogen supply was sufficient for cereals above ground growth and no significant effect was observed on accumulation dry matter and radiation interception by nitrogen application increasing. Extinction coefficient depends on leaf shape, leaf structure, leaf area index and plant height. The difference in extinction coefficient through the years was mainly related to variation of leaf angle, leaf area index and plant height. Akmel and Janson (2004) declared that any variation in extension coefficient in plants relates to leaf structure and leaf area index. A liner regression described relationship between accumulation dry matter and radiation based of PAR value and the slope considered as RUE. The higher radiation use efficiency for triticale was related to maximum leaf area index and plant height that led to receiving more radiation and dry matter production by the higher plant capacity (Chen et al., 2003). It seems climate condition in the second year with low precipitation winter, cloudy weather in spring and final season heat stress provided appropriate condition for barley genotypes for more radiation use efficiency. It is observed triticale radiation use efficiency decreased in the second year by decreasing leaf area index and different response of longer phonological stages to environment (table 2). Canopy earlier closing, higher leaf area index and reaching to maximum of leaf area according to maximum of radiation interception explain the further radiation use efficiency in triticale and more accumulation dry matter. Enough soil nitrogen supply increases leaf growth and development and more intercepted radiation. Ahmad et al (2012) reported that variation in radiation use efficiency in wheat and oat depends on their leaf area index and extension coefficient that was according to Makela et al (2004) results. Crop yield was positively related to radiation use efficiency such as other results in Lie et al (2006) and Chen et al (2003) studies. Acreche et al (2009) declared that for crops biomass improving in dry land condition, cumulative PAR and RUE should be increased with increasing leaf area at earlier growth stages. Besides that, balance between nitrogen validity and moisture supplies is important. Quangi et al (2009) reported that application of nitrogen fertilizer increases PAR interception as reported by Muurinen and Peltonen-Sainio(2007) .

CONCLUSION

In the present study, various winter cereals have been compared for their ability to reach radiation interception and radiation use efficiency. Variation of leaf area index and, accumulation dry matter and extinction coefficient in different cereals led to variation in radiation interception and radiation use efficiency. Cereals had higher radiation use efficiency in the second year that shows more dry matter production by accumulation photosynthetic active radiation. The relationship among leaf area index, dry matter production, and extinction coefficient and radiation use efficiency showed that triticale had the main significant factors to be an adaptable plant in this region.

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REFERENCES

Acreche, M. M., Briceno-Felix, G., M,Sanchez J. A., Slafer, G. A. 2009. Radiation Interception and Use Efficiency as Affected by Breeding in Mediterranean Wheat. Field. Crops. Res. 110, 91–97.

Ahmad, S. H., Ali, M., Ismail, M., Nadeem, M. A., Anjam, N., Zia-ul-haq, M., Khan, M. A. 2012. Radiation and nitrogen use efficiency of c_3 winter cereals to nitrogen spilt application. Paki. J. Bot. 44(1), 139-149.

Akmal, M., Janssens, M. J. 2004. Productivity and light use efficiency of perennial ryegrass with contrasting water and nitrogen supplies. Field. Crop. Res. 88, 143-155.

Caviglia, O. P., Sadras, V. O. 2001. Effect of nitrogen supply on crop conductance, water- and radiation-use efficiency of wheat. Field Crops Res. 69, 259-266.

Chen, YH., Yu, S. L., Yu, Z. W. 2003. Relationship between Amount or Distribution of PAR Interception and Grain Output of Wheat Communities. Acta. Agron. Sin. 29, 730–734.

Diepenbrock, W. 2000. Yield components of winter oilseed rape (*Brassica napus* L.): review. Field. Crops. Res. 67, 35-49.

Felent, F., kiniry, J. R., Board, J. E., Westgate, M. E., Reicosk, D .C. 1996. Row spacing effects on light extinction coefficient of corn, sorghum, soybean and sunflower. Agronomy Journal. 88, 185-190.

Giunta, F., Motzo, R., Pruneddu, G. 2008. Has long term selection for yield in durum wheat also induced changes in leaf and canopy traits? Field Crops Res. 106, 68–76.

Kalaji, H. M., Bosa, K., Kościelniak, J., Żuk-Gołaszewska, K. 2011. Effects of salt stress on photosystem II efficiency and CO2 assimilation of two Syrian barley landraces. Environmental and Experimental Botany. 73, 64–72.

Kemanian, A. R., & Stockle, C. O. 2004. Variability of barley radiation-use efficiency. Crop Sci. 44, 1662–1672.

Koochaki, A., Sarmadnia, G. H. 1993. Crop physiology. Mashhad Jihad Daneshgahi Press. Pp. 477.

Lecoeur, R., Ney, B. 2003. Change with time in potential radiation use efficiency in field pea. European Journal Agronomy. 19, 91-105.

Li, M., Liu, J., Zhang, B .D., Bai, Q. 2009. Biomass accumulation and radiation use efficiency of winter wheat under deficit irrigation regimes. Plant Soil Environment. 55(2), 85–91.

Makela, P., Muurinen, S., Peltonen-Sainio, P. 2004. Alterations in growth and canopy architecture among dwarf, semi dwarf and tall oat lines grown under northern conditions. Agric. Food. Sci. 13, 170-185.

Miranzadeh, H., Emam, Y., Seyyed, H., Zare, S. 2011. Productivity and Radiation Use Efficiency of Four Dryland Wheat Cultivars under Different Levels of Nitrogen and Chlormequat Chloride. J. Agr. Sci. Tech. 13, 339-351.

Muurinen, S., Peltonen-Sainio, P. 2006. Radiation-use Efficiency of Modern and Old Spring Cereal Cultivars and Its Response to Nitrogen in Northern Growing Conditions. Field Crops Res. 96, 363–373.

O'Connell, M. G., O'Leary, G. J., Whitfield, D.M., Connor, D. J. 2004. Interception of Photosynthetically Active Radiation and Radiation-use Efficiency of Wheat, Field Pea and Mustard in a Semi-arid Environment. Field Crops Res. 85, 111–124.

Quanqi, L., Yuhai, C., Mengyu, L., Xunbo, Z., Songlie, Y., Baodi, D. 2008. Effects of irrigation and planting patterns on radiation use efficiency and yield of winter wheat in north China. Agric. Water. Manag. 95, 469 – 476.

Salvagiotti, F., Miralles, D. J. 2008. Radiation Interception, Biomass Production and Grain Yield as Affected by the Interaction of Nitrogen and Sulfur Fertilization in Wheat. Europ. J. Agro. 28, 282–290.

Sandana. P., Ramírez, P., Pinochet, M. D. 2012. Radiation interception and radiation use efficiency of wheat and pea under different P availabilities. Field. Crops. Research. 127, 44–50.

Singer, J. W., O'Leary, G. J., Whitfield, D. M., Connor, D. J. 2007. Radiation Use Efficiency in Dual Winter Cereal–Forage Production Systems. Agronomy Journal. 99: 1175–1179.

Yu-guo, Z., Zaho-rong, D., Li Xia-Ling, C., He, S. 2006. Effects of nitrogen application on growth and forage yield of triticale re growth. Journal of Anhui Agriculture University. 3, 35-39.

Zahoor, A., Riaz, M., Ahmad, S. H., AliKhan, M. B., Javed, K., Anjum, M. A., Zia-ul-Haq, M., Khan, M. A. 2010. Ontogeny growth and radiation use efficiency of Helianthus annuus L. as affected by hybrids, nitrogenous regimes and planting geometry under irrigated arid conditions. Pak. J. Bot. 42, 3197-3207.

Zhang, N., Turner, C., Poole, M. L. 2012. Increasing the harvest index of wheat in the high rainfall zones of southern Australia. Field Crops Research. 129 (11), 111–123.

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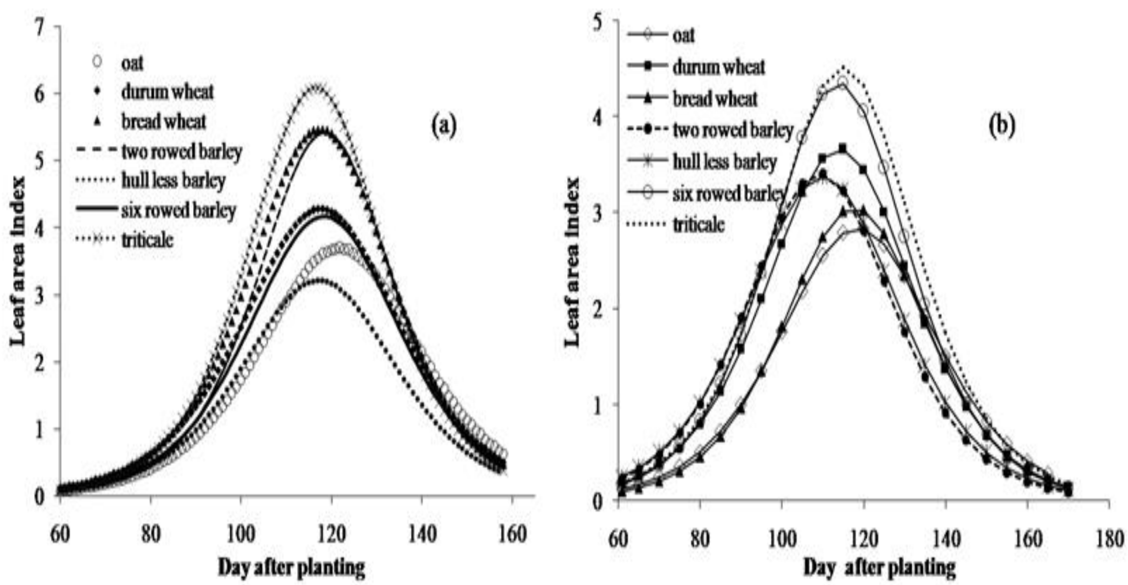

Fig 1 Variations of leaf area index during the crop cycle of different cereals in 2013/2014 (a) and 2014/2015 (b).

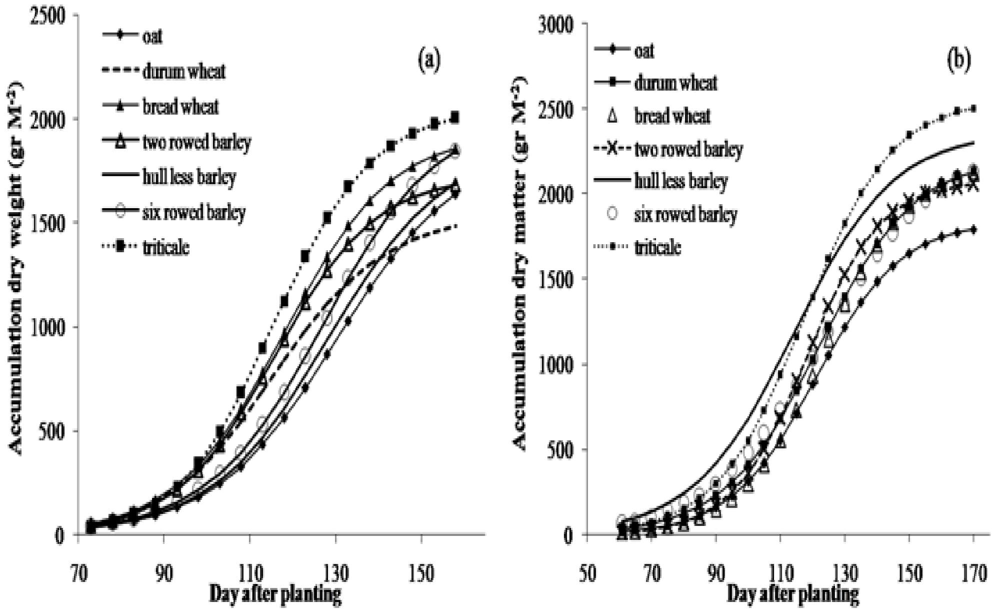

Fig 2 Patterns of accumulation dry matter during the crop cycle of different cereals in 2013/2014 (a) and 2014/2015 (b).

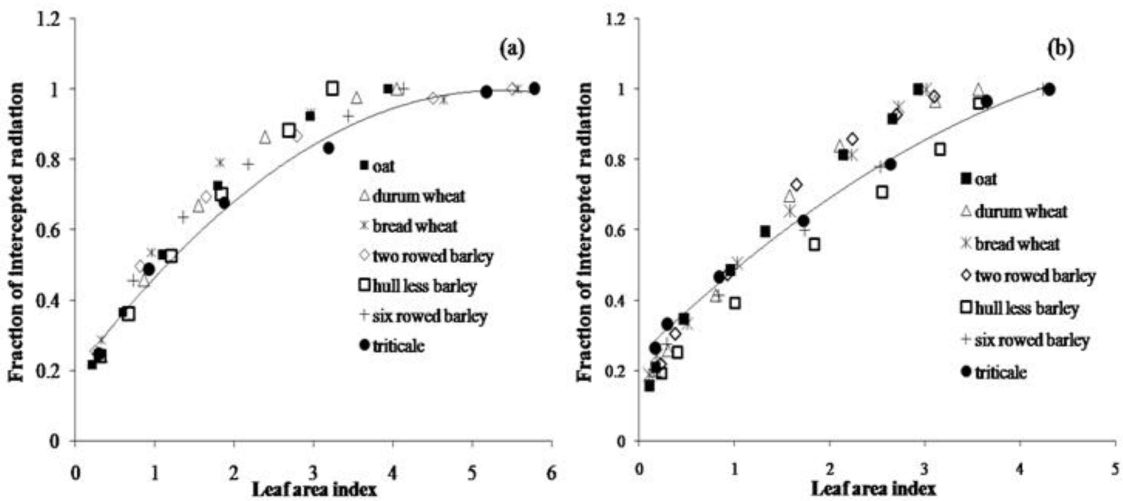

Fig 3 Variations of fraction of intercepted radiation to leaf area index of different cereals in 2013/2014 (a) and 2014/2015 (b).

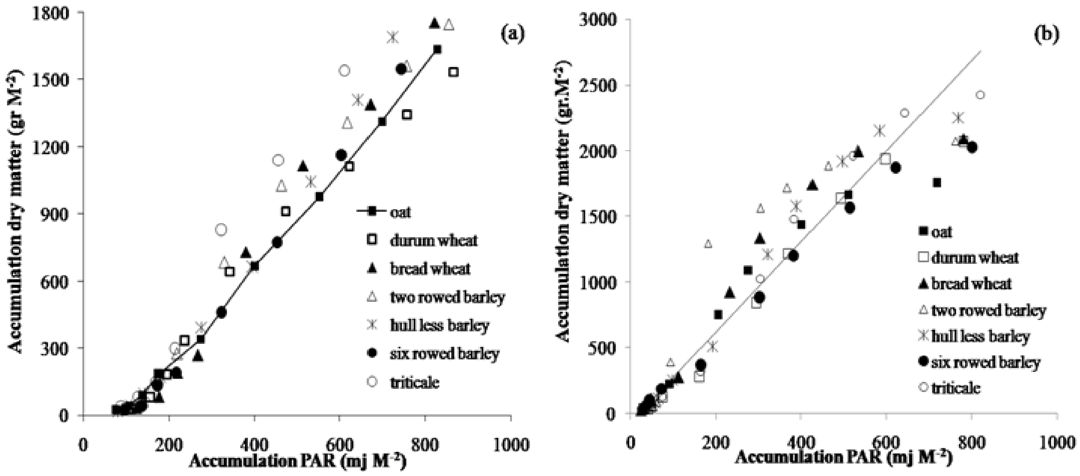

Fig 4 Linear regressions between accumulation dry matters and accumulation PAR in 2013/2014 (a) and 2014/2015 (b).

Table 1. Extinction coefficient (k), standard error (SE), coefficients of determination (R2) in cereal at two nitrogen rates in 2013/2014 and 2014/2015.

Cereal	Nitroge	K±SE	R^2	K±SE	R^2
		2013/2014		2014/2015	
Oat	zero	0.70± 0.04	0.99	0.79± 0.08	0.98
Oat	optimum	0.83± 0.05	0.99	0.85± 0.06	0.99
Durum wheat	zero	0.75± 0.03	0.99	0.80± 0.06	0.99
Durum wheat	optimum	0.79± 0.05	0.99	0.85± 0.07	0.99
Bread wheat	zero	0.88± 0.03	0.99	0.77± 0.08	0.99
Bread wheat	optimum	0.84± 0.06	0.99	0.86± 0.1	0.98
Two rowed barley	zero	0.79± 0.06	0.99	0.86± 0.05	0.99
Two rowed barley	optimum	0.81± 0.04	0.99	0.86± 0.07	0.99
Hull less barley	zero	0.87± 0.06	0.99	0.56± 0.04	0.99
Hull less barley	optimum	0.64± 0.05	0.99	0.53± 0.06	0.98
Six rowed barley	zero	0.86± 0.06	0.99	0.64± 0.06	0.99
Six rowed barley	optimum	0.72± 0.03	0.99	0.69± 0.09	0.99
Triticale	zero	0.73± 0.04	0.99	0.75± 0.09	0.99

Triticale	optimum	0.61± 0.05	0.99	0.72± 0.12	0.98
Oat	-	0.76± 0.04	0.99	0.82± 0.05	0.99
Durum wheat	-	0.77± 0.03	0.99	0.83± 0.04	0.99
Bread wheat	-	0.86± 0.03	0.99	0.81± 0.06	0.99
Two rowed barley	-	0.80± 0.03	0.99	0.86± 0.04	0.99
Hull less barley	-	0.74± 0.05	0.99	0.54± 0.03	0.99
Six rowed barley	-	0.79± 0.03	0.99	0.66± 0.05	0.99
Triticale	-	0.67± 0.03	0.99	0.73± 0.07	0.98

Table 2. Radiation use efficiency (RUE), standard error (SE) and coefficients of determination (R2) in cereal at two nitrogen rates in 2013/2014 and 2014/2015.

Cereal	**Nitrogen**	**RUE±SE**	**R^2**	**RUE±SE**	**R^2**
		2013/2014		2014/2015	
Oat	zero	2±0.048	0.99	2.60±0. 2	0.98
Oat	optimum	2.33±0.06	0.99	2.97±0.41	0.99
Durum wheat	zero	2.05±0.148	0.96	2.78±0.15	0.96
Durum wheat	optimum	2.01±0.065	0.99	3.32±0.27	0.97
Bread wheat	zero	2.12±0.17	0.95	3.24±0.35	0.96
Bread wheat	optimum	2.69±0.69	0.98	3.07±0.30	0.96
Two rowed barley	zero	2.23±0.12	0.97	2.91±0.38	0.95
Two rowed barley	optimum	2.47±0.07	0.99	3.27±0.18	0.99
Hull less barley	zero	2.44±0.04	0.99	3.35±0.29	0.98
Hull less barley	optimum	2.72±0.17	0.97	3.53±0.32	0.97
Six rowed barley	zero	2.44±0.07	0.99	2.88±0.19	0.99
Six rowed barley	optimum	2.44±0.05	0.99	2.73±0.06	0.99
Triticale	zero	2.81±0.19	0.96	3.21±0.17	0.99
Triticale	optimum	2.85±0.09	0.99	3.66±0.36	0.96
Oat	-	2.17±0.047	0.98	2.83±0.24	0.95
Durum wheat	-	2.02±0.07	0.97	3.01±0.2	0.97
Bread wheat	-	2..42±0.13	0.94	3.14±0.25	0.94
Two rowed barley	-	2.33±0.09	0.99	3.11±0.20	0.97
Hull less barley	-	2.52±0.11	0.96	3.44±0.24	0.96
Six rowed barley	-	2.39±0.08	0.98	2.80±0.12	0.99
Triticale	-	2.78±0.14	0.96	3.43±0.25	0.95