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ORGANIC AND INORGANIC FERTILIZATION CHANGES THE PHENOPHASES OF RICE (*Oryza sativa* L.) AND WHEAT (*Triticum aestivum* L.) BY MODULATING THE PHOTOSYNTHETIC CAPACITY OF LEAVES

Muhammad Shaukat[1,*], Ashfaq Ahmad[1], Tasneem Khaliq[1] and Irfan Afzal[1]

[1]Deparment of Agronomy, University of Agriculture, Faisalabad, Pakistan
[*]Corresponding author's email: shaukat.9@osu.edu

Phenological modification followed by yield stagnation of rice and wheat is a major concern of South Asian agriculture, linked with decline in soil health by excessive use of mineral fertilizers. The excessive use of nitrogenous fertilizers not only depleting the soil fertility but also accelerating the environmental risks such as greenhouse gases (GHGs) emission and nitrate leaching into underground water. In this context, a 2-year field experiment was established at Agronomic Research Area of the University of Agriculture, Faisalabad, Pakistan to find out the promising nutrient management strategy to modulate the phenological events of rice cv. Basmati-515 and wheat cv. MILLAT-2011 by stimulating the leaf area duration (LAD) under different tillage methods. The fertilization treatments comprised of: control (T1); recommended dose of NPK (T2); animal manure (M, T3), 100% crop stubbles incorporation (CSI, T4), 50% NPK and 50% M (T5), 50% NPK and 50% CSI (T6), 0 25% NPK with 25% M and 50% CSI (T7) and 25% NPK with 50% M and 25% CSI (T8) were randomly allocated in a split plot design under conventional tillage (CT) and reduced tillage (RT) systems. The CT practices include two cultivations along with one rotavator followed by planking for rice, and three cultivations along with one rotavator followed by planking for wheat, while RT treatment includes one cultivation along with one rotavator for both crops. Results show that tillage did not significantly altered the phenological events of both rice and wheat. However, the combined use of organic and inorganic fertilizers significantly induced early tillering and anthesis, and delayed the physiological maturity of rice and wheat. Further, organo-mineral treatments increased the LAD of rice by 35.12 to 49.19% and wheat by 32.28 to 50.19% relative to control. In conclusion, the combined use of organic and inorganic fertilizers could change the phenological events in rice and wheat by modulating the LAD.
Keywords: Animal manure, crop residue, reduced tillage, physiological maturity, leaf area duration

INTRODUCTION

Rice-wheat cropping sequence (RWS) is one of the predominant cropping systems, occupying in almost 26.7 M ha in various Asian countries. Indo-Gangetic Plains (IGP) of South Asia contributes about 13.0 M ha in the total area of RWS (Timsina and Connor, 2001). Among South Asian countries, this system is occupied on 12.5 M ha in India (10 M ha is that of the IGP), 2.3 M ha in Pakistan, 0.8 M ha in Bangladesh and 0.5 M ha in Nepal (Timsina and Connor, 2001).

Keeping in view the importance of RWS, the productivity of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) must be enhanced either through the best farm management practices, including nutrient, irrigation and weed management etc. or via genetic modification. In this scenario, the phenological events of both crops can play a significant role to harvest the maximum yields in RWS. Therefore, growth and developmental events as well as partitioning of photo-assimilates are mainly determined by the crop phenology (Rehman *et al.*, 2010).

Recently, depletion of soil fertility and stagnation or decline in rice and wheat yields were highlighted (Prasad, 2005); furthermore, the increased environmental risks linked with the use of unbalanced N and N-leaching losses in the RWS have also been documented (Singh *et al.*, 2005). The excessive use of N in the RWS can also stimulate N_2O emission, which arises from denitrification process in the soils (Singh and Singh, 2001). On the other hand, N plays a crucial role in plant growth, development, and final productivity. Therefore, the application of an organic source of N must be explored in RWS to get higher yield without declining soil health (Arif *et al.*, 2012). In this way, the N losses from sole synthetic N fertilizers could be compensated by the inclusion of organic amendments.

Hossain *et al.* (2002) and Manna *et al.* (2005) observed that the combine use of organic and inorganic fertilizers enhanced days to 50% heading, plant height, yield, and related traits, and leaf area index of wheat compared to organic-alone or inorganic-alone. The LAD represents the photosynthetic capacity of leaves (Shaukat, 2013) which is directly linked with the final dry matter accumulation and yield (Pholsen and Suksri, 2004).

However, the limited studies on the use of organic and inorganic fertilizers in RWS of Pakistan under reduced tillage system have been tested. So, this study was planned with the aim; to find out the best nutrient management practice to modulate the phenology of rice and wheat by modifying the photosynthetic capacity of leaves. We hypothesized that the combined application of organic and inorganic fertilization changes the phenological events of rice and wheat by modulating the LAD.

MATERIAL AND METHODS

***Site description*:** The field experiment was conducted in a natural environment at the research farm of the Department of Agronomy (31° 26'24.118" N, 73° 4'29.317" E, the elevation of 185 m), University of Agriculture, Faisalabad-Pakistan, located in plain areas of central Punjab province of Pakistan. The climate of the region is semi-arid, subtropical continental lowland. The annual average precipitation was 393 mm of which 68.42% (269 mm) occurred in summer rice growing season (June–October) while the remaining 31.58% (124 mm) took place during winter wheat growing season (November-May). However, the average annual air temperature was 24.22°C. The soil type is silt loam (19.0% sand, 54% silt, and 27% clay at a soil depth of 0-15 cm).

***Experimental design and crop management*:** The experiment was a split plot design with three replicates of each treatment. Each replicate (80 × 10 m) consisted of two main-plots and sixteen sub-plots. The tillage treatments, including CT and RT, were randomized in main plots, and fertilization management treatments were allocated randomly in sub-plots. Tillage systems during rice and wheat season were: CT treatment was consisted of the two cultivations with tractor-drawn cultivator along with one rotavator followed by planking for rice, and three cultivations along with one rotavator followed by planking for wheat, and RT treatment was comprised of one cultivation along with one rotavator for both crops. However, one more cultivation of tillage during the transplanting of rice is performed by most of the farmers. The secondary operation in rice crop includes the puddling of the field in standing water to keep water stagnation during the growth period. The fertilization management treatments were as follow: control (T1); recommended dose of NPK (T2, NPK-alone); animal manure (T3, M), 100% crop stubbles incorporation (T4, CSI), 50% NPK and 50% M (T5, abbreviated as NPKM 5/5), 50% NPK and 50% CSI (T6, abbreviated as NPKCSI 5/5), 0 25% NPK with 25% M and 50% CSI (T7, 0.25NPKM + 0.5CSI) and 25% NPK with 50% M and 25% CSI (T8, 0.25NPKCSI + 0.5M).

Among nutrient treatments, in T2, application of mineral N, P and K for rice were 140, 80, and 86 kg ha^{-1}, respectively. While for wheat were 120, 80 and 60 kg ha^{-1}, respectively. In T5 and T6, the application rate of N, P and K, excluding nutrient content of straw and manure, for wheat were 60, 40 and 30 kg ha^{-1}, respectively. Whereas, for rice were 70, 40 and 43 kg ha^{-1}, respectively. In T7 and T8, the application rate of N, P and K, for wheat were 30, 20 and 15 kg ha^{-1}, respectively; while for rice were 35, 20 and 21.5 kg ha^{-1}, respectively. All P, K, and one-third N were applied at the time of seeding or transplanting stage. One-third N was top-dressed at the tillering stage of both crops. The last dose of N was top-dressed at booting stage of rice and wheat. The sources of inorganic N, P and K were urea (46-0-0), diammonium phosphate (DAP; 18-46-0) and potassium sulfate (SOP; 0-0-50), respectively. In T4, aboveground crop stubbles were collected from pre-existing rice grown under recommended dose of N, P and K. These rice stubbles per unit area were taken from three different points and weighed, which ranged from 6000 to 7200 kg ha^{-1}. Therefore, 6000 kg ha^{-1} of rice stubbles were cut into 3 cm sections (Cheng *et al*., 2015), and returned to the field. Subsequently, after harvesting of wheat, straw yield under T2 treatment was ranged from 5500 to 6500 kg ha^{-1}. Hence, wheat stubbles @ 5500 kg ha^{-1} were incorporated into the soil before transplanting of rice. In T3, animal manure @ 20 Mg ha^{-1} were applied before sowing of wheat, and transplanting of rice.

Wheat cv. MILLAT-2011 was sown after ten days from the application of organic amendments that was the last week of November and harvested after mid of April. The 30-days old seedlings of rice cv. Basmati-515 were transplanted before mid-July. Both crops were harvested at 5-10 cm from above ground by sickle.

***Growth and development*:** For growth analysis, we adopted the protocols published by Shaukat *et al*. (2017). The first destructive sampling was done 30 days after sowing (DAS) in both crops. A 100 cm long row from each plot under both crops was harvested at ground level after 15 d intervals. The fresh weight of each sample and their fractions (leaf and stem) were determined immediately. A sub-sample of 5 g of green leaf laminae was used to record the leaf area with a leaf area meter (Model CI-202, CID Bio-Science, Inc. USA). From leaf area measurements, LAD was measured by using the formula proposed by Hunt (1978);

$$LAD = (LAI_1 + LAI_2) \times (t_2 - t_1) / 2$$

For the developmental observations, five plants from each plot were tagged and visited daily to record commencing dates of phenological events, including heat units required to initiate tillering, anthesis, and physiological maturity in both rice and wheat. Heat units (degree days, °C-days) for each developmental event were calculated using the formula proposed by Gallagher (1979). The base temperatures (T-base) used for these calculations were 5 and 10°C for wheat and rice crop, respectively.

$$\text{Heat units} = \left(\frac{\text{Tmax.} - \text{Tmin.}}{2}\right) - \text{Tbase} \quad (1)$$

***Statistical analysis*:** Statistical analyses of observed parameters were processed using analysis of variance (two-way ANOVA) following the Tukey's honestly significant difference (HSD) test to compare the mean values at a probability level of 5% or less (Steel *et al*., 1997) in computer software "Statistix 8.1" (McGraw-Hill, 2008).

RESULTS

Nutrient management practices significantly affected the accumulated heat units for commencing the tillering, anthesis, and physiological maturity (Fig. 1-3) of both rice and wheat. However, the main effect of tillage, and interactions between nutrient management and tillage were found statistically non-significant (mean data not shown).

***Days to tillering*:** During both years of the study, heat units acquired by the rice plants to initiate tillering have maximum values of 686 and 758°C-days under control plots. However, the early tillering was observed in plants of NPKM 5/5 treatment. Organo-mineral amendments (T5-T8; the combined use of organic and inorganic fertilizers) reduced the heat units to commence tillering by 3.94 to 12.0% compared with control during both years (Fig. 1a-b).

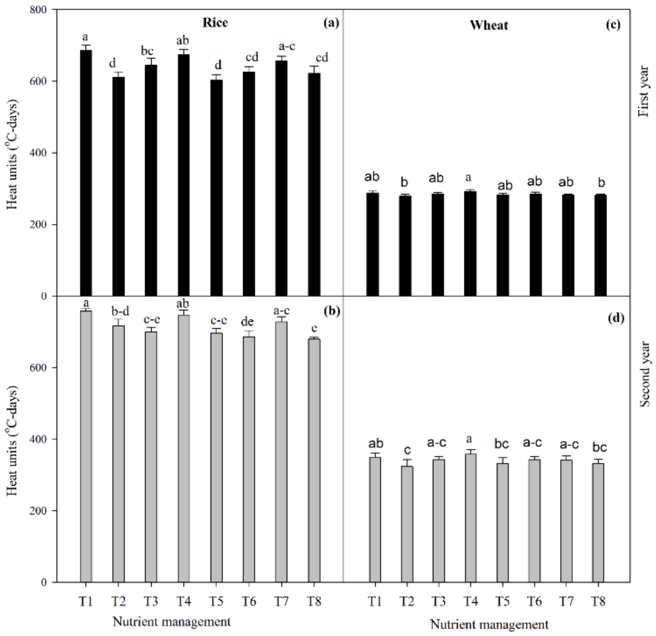

Figure 1. Effect of nutrient management on heat units accumulation to commence tillering in rice (a & b) and wheat (c & d) during two growth seasons. Bars containing similar letters are statistically alike with each other at $P < 0.05$. Each bar shows Mean ± SD. T1, control; T2, recommended dose of NPK; T3, animal manure (M, 20.0 Mg ha^{-1}); T4, 100% crop stubbles incorporation (CSI); T5, 50% NPK and 50% M; T6; 50% NPK and 50% CSI; T7, 0 25% NPK with 25% M and 50% CSI and T8, 25% NPK with 50% M and 25% CSI.

In wheat, the amount of heat units required to initiate tillering was increased by the addition of organic amendments relative to control. Maximum values of 291 and 356°C-days were observed under CSI treatment, and the minimum heat units (279 and 324°C-days) were recorded from NPK-alone (Fig. 1c-d).

***Days to anthesis*:** Stubbles incorporation delayed the anthesis in rice, leading to the accumulation of 1830 to 1944°C-days during both years (Fig. 2a-b). However, NPKM 5/5 and 0.25NPKCSI + 0.5M treatments induced early anthesis. On average, the organic amendments-only and NPK-alone were ranked on an increasing trend for heat units required to initiate anthesis by S > M > NPK (Fig. 2a-b).

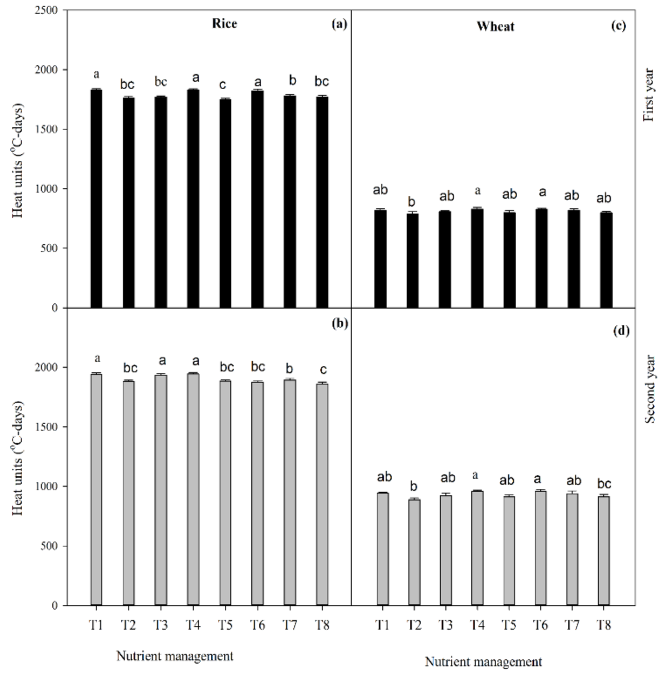

Figure 2. Effect of nutrient management on heat units accumulation by rice (a & b) and wheat (c & d) for anthesis initiation during both years of the study. Bars containing similar letters are statistically alike with each other at $P < 0.05$. Each bar shows Mean ± SD. T1, control; T2, recommended dose of NPK; T3, animal manure (M, 20.0 Mg ha^{-1}); T4, 100% crop stubbles incorporation (CSI); T5, 50% NPK and 50% M; T6; 50% NPK and 50% CSI; T7, 0 25% NPK with 25% M and 50% CSI and T8, 25% NPK with 50% M and 25% CSI.

In wheat, CSI treatment also delayed to commence anthesis by enhancing the amount of heat units that ranged from 830 to 959°C-days (Fig. 2c-d). Additionally, NPK-alone and organic amendments-alone were ranked relative to the increasing trend for thermal units accumulation to start anthesis by order of CSI > M > NPK.

***Days to physiological maturity*:** Organo-mineral fertilizers significantly delayed the physiological maturity in rice. Maximum heat units of 2122°C-days were recorded from NPKM 5/5 treatment followed by 0.25NPKCSI + 0.5M with 2107°C-days and NPKCSI 5/5 with 2103°C-days. Minimum heat units (2084°C-days) were observed from 0.25NPKM + 0.5CSI (Fig. 3a-b). The organo-mineral treatments were ranked on increasing trends in heat unit accumulation by an order of 0.25NPKCSI + 0.5M > NPKCSI 5/5 > NPKM 5/5 > 0.25NPKM + 0.5CSI.

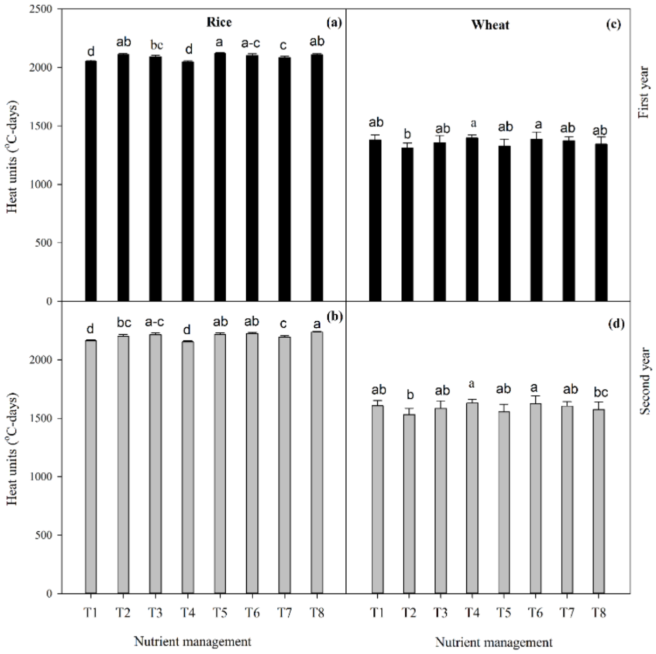

Figure 3. Effect of nutrient management on heat units accumulation from sowing to physiological maturity by rice (a & b) and wheat (c & d) during both years of the study. Bars containing similar letters are statistically alike with each other at P < 0.05. Each bar shows Mean ± SD. T1, control; T2, recommended dose of NPK; T3, animal manure (M, 20.0 Mg ha^{-1}); T4, 100% crop stubbles incorporation (CSI); T5, 50% NPK and 50% M; T6; 50% NPK and 50% CSI; T7, 0 25% NPK with 25% M and 50% CSI and T8, 25% NPK with 50% M and 25% CSI.

In wheat, the NPK-alone and M-only treatments stimulated early physiological maturity compared to control (Fig. 3c-d). On an average, organo-mineral treatments were ranked on increasing order of the accumulation of heat units by following order of 0.25NPKM + 0.5CSI > 0.25NPKCSI + 0.5M > NPKM 5/5 > NPKCSI 5/5.

***Leaf area duration*:** The LAD has a maximum value of 215.26 days by NPKM 5/5 under CT and a minimum value of 97.27 days from control under CT treatment during the first year (Fig. 4a-b). During the second season, LAD has a maximum value of 215.55 days from RT-0.25NPKCSI + 0.5M treatment and a minimum value of 105.02 days by control under CT (Fig. 4c-d). The organo-mineral treatments enhanced the LAD by 35.12 to 49.19% relative to control, but organic amendments-alone and NPK-alone improved the LAD by 19.22 to 41.62% compared with control (Fig. 4a-d).

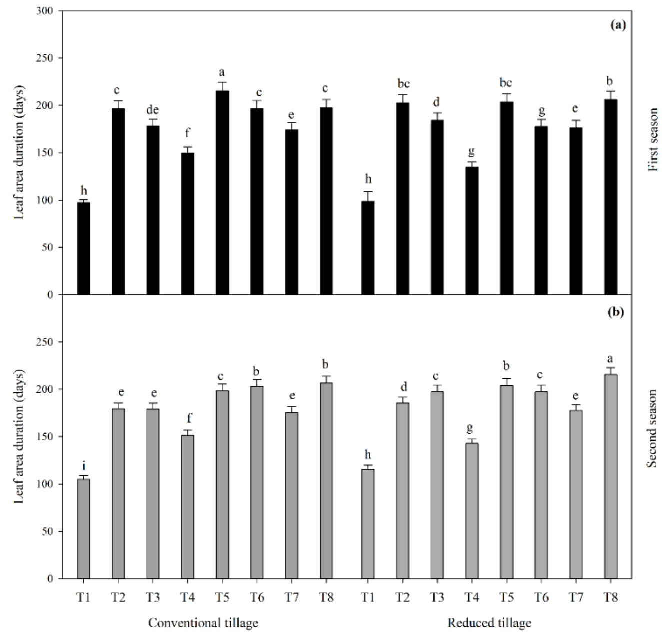

Figure 4. Influence of nutrient management practices on leaf area duration of rice under CT and RT systems during first (a) and second year (b) of the study. Bars containing similar letters are statistically alike with each other at P < 0.05. Each bar shows Mean ± SD. T1, control; T2, recommended dose of NPK; T3, animal manure (M, 20.0 Mg ha-1); T4, 100% crop stubbles incorporation (CSI); T5, 50% NPK and 50% M; T6; 50% NPK and 50% CSI; T7, 0 25% NPK with 25% M and 50% CSI and T8, 25% NPK with 50% M and 25% CSI.

In wheat, the LAD has a maximum value of 218.53 days by NPKM 5/5 under CT and a minimum value of 105.74 days from control under RT treatment during the first year (Fig. 5a). Furthermore, LAD has a maximum value of 240.47 days from RT-0.25NPKCSI + 0.5M treatment and a minimum value of 100.30 days by control under CT during the second year (Fig. 5b).

DISCUSSION

Generally, crop productivity can be influenced by the available status of mineral nutrients in the soils (Khan *et al*., 2008). Organic and inorganic fertilization under different tillage systems significantly enhanced soil water contents (Al-Kaisi and Yin, 2005), SOC stocks (Dolan *et al*., 2006), and active N and C fractions (Sainju *et al*., 2007). In this investigation, tillage did not significantly affect the heat units required to commence the phenological phases of both rice and wheat; however, nutrient management strategies significantly altered the accumulation of heat units to initiate tillering, anthesis and physiological maturity. Sole use of organic amendments were not effective to decrease or increase heat units accumulation compared to control. However, stubble incorporation enhanced the accumulation of heat units for commencing the tillering in rice and wheat relative to control. Similar results were also found by Khan *et al*. (2008), who observed the delaying in tillering in wheat after organic fertilization. It could be associated with higher CN ratio of organic materials, resulted in the less availability of mineral nutrients to the plants. However, the combined use of organic and inorganic fertilizers induced early tillering and anthesis initiation because of higher availability of mineral nutrients, leading to more LAD and aboveground biomass accumulation. The LAD represents the tenacity of leaf canopy to remain photosynthetically active (Shaukat, 2013), and organo-mineral fertilizers significantly enhanced the LAD.

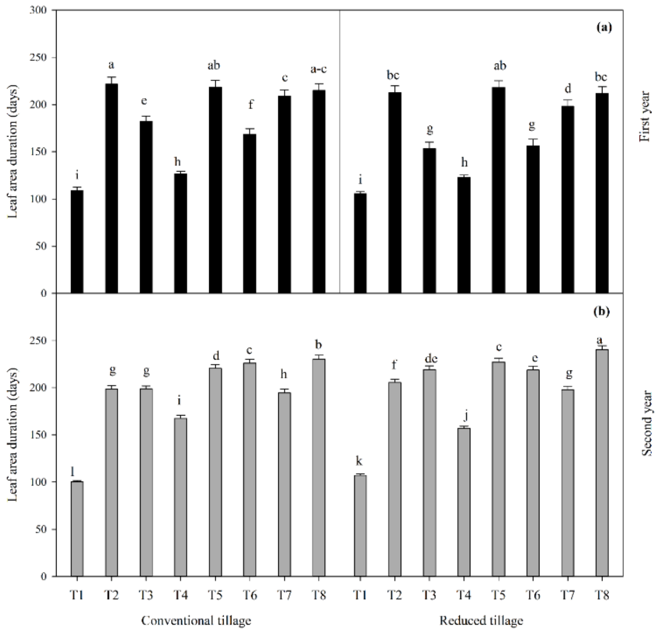

Figure 5. Influence of nutrient management practices on leaf area duration of wheat under CT and RT systems during first (a) and second year (b) of the study. Bars containing similar letters are statistically alike with each other at $P < 0.05$. Each bar shows Mean ± SD. T1, control; T2, recommended dose of NPK; T3, animal manure (M, 20.0 Mg ha-1); T4, 100% crop stubbles incorporation (CSI); T5, 50% NPK and 50% M; T6; 50% NPK and 50% CSI; T7, 0 25% NPK with 25% M and 50% CSI and T8, 25% NPK with 50% M and 25% CSI.

Frederick and Camberato (1995) and Deldon (2001) recorded the delay in booting, milking, anthesis and maturity stages in plants of fertilized plots due to increasing in LAD, more vegetative growth and higher light use efficiency. We found similar vigorous growth of both rice and wheat from the combined application of organic and inorganic fertilizers, resultantly delaying in the physiological maturity. It could be associated with the higher availability of mineral nutrients and good soil conditions, which were resulted by addition of organic materials that led to vigorous crop growth and elongated the growth period (Li, 2003). The combined use of organic and inorganic fertilizers increased the days to accomplish 50% heading, plant height, yield, and related traits, and leaf area index relative to organic-alone or inorganic-alone (Hossain *et al*., 2002; Manna *et al*., 2005). The slow release of mineral nutrients from organic materials (Matsi *et al*., 2003) could be a possible explanation for delay in phenological events in plants of organically amended plots. The N addition can delay the leaf senescence, and stimulated the leaf photosynthesis during grain filling period, and thus have extended the duration of grain filling (Frederick and Camberato, 1995). Animal manure incorporation resulted in higher soil N status, accelerated the chlorophyll contents in wheat due to higher N absorption (Houles *et al*., 2007). The N fertilization significantly stimulates the growth of leaf, assimilation capacity due to higher photosynthetic surface area and thus leaf area (Khan *et al*., 2008). Our results are in accord with those reported by Deldon (2001) who observed a reduction in leaf area due to poor N-fertilization. Similarly, Kibe *et al*. (2006) also recorded the higher leaf area and LAI, resultantly more LAD in N-fertilized plots as compared to control.

***Conclusion*: **The organic amendments-alone delayed the tillering, but accelerated early anthesis and physiological maturity. However, organo-mineral treatments promoted the early tillering and anthesis, but prolonged the grain filling period as indicated by the delay in physiological maturity. The organo-mineral treatments increased the LAD of rice by 35.12 to 49.19% and wheat by 32.28 to 50.19% relative to control. In conclusion, the combined use of organic and inorganic fertilizers changes the phenological events in rice and wheat by modulating the LAD. Farmers could regulate the phenological events in rice and wheat to achieve maximum production by applying the combined use of organic and inorganic fertilizers.

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