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# RADIATION AND NITROGEN USE EFFICIENCIES OF $C_3$ WINTER CEREALS TO NITROGEN SPLIT APPLICATION

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**Abstract**

Three field experiments were conducted at the Experimental Farm, Bahauddin Zakariya University, Multan, Pakistan during the winter season 2010-11 to study the response of 3 winter cereal crops viz., wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) to nitrogen split application in terms of growth, final yield, radiation and nitrogen use efficiencies (R&NUEs). There were 2 variables; 3 cultivars each of wheat (Sahar-2006, Lasani-2008 and AARI-2010), oat (CK-1, F-411 and Ravi) and barley (Jao-87, Haider-93 and BO-7022) crops and 4 nitrogen split applications i.e., $NS_1$ = whole N at sowing, $NS_2$ = ½ N at sowing + ½ N at 1st irrigation, $NS_3$ = 1/3 N at sowing + 1/3 N at 1st irrigation + 1/3 N at 2nd irrigation and $NS_4$ = ¼ N at sowing + ¼ N at 1st irrigation + ¼ N at 2nd irrigation + ¼ N at 3rd irrigation). The wheat cv. Sahar-2006, oat cv. CK-1 and barley cv. BO-7022 out yielded other cultivars by producing total dry matter 574 to 722 g $m^{-2}$, 429 to 533 g $m^{-2}$ and 455 to 555 g $m^{-2}$, respectively. Similarly, the respective grain yield values for these cultivars were 265 to 350 g $m^{-2}$, 205 to 265 g $m^{-2}$ and 202 to 263 g $m^{-2}$, respectively. For wheat, oat and barley crops radiation use efficiency (RUE) ranged from 1.14 g $MJ^{-1}$ to 1.47 g $MJ^{-1}$, 0.85 g $MJ^{-1}$ to 1.08 g $MJ^{-1}$ and 0.91 g $MJ^{-1}$ to 1.13 g $MJ^{-1}$, respectively. In general, wheat, oat and barley had higher RUE values at 3rd N split application and the lowest were found in case of 4th N split application regime. Over all agronomic nitrogen use efficiency (ANUE) for wheat, oat and barley ranged from 10.96 to 19.20 kg $kg^{-1}$, 7.04 to 13.30 kg $kg^{-1}$ and 17.00 to 30.60 kg $kg^{-1}$, respectively. Among N split applications, 3rd N application produced the higher ANUE of 16.96 to 19.20 kg $kg^{-1}$, 11.74 to 13.30 kg $kg^{-1}$ and 29 to 30.60 kg $kg^{-1}$ in case of wheat, oat and barley crops, respectively. Over all, economic nitrogen use efficiency (ENUE) for wheat, oat and barley ranged from 3.03 to 5.30 \$ $kg^{-1}$, 2.73 to 5.16 \$ $kg^{-1}$ and 2.27 to 4.09 \$ $kg^{-1}$, respectively.

## Introduction

The production of grain crops is very important for any country in the world in order to achieve food and economic stability for their survival. Wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) are 3 winter cereals grown in Pakistan. Wheat is also staple food of the country. In Pakistan, the yield of winter cereals is very low as compared to other advanced and regional countries. Low productivity leads to poor utilization of labor, land and costly input resources, like water and fertilizer. The farmers rarely act upon the recommendations of the Agricultural Extension Department for sowing of approved cultivars to get optimum yield and ultimately higher radiation and nitrogen use efficiencies. In addition to failure of sowing of newly developed high yielding cultivars of winter cereals by the growers, another possible cause is the nitrogen application without splitting that leads to nitrification, volatilization and runoff losses at once under marginal soil and adverse climatic conditions.

Radiation use efficiency (RUE) is the net gain in assimilation in photosynthesis over respiratory losses by the crop canopies to the quantity of intercepted radiation (Zahoor *et al*., 2010) in harmony by the canopy size, leaf area index (LAI), structure, leaf angle and orientation, and radiation extinction coefficient (k) concurrently. Crop canopy RUE of diverse field crops including winter cereals without biotic and abiotic stresses has been found to be comparatively conservative with species-specific performance (Kiniry *et al*., 1989). However, RUE is mainly affected by various abiotic factors likely vapor pressure (Kemanian *et al*., 2004), drought (Jamieson *et al*., 1995), low temperature (Goyne *et al*., 1993) and nutrient availability (Muurinen & Peltonen-Sainio, 2006; Ahmad *et al*., 2008, 2009). Furthermore, RUE may vary with crop to crop and their growth stages (Gallagher & Biscoe, 1978; Zahoor *et al*., 2010). These are reports that photosynthetically active radiation (PAR) based radiation extinction coefficient 'k' and RUE values vary from 0.37-0.82, 0.44-0.74 and 0.41-0.66, and 1.46-2.93, 1.11-1.12 and 1.79-2.33 g $MJ^{-1}$ for wheat, oat and barley crops, respectively (Gregory *et al*., 1992; Goyne *et al*., 1993; Yunusa *et al*., 1993; Jamieson *et al*., 1995; Calderini *et al*., 1997; O'Connell *et al*., 2004; Muurinen & Peltonen-Sainio, 2006).

Nitrogen being an integral part of structural and functional proteins, chlorophyll and nucleic acid affects plant growth and development pattern by changing canopy size and structure, ultimately altering RUE (Tisdale *et al*., 1990; Sinclair, 1990; Muchow & Sinclair, 1994) and is required throughout the crop growth period from vegetative stage to subsequent harvesting (Rafiq *et al*., 2010; Ali, 2011). The most pressing target of improving agricultural NUE is to improve the recovery of N from fertilizer (Dawson *et al*., 2008) and globally, only a third of the N in fertilizer applied to cereal crops is harvested in the grain (Raun & Johnson, 1999). NUE of cereals is estimated to be 42% and 29% in developed and underdeveloped nations, respectively (Pilbeam, 1996; Raun & Johnson, 1999; Beatty *et al*., 2010). Radiation and nitrogen use efficiencies (R&NUEs) had synergistic effect as RUE increased at higher leaf nitrogen contents (Fischer, 1993; Abbate *et al*., 1995; Sinclair & Muchow, 1999) and decreased at lower leaf nitrogen contents (Bange *et al*., 1997). Nitrogen losses particularly nitrification, volatilization and runoff are the main reasons for low NUE in agricultural systems (Jan *et al*., 2010) in addition to high cropping intensity and failure of sowing of leguminous crops in stable cropping patterns like wheat-rice and wheat-cotton etc. (Ahmad *et al*., 2009). Therefore, nitrogen application in splits to increase NUE may be an alternative to deal with nitrogen recovery. So, there is a dire need to study the nitrogen response to split applications to approved cultivars of existing cereals to achieve economic and environmental viability of agro-ecosystems. Selection of efficient users of input resources is becoming increasingly important strategy for gaining the economic and environmental viability of various agro-ecosystems particularly arid environments to enhance R&NUEs.

The most recent work on radiation and nitrogen use efficiencies (R&NUEs) include various crop management strategies on a wide variety of growing environments. However, R&NUEs related information regarding wheat, oat and barley crops on calcareous soils under irrigated arid environment, particularly for Pakistan, is limited. The objectives of this study were to; (1) determine the performance of wheat, oat and barley cultivars in terms of growth and final yield, (2) demonstrate RUE and NUE of selected winter cereals to nitrogen split applications on calcareous soils.

## Materials and Methods

**Experimental site and soil analysis:** Three field experiments were conducted at the Experimental Research Farm, Bahauddin Zakariya University (BZU), Multan, Pakistan (latitude = 30.15 °N; longitude = 71.30 °E; and 126.6 m from sea level) during the winter season 2010-11. The soil was silt-clay-loam in nature with soil texture of sand 28%, silt 52% and clay 20%. Prior to sowing, soil analysis showed pH 9.6, EC 3.42 ds $m^{-1}$, organic matter content 0.74%, total nitrogen 0.033%, available phosphorus 4.92 ppm and available potassium 255 ppm.

**Weather data:** Standard meteorological data were obtained from the Central Cotton Research Institute (CCRI), Multan. Figure 1 summarizes the daily weather data for the experimental site during the winter season 2010-11. The winter season daily maximum and minimum above air temperatures ranged from 7.7 to 43.6 ºC and 0.3 to 24.7 ºC, respectively. However, average maximum and minimum temperatures during this period were 25.3 and 10.6 ºC, respectively. The daily solar radiation values for the winter season ranged from 4.9 to 24.8 MJ $m^{-2}$, while, average value was 14.8 MJ $m^{-2}$ (Fig. 1). The total seasonal precipitation during the winter season was 66.7 mm and there was no rainfall during the vegetative period of crop growth. Out of this half rainfall occurred during the month of February, while, remaining half in the month of April. The last rainfall was of not beneficial for the crops because at that crops had already reached its maturity stage and it only delayed the harvesting time.

**Treatments and experimental design:** The treatments included in the present research work were 3 selected winter cereal (wheat, oat and barley) crops, having 3 cultivars of each and four nitrogen split applications. Factor 1 for these experiments includes three cultivars each of wheat ($V_1$ = Sahar-2006, $V_2$ = Lasani-2008 and $V_3$ = AARI-2010), oat ($V_1$ = CK-1, $V_2$ = F-411 and $V_3$ = Ravi) and barley ($V_1$ = Jao-87, $V_2$ = Haider-93 and $V_3$ = BO-7022 crops for experiments 1, 2 and 3, respectively, while, factor 2 was 4 nitrogen split applications, i.e., $NS_1$ = whole N at sowing; $NS_2$ = ½ N at sowing + ½ N at 1$^{st}$ irrigation; $NS_3$ = 1/3 N at sowing + 1/3 N at 1$^{st}$ irrigation + 1/3 N at 2$^{nd}$ irrigation; and $NS_4$ = ¼ N at sowing + ¼ N at 1$^{st}$ irrigation + ¼ N at 2$^{nd}$ irrigation + ¼ N at 3$^{rd}$ irrigation. All these experiments were laid out in a Randomized Complete Block Design with factorial arrangements having three replications. The total nitrogen applied as per treatments to wheat, oat and barley crops was 125, 115 and 50 kg $ha^{-1}$, respectively. Sowing date for these experiments was 14$^{th}$ November 2010. While, final harvesting dates were 22, 24 and 26$^{th}$ April, 2011 for barley, wheat and oat crops, respectively. However, harvesting was little bit delayed due to light showers of rainfall. First, second, third and four irrigations were applied on 7$^{th}$ December (23 DAS), 14$^{th}$ January (61 DAS), 1$^{st}$ February (79 DAS) and 11$^{th}$ March (117 DAS) to wheat, oat and barley crops, respectively. Similarly, first, second, third and fourth doses of N were applied on 14$^{th}$ November (0 DAS), 10$^{th}$ December (26 DAS), 17$^{th}$ January (64 DAS) and 3$^{rd}$ February (81 DAS) to wheat, oat and barley crops, respectively. Weeds from the experimental plots were managed chemically at early growth stage 10-12 (Zadoks *et al*., 1974).

**Sampling:** A total of nine harvests were made to record the measurements relating to ontogeny growth and development in all three experiments. A dry weight sample for various components i.e., leaf, stem, root and head of winter cereal crops was recorded by using an electronic balance. An appropriate sub-sample of fresh weight of respective crops was dried to a constant weight at 75 °C. A sub-sample of 10 g of leaf lamina of wheat, oat and barley crops was also taken and leaf area was measured on an area meter. Leaf area index (LAI) was calculated as suggested by Watson (1947).

$$\mathrm{LAI} = \frac{\text{Leaf area}}{\text{Land area}}$$

**Intercepted photosynthetically active radiation (IPAR):** The fraction of intercepted radiation ($F_i$) of winter cereal crops was estimated from respective crop leaf area indices using the exponential equation as suggested by Monteith & Elston (1983).

$$F_i = 1 - \exp\left(-k \times LAI\right)$$

where, 'k' is the extinction co-efficient for total solar radiation (Monteith 1977). Values of 'k' for wheat, oat and barley crops were 0.70, 0.63 and 0.74, respectively (Muurinen & Peltonen-Sainio, 2006). PAR was assumed to equal half (50%) of daily total incident radiation (Szcicz 1974). Multiplying these totals by appropriate estimates of $F_i$ and $S_i$ gave the amount of intercepted radiation (Sa) for wheat, oat and barley crops.

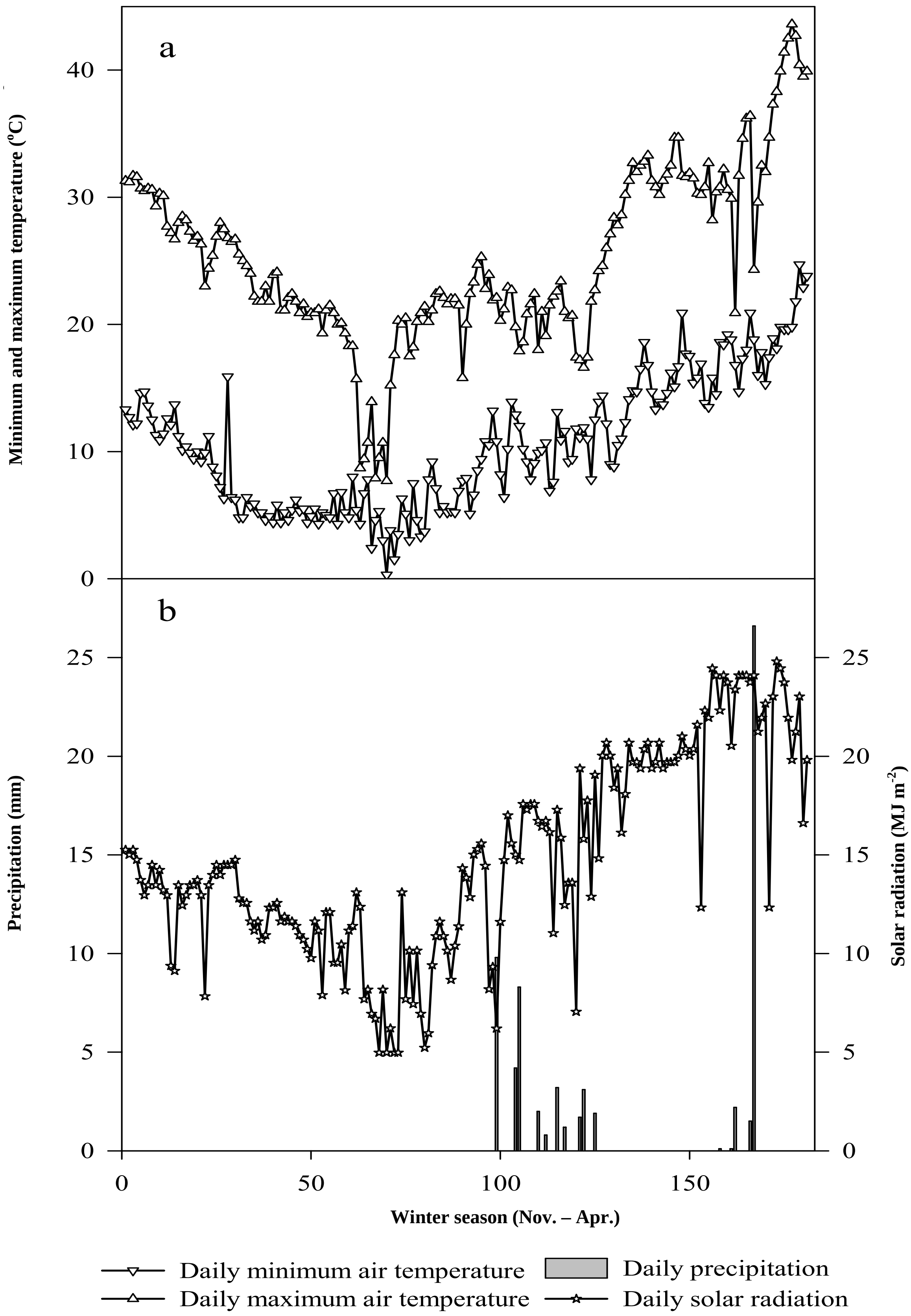


Fig. 1. Daily minimum and maximum temperatures (a), precipitation and solar radiation (b) during the winter cereals season 2010-11.

$$Sa = F_i \times S_i$$

where, $S_i$ is the incident PAR.

**Radiation use efficiency:** Radiation use efficiencies for wheat, oat and barley crops for total dry matter were calculated individually by following the equation.

$$RUE_{TDM} = \frac{TDM}{\sum Sa}$$

where, ∑Sa is the cumulative PAR.

**Nitrogen utilization:** Agronomic nitrogen utilization efficiencies (kg $kg^{-1}$) of crops studied for grain yields were calculated by using following formulas (Nyborg *et al*., 1995).

$$ANUE_{\langle GY \rangle} = \frac{N_x \langle GY \rangle - N_c \langle GY \rangle}{N \ application \ rate}$$

where, $N_x$ and $N_c$ are grain yields at given nitrogen split application regimes and at control, respectively.
Nitrogen use efficiencies (kg $kg^{-1}$) of crops as the ratio of grain yield to amount of nitrogen applied was also calculated by using the following formula (Rahimizaden *et al*., 2010).

$$NUE = \frac{N_x \langle GY \rangle}{N \ applicatio \ n \ rate}$$

**Economic nitrogen use efficiency:** Economic nitrogen use efficiencies (ENUEs) of the crops ($ $kg^{-1}$) were calculated by the following formula.

$$ENUE_{GY} = \frac{Value \ of \ N_x \ GY - Value \ of \ N_c \ GY}{Value \ of \ N \ application \ rate}$$

**Statistical analysis:** The data collected from these experiments were statistically analyzed separately for analysis of variance (ANOVA). The treatment means were compared by using least significant differences test. MSTATC computer software was used to carry out statistical analysis (Russel & Eisensmith, 1983).

## Results

**Total dry matter accumulation:** The total dry matter (TDM) accumulation differed significantly for winter cereal cultivars and at various N split applications. This occurred already before heading in all 3 winter cereal crops and their cultivars and thereafter the differences increased (Fig. 2). Over all TDM ranged from 447 to 722 g $m^{-2}$ for winter cereal cultivars and nitrogen split applications. The most of the cultivars of the 3 winter cereals had less than half of their TDM accumulated up to heading, as shown in Fig. 2. TDM accumulation for wheat cultivar Sahar-2006 was most and it ranged from 574 to 722 g $m^{-2}$, while the lowest was recorded in case of AARI-2010 (560 to 688 g $m^{-2}$). For wheat, the 3rd N split application accumulated most TDM, reaching over 722 g $m^{-2}$, while, it was about 699 g $m^{-2}$ for the 2nd split application. The lowest TDM was observed in case of 4th N split application (560 to 574 g $m^{-2}$). Wheat also had higher TDM accumulation than oat and barley crops (Fig. 2). Oat cultivar CK-1 accumulated most TDM ranging from 429 to 533 g $m^{-2}$, while, the lowest was recorded in case of Ravi (416 to 511 g $m^{-2}$). For oat, the 3rd N split application accumulated most TDM, reaching over 533 g $m^{-2}$, while, it was about 515 g $m^{-2}$ for the 2nd split application. The lowest TDM was observed in case of 4th N split application (416 to 429 g $m^{-2}$). TDM accumulation for barley cv. BO-7022 ranged from 455 to 555 g $m^{-2}$, while, the lowest was recorded in case of Jao-87 (447 to 511 g $m^{-2}$). For barley, the 3rd N split application accumulated most TDM, reaching over 555 g $m^{-2}$, while, it was about 529 g $m^{-2}$ for the 2nd split application. The lowest TDM was observed in case of 4th N split application (447 to 455 g $m^{-2}$). These all three winter cereal crops and their cultivars reached maximum LAI before heading. No major differences in LAI between wheat, oat and barley crops and their cultivars were recorded. The maximum LAI varied at various N split applications from 3.5 to 5.2 in wheat, from 3.3 to 4.7 in oat and from 3.1 to 4.4 in barley (Data not shown).

**Grain yield:** The total grain yield (GY) accumulation differed significantly for three winter cereal crop cultivars and at various N split applications. Over all GY ranged from 191 to 350 g $m^{-2}$ for three winter cereal crop cultivars and nitrogen split applications, as shown in Fig. 3. The most GY accumulation for wheat cultivar Sahar-2006 ranged from 265 to 350 g $m^{-2}$, while the lowest was recorded in case of AARI-2010 (247 to 322 g $m^{-2}$). The 3rd N split application in wheat accumulated most GY, reaching over 350 g $m^{-2}$, while it was about 340 g $m^{-2}$ for the 2nd split application. The lowest GY was observed in case of 4th N split application (247 to 265 g $m^{-2}$). Wheat crop also had higher GY accumulation than oat and barley crops (Fig. 3). Oat cultivar CK-1 accumulated most GY ranging from 205 to 263 g $m^{-2}$, while the lowest was recorded in case of Ravi (191 to 245 g $m^{-2}$). For oat, the 3rd N split application accumulated most GY, reaching over 263 g $m^{-2}$, while, it was about 253 g $m^{-2}$ for the 2nd split application. The lowest GY was observed in case of 4th N split application (191 to 205 g $m^{-2}$). GY accumulation for barley cultivar BO-7022 ranged from 205 to 263 g $m^{-2}$, while the lowest was recorded in case of Jao-87 (195 to 255 g $m^{-2}$). In case of 3rd N split application, barley accumulated most GY, reaching over 263 g $m^{-2}$, while it was about 255 g $m^{-2}$ for the 2nd split application. The lowest GY was observed in case of 4th N split application (195 to 205 g $m^{-2}$).

**Fraction of intercepted photosynthetically active radiation:** Fraction of intercepted photosynthetically active radiation ($F_i$) differed between the three winter cereal crops and their cultivars (data not shown). The 95% light interception was reached just before heading, when LAI reached its maximum values for wheat, oat and barley crops. $F_i$ also differed between N split applications. Data for three winter cereal crops were analyzed separately to detect the differences between species and cultivars at various N split application regimes. For these three winter cereal crops, the cumulative intercepted photosynthetically active radiation (CIPAR) ranged from 444 MJ $m^{-2}$ to 492 MJ $m^{-2}$. For all these three winter cereal crops, half or more of the IPAR was accumulated during the period just before heading. The differences in CIPAR between the various N split application regimes were significant. The relationship between accumulated TDM and CIPAR was linear for all these three winter cereal crops (data not shown).

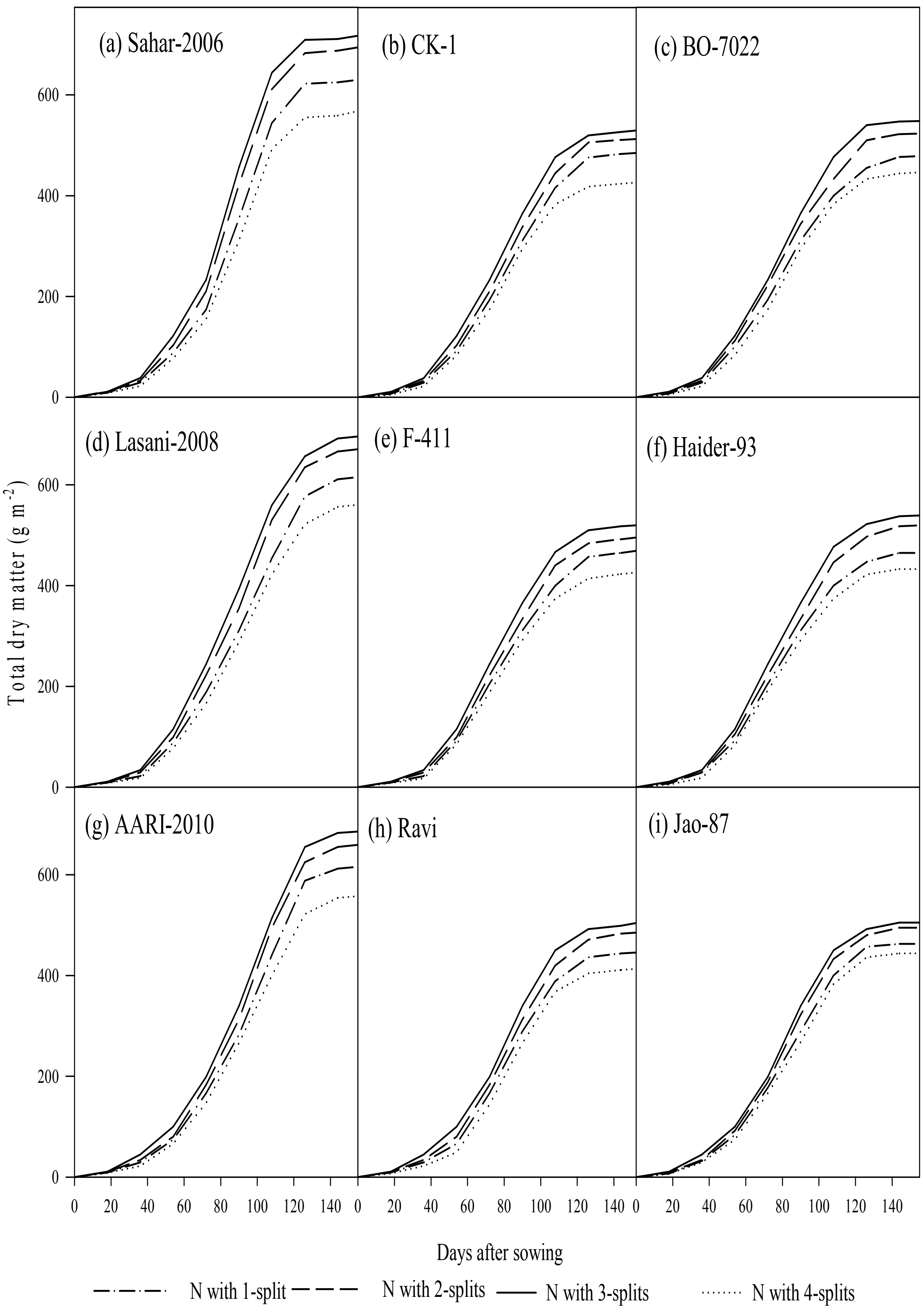


Fig. 2. Total dry matter production of wheat (a, d and g), oat (b, e and h) and barley (c, f and i) cultivars as affected by nitrogen split applications at Multan, Pakistan during winter season 2010-11.

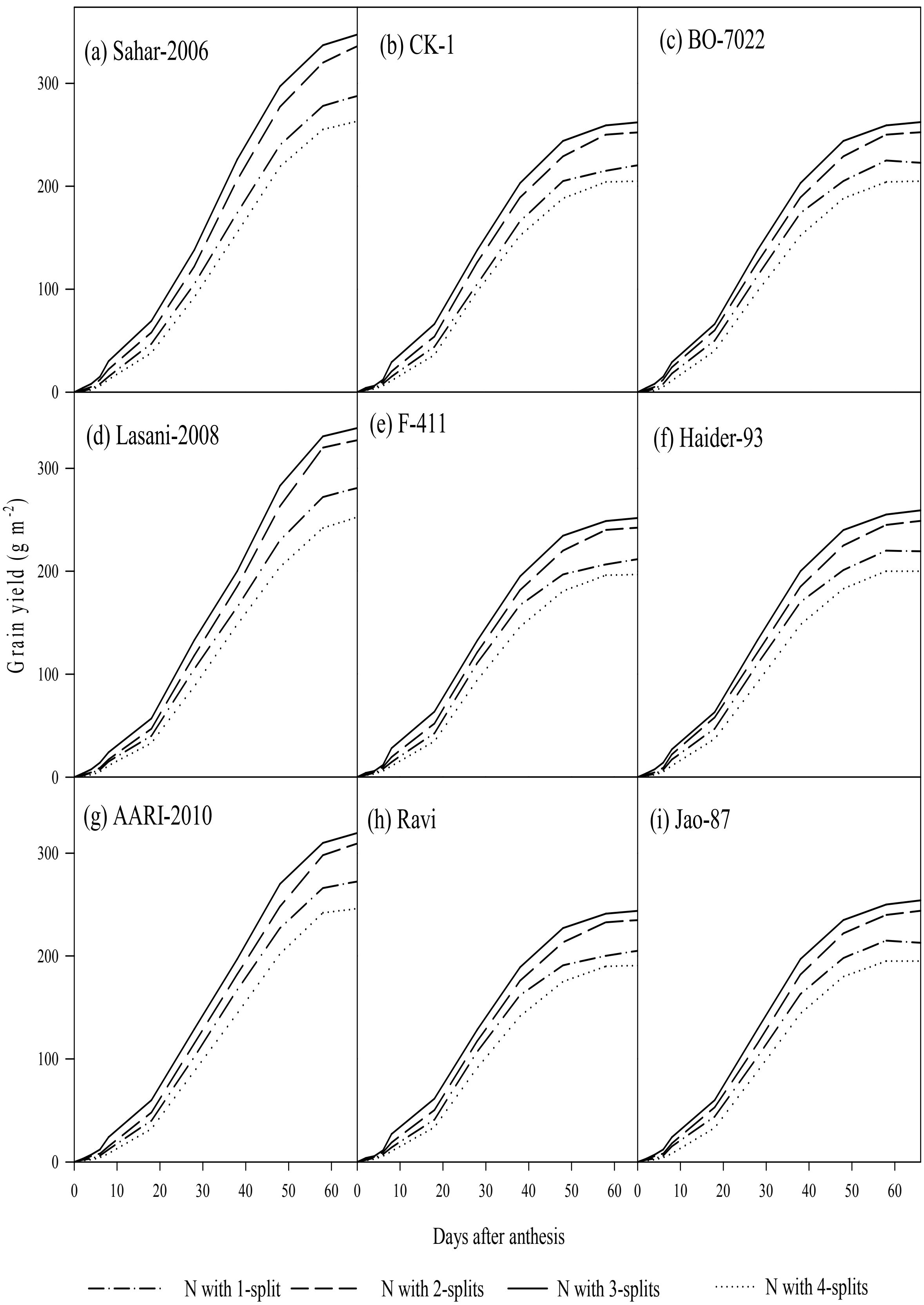


Fig. 3. Grain yield of wheat (a, d and g), oat (b, e and h) and barley (c, f and i) cultivars as affected by nitrogen split applications at Multan, Pakistan during winter season 2010-11.

**Radiation use efficiency:** Radiation use efficiency (RUE) did not differ between the three winter cereal crops and their cultivars. However, the N split applications regimes differed significantly (Fig. 4). The TDM and cumulative intercepted photosynthetically active radiation correlated at all N split application regimes ($R^2 > 0.88$). Overall RUE for three winter cereals ranged from 0.85 g $MJ^{-1}$ to 1.47 g $MJ^{-1}$. For wheat, oat and barley crops RUE ranged from 1.14 g $MJ^{-1}$ to 1.47 g $MJ^{-1}$, 0.85 g $MJ^{-1}$ to 1.08 g $MJ^{-1}$ and 0.91 g $MJ^{-1}$ to 1.13 g $MJ^{-1}$, respectively. In general, wheat, oat and barley had higher RUE values at 3rd N split application and the lowest were found in case of 4th N split application regime. Specifically for N application regimes RUE ranged from 0.91 g $MJ^{-1}$ to 1.29 g $MJ^{-1}$, 0.99 g $MJ^{-1}$ to 1.42 g $MJ^{-1}$, 1.04 g $MJ^{-1}$ to 1.47 g $MJ^{-1}$ and 0.85 g $MJ^{-1}$ to 1.17 g $MJ^{-1}$ for 1st, 2nd, 3rd and 4th, respectively.

**Nitrogen use efficiency:** The agronomic nitrogen use efficiency (ANUE) differed significantly for these three winter cereal crop cultivars and various N split applications. Over all ANUE for wheat, oat and barley ranged from 10.96 to 19.20 kg $kg^{-1}$, 7.04 to 13.30 kg $kg^{-1}$ and 17.00 to 30.60 kg $kg^{-1}$, respectively. Among N split applications, 3rd N application produced the higher ANUE of 16.96 to 19.20 kg $kg^{-1}$, 11.74 to 13.30 kg $kg^{-1}$ and 29 to 30.60 kg $kg^{-1}$ in case of wheat, oat and barley crops, respectively (Fig. 5 a, b and c), while the 4th nitrogen split application produced the lowest ANUE for all these three winter cereal crops. The nitrogen use efficiency (NUE) differed significantly for crops cultivars and at various N split applications. Over all NUE for wheat, oat and barley ranged from 19.76 to 28.00 kg $kg^{-1}$, 16.61 to 22.87 kg $kg^{-1}$ and 39.00 to 52.60 kg $kg^{-1}$, respectively. Among N split applications, 3rd N application resulted the higher NUE of 25.76 to 28.00 kg $kg^{-1}$, 21.30 to 22.87 kg $kg^{-1}$ and 51.00 to 52.60 kg $kg^{-1}$ in case of wheat, oat and barley crops, respectively (Fig. 5 d, e and f). The 4th nitrogen split application produced the lowest NUE for all three winter cereal crops. The economic nitrogen use efficiency (ENUE) differed significantly for three winter cereal crop cultivars and various N split application regimes. Over all ENUE for wheat, oat and barley ranged from 3.03 to 5.30 \$ $kg^{-1}$, 2.73 to 5.16 \$ $kg^{-1}$ and 2.27 to 4.09 \$ $kg^{-1}$, respectively. Among N split applications, 3rd N application produced the higher ENUE of 4.68 to 5.30 \$ $kg^{-1}$, 4.55 to 5.16 \$ $kg^{-1}$ and 3.88 to 4.09 \$ $kg^{-1}$ in case of wheat, oat and barley crops, respectively (Fig. 5 g, h and i). However, the 4th nitrogen split application resulted in the lowest ENUE for these three winter cereal crops. The relationship between RUE and ENUE was significant and linear for wheat, oat and barley crops having 92%, 88% and 74% variance in the data, respectively (Fig. 6).

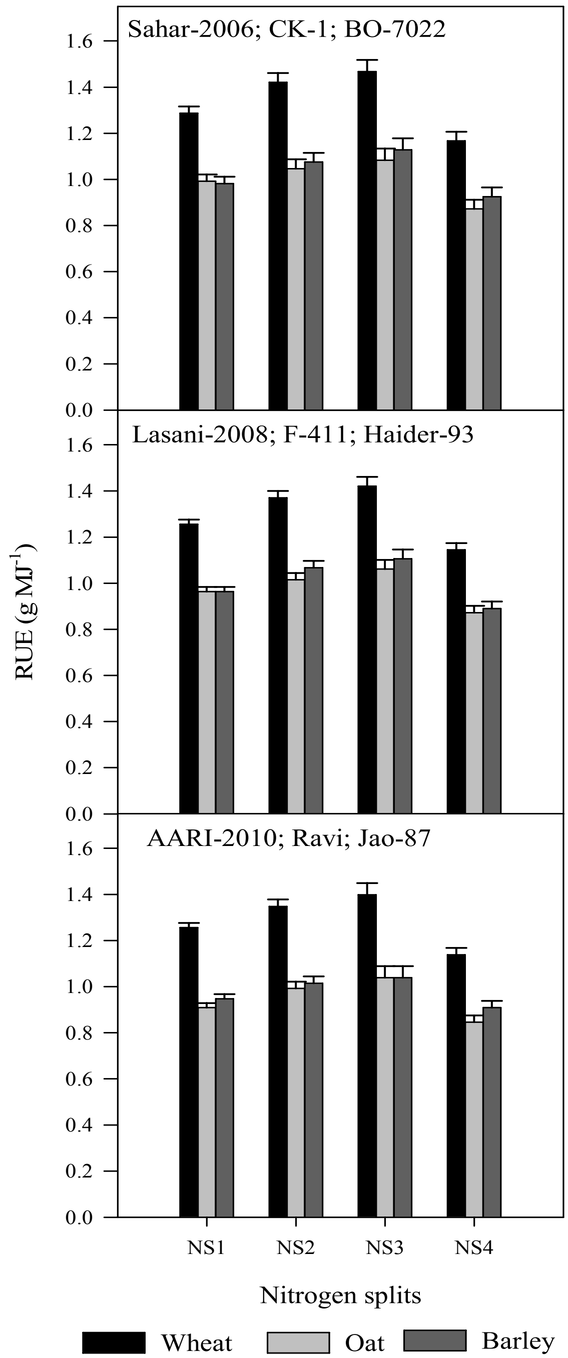


Fig. 4. Radiation use efficiency for total dry matter of wheat, oat and barley cultivars as affected by nitrogen split applications at Multan, Pakistan during winter season 2010-11 (error bars represent SD).

## Discussion

Cereal crops show differences in RUE (Kiniry *et al*., 1989; Sinclair & Muchow, 1999). However, differences between the winter cereal crops selected in the present study i.e. wheat, oat and barley are reported to be fairly small, which was also supported by our experiments conducted at Multan, Pakistan under irrigated arid environment on saline soils. RUE values in wheat (1.14-1.47 g $MJ^{-1}$), oat (0.85-1.08 g $MJ^{-1}$) and for barley (0.91-1.13 g $MJ^{-1}$) were less than those recorded at other agro-environmental conditions by various workers (Goyne *et al*., 1993; de Ruiter, 2000; Kemanian *et al*., 2004; Muurinen & Peltonen-Sainio, 2006). The proposition that RUE under stress-free environments would be relatively stable within crops might be true; however, this may not be valid for the present study conducted under stressful conditions i.e., in saline soils. On the other hand, our results are supported by the studies of Siddique *et al*., (1989) and Yunusa *et al*., (1993) conducted in Mediterranean-type environment. Our results showed that wheat cultivars had higher RUE values than oat and barley cultivars at various N split application regimes (Fig. 5). These differences were also observed in dry matter production between wheat, oat and barley crops possibly due to changed canopy structure. Furthermore, our finding were also in line with the results of Calderini *et al*., (1997) who indicated that in Argentina wheat cultivars were very efficient to use intercepted radiation to TDM production when compared with other crops cultivars. This efficiency could be related to differences in canopy architecture. The difference in canopy height could be associated with different radiation distribution, interception and its utilization efficiency. The oat cultivars had the lowest TDM and GY accumulation compared to wheat and barley cultivars used in this study (Fig. 3). However, the difference between cultivars may have been associated with differences in leaf angles based to k-values, as more horizontal leaves during pre-heading period could be more favorable for these selected winter cereals under other environmental conditions. The CIPAR is a function of k and LAI. Therefore, change in the amount of CIPAR likely resulted from differences in LAI. In the present study, LAI was greatly altered by N split application on selected winter cereal crops (data not shown). However, the LAI values of these selected three winter cereal crops are consistent with earlier findings regarding oat, wheat and barley (Peltonen-Sainio *et al*., 1997; Ma¨kela¨ *et al*., 2004). The LAI values of crops for the 4th N split application were especially low in all these three winter cereal crops. The lower LAI of the oat and barley crops compared with the wheat cultivars possibly contributed to the lower RUE.

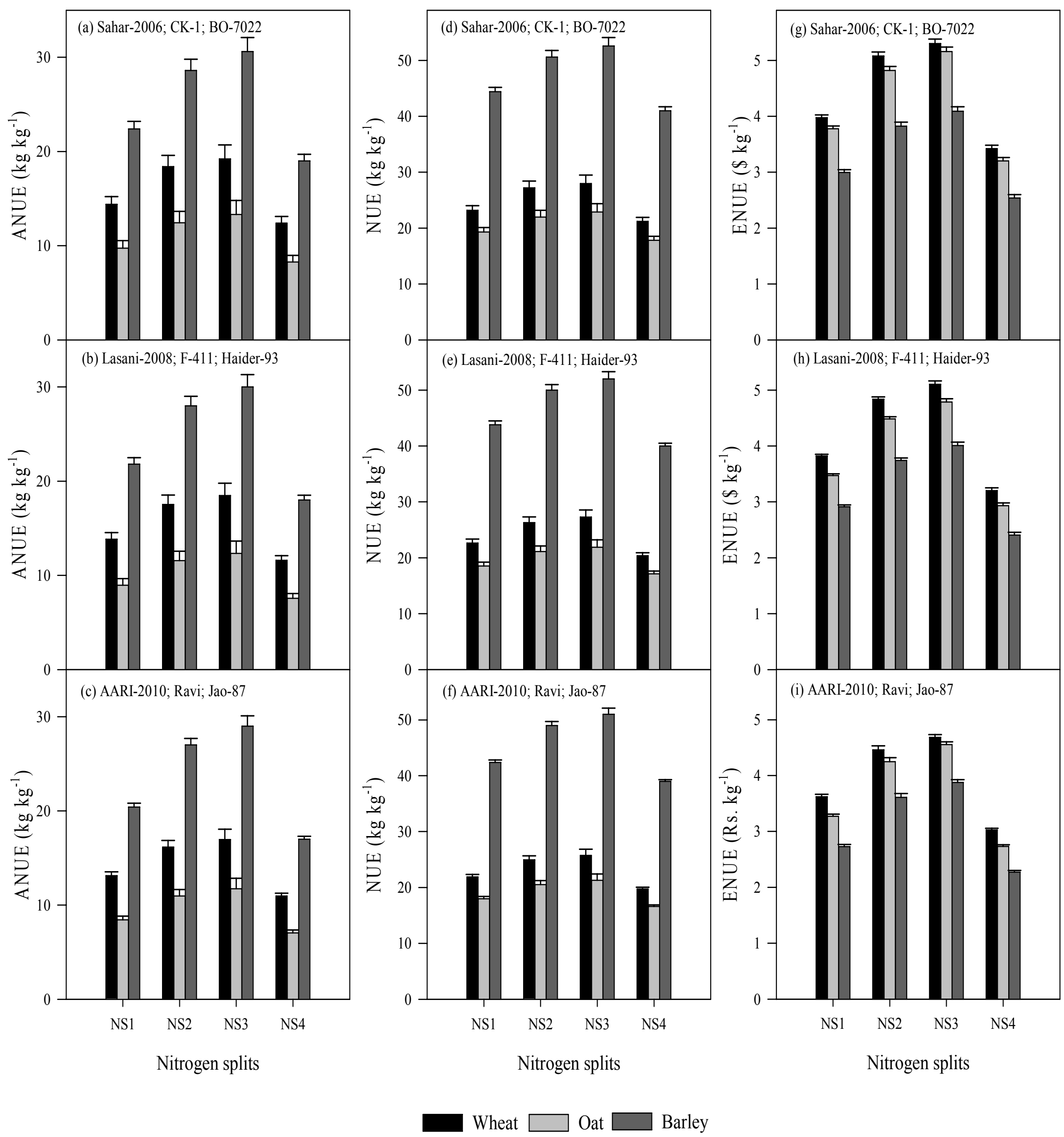


Fig. 5. Nitrogen use efficiencies of wheat, oat and barley cultivars as affected by nitrogen split applications at Multan, Pakistan during winter season 2010-11 (error bars represent SD).

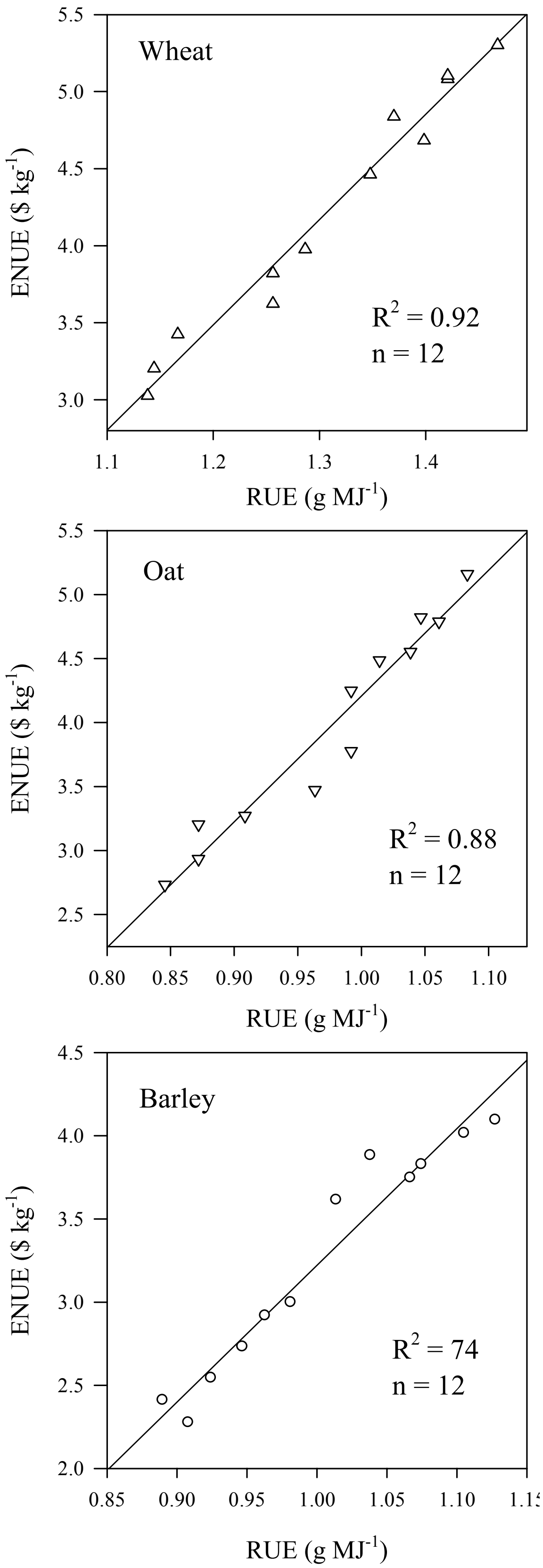


Fig. 6. Relationships between radiation use efficiency and economic nitrogen use efficiency of wheat, oat and barley crops at Multan, Pakistan during winter season 2010-11.

Nitrogen is often the most limiting nutrient for crop yield in many regions of the world (Giller, 2004) and nitrogen use efficiency reflects the efficiency of the crop in obtaining N from the soil (Rahimizadeh *et al*., 2010). Results from our study showed that ANUE and NUE for winter cereal crops i.e. wheat, oat and barley was affected by nitrogen split application and GY and TDM increased in all the cultivars. Increased cereal crop NUE would be economically beneficial to the low-value crop growers and environmentally beneficial to the world population (Beatty *et al*., 2010). Our findings are in agreement with that of Anderson (1985), Ramos *et al*., (1995), Kumari *et al*., (2000), Anthony *et al*., (2003) who found that split nitrogen equally between sowing and tillering or else with the greater proportion applied at tillering led to higher yield in cereal crops. Furthermore, Roy & Singh, (2006) concluded that splitting nitrogen fertilizer to few doses increase efficiency of the fertilizers used by decreasing leaching to a large extent and results in increased both yield and quality of crops in favor of the highest number of splitting as indicated by many other scientists (Gauer *et al*., 1992; Shalaby *et al*., 2006; Ali *et al*., 2011; Ali, 2011). The reported values for wheat, oat and barley largely represented ANUE rather than NUE and varied widely depending upon agro-environmental conditions (Delogu *et al*., 1998; Sinebo *et al*., 2003; Muurinen *et al*., 2006).

## Conclusions

Nitrogen and radiation use efficiencies in cereal crops increased when it is applied in splits as a top dressing in irrigated arid conditions on saline soils, whereas application of N in only once, prior to sowing, yielded poor efficiencies. The common practice among growers of arid areas for applying N fertilizer without splitting led to potential losses of soil nitrates through nitrification, runoff and leaching. Therefore, N split application as top dressed along with basal dose at sowing to cereal crops under irrigated arid conditions on saline soils may be adopted as an alternate strategy to enhance NUE and RUE by avoiding its losses.

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