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Crop performance, nitrogen and water use in partially-flooded and aerobic rice systems

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ABSTRACT

The adoption of non-flooded rice systems, either partial or full, will become a major imperative in Pakistan for rational use of declining water resources. This study aimed to compare partial and fully aerobic rice systems by quantifying crop performance, water productivity WP, and nitrogen use efficiency NUE in a field experiment was conducted at the research area of the Department of Agronomy, University of Agriculture, Faisalabad to evaluate the potential of different fertilizers under alternate submerged non-submerged condition (ASN) and continuous non-submerged system (CN). Experimental design was randomized complete block design in a split-plot arrangement with three replicates. Net plot size was 5 m × 3 m. Using rice cultivar Super Basmati as experimental material, two water regimes i.e. ASN and CN will be tested against three different sources of nitrogenous fertilisers i.e. urea, ammonium sulphate and calcium ammonium nitrate with nitrogen application rate of 120 kg ha^{-1}. The collected experimental data on growth, developmental, physiological, resource-use, and yield parameters will b statistically analysed statistically by the Fisher's analysis of variance (ANOVA) technique using F-test (5%) for significance. Results indicated that in all parameters either growth or yield, treatments of ammonium sulfate performed better than control. Growth attributes of rice were significantly affected by ammonium sulfate treatments. Emergence count showed non-significant under irrigation regimes. Maximum plant height was observed in ammonium sulphate treatment have highest plant height of 113 cm under ASN regime. Maximum nuber of tillers m^{-2} was observed in ASN treatment with ammonium sulphate application which was 328 m^{-2}. Physiological maturity takes 137 days (DAS) in CN treatment with no fertilizer application. Panicle length increased with the application ammonium sulphate application under ASN regime which was 26.73 cm. Maximum number of kernels were recorded in ammonium sulphate which was 98. Maximum grain yield was observed in ammonium sulphate under ASN which was 4.21 Mg ha^{-1}. Maximum harvest index was calculated in ASN which was 35%. Maximum water productivity was observed in ASN with value of 0.31. ASN enhanced the AEN because nitrogen losses decreased in this irrigation regime. ASN increase the nitrogen use efficiency and also the paddy yield. So, it was concluded that ammonium sulfate under ASN increased the NUE and water productivity this process increased the availability and take up of N by plants and reduced the losses of N which ultimately increased the NUE and WUE and benefits.

Keywords: Rice, nitrogen, alternate submerged non-submerged condition (ASN), water productivity (WP)

1. INTRODUCTION

Rice (*Oryza sativa* L.) remains an important food crop in Asia. With a quarter of world's population, the South Asian region accounts for nearly 40% of the total harvested rice area. By 2050, the demand for rice is projected to be doubled. To maintain a continuous supply of rice for the populated region, one of the key challenges is decreasing water availability for rice-based systems. Sustainable production of rice necessitates rational use of scarce resources without negatively impacting on society and environment (Avtar Singh *et al*. 2012). In Pakistan, rice essentially grows on irrigated lands covering 2.7 million hectares with per annum production of about 6.5 million tonnes (6.85 million tonnes in 2016-17). Being a high water-requiring crop and major export commodity, exporting rice means exporting water in economic terms, which puts huge pressure on already limited water resources (Chapagain and Hoekstra, 2011; GOP, 2017). Due to a high population growth rate of 2.4% per annum (Okoye, 2017), the percapita surface water availability declined from 5650 cubic metres (m^3) in 1951 to 950 m^3 in 2015. Pakistan's dependence on a single river system, limited water storage capacity of 28 days, and wasteful use of water in high water requirement crops such as sugarcane and rice offer little robustness to our cropping systems (Arshad and Oad, 2017). Paddy rice is conventionally grown by transplanting-puddling method using 30–35 day old rice seedlings in flooded soils. The poding water depths maintained in the range of 50–75 mm require 15 to 25 irrigations. In total, the applied irrigation water ranged between 1200 to 1600 mm during 100 to 150 day rice growing season depending on the cultivar used. However, the total amount of water applied varies between 465 and 3642 mm (Ahmad *et al.,* 2007; Joab Onyango Wamari, 2019). Rice grain prices declined in local markets, which led to a decrease in rice areaby 4.9% during fiscal year 2015-16 and dropped further by 0.6% in 2016-17 (GOP, 2017). The decline in rice acreage shows that the conventional transplanted-puddled rice system is becoming cost-ineffective for resource constrained farmers (Erenstein, 2009). To grow rice sustainably, farmers must be able to adopt the emerging alternative non-flooded systems. In this regard, demonstration of the potential value of water-saving technologies such as partially flooded (i.e. alternately submerged-nonsubmerged system; ASNS) and aerobic rice systems (i.e. continuously non-submerged system; CNS) is critical for wide-spread adoption by farmers. The alternative aerobic rice systems entail the growing of direct-seeded or in some cases transplanted rice crop by introduction of non-saturated cycles during a growing season (i.e. alternate periods of wetting and drying/partially flooded systems/ASNS) or maintaining non-flooded conditions throughout the growing season (i.e. aerobi rice system or CNS) as detailed by Bouman *et al.* (2007). The emerging direct-seeded aerobic rice systems, either partially flooded or non-flooded throughout the season, are becoming a viable option for improving use efficiencies of water, labour, and energy resources as well as net profitability of farmers (Awan *et al.,* 2014). The nitrogen use efficiency declined due to rapid nitrification and denitrification processes and the rundown of organic matter (Sahrawat, 2012). The ammonium-N (NH4-N) accumulates under flooded conditions in rice fields, which can be converted to nitrate-

N (NO3-N) under aerobic conditions. If the NO3-N is not utilised due to limitations in water availability, crop biomass or microbial activity, it may be readily lost (Sahrawat, 2012). Under aerobic conditions, rice growth was higher when supplied with the NH4- N than with the NO3- N. Among sources of nitrogenous fertilisers applied to aerobic rice in pot experiments, ammonium sulfate was found more effective than urea in terms of enhanced nitrogen use efficiency, overall vegetative growth, and grain yield whereas potassium nitrate generally decreased plant growth (Nie *et al.,* 2009). The nitrogen use efficiency was 30–45% (Zia *et al.*, 2002) compared to the world average estimates of upto 60% (Dobermann and Fairhurst, 2000). Under aerobic conditions, water productivity of upto 0.38 g kg^{-1} was achieved at field scale by Awan (2013). Shifting of water regimes from fully flooded (i.e. anaerobic) to aerobic condition in rice systems influences the availability and form of soil nitrogen and crop performance. Consequently the shift in water management necessarily requires a different approach to nitrogen nutrition and crop management in aerobic systems (Nie *et al.,* 2009). In order to reduce the overall N losses in aerobic soils, different options have been explored or suggested e.g. compensation of losses by increasing N doses (Devkota *et al.*, 2013), organic amendments, and varying number of N splits (Li *et al.*, 2013). Likewise, changes in field hydrology from flooded to non-flooded systems might affect crop performance by changes in canopy structure, root growth, hormonal levels, remobilisation of carbon from stems to grains, grain filling, harvest index, and use-efficiencies of nitrogen or water (Xue *et al.,* 2013). A synergistic interaction between soilmoisture levels and nitrogenous fertiliser requires proper management of water and nitrogen resources to improve overall crop performance, water productivity and nitrogen use efficiency (Yang *et al.,* 2017; Vijaya Vani *et al.* 2013). In rice, the grain yield and resource-use efficiencies of water or nitrogen are determined by interaction between irrigation regimes and nitrogen (Wang *et al.,* 2016). High nitrogen losses under aerobic conditions necessitate exploring the suitable options for increasing nitrogen use efficiency (Devkota *et al.*, 2013). It is hypothesised that using right source of nitrogenous fertiliser and understanding the irrigation×nitrogen interaction will provide guidelines to reduce nitroegn losses under aerobic soil conditions. This study has implications for rational use of resources, robustness of cropping systems, food security, and improving farmer’s net profitability. With an overall objective of understanding the irrigation×nitrogen interaction under partially-flooded or aerobic rice systems, the specific objectives of this study will be:

1. To compare two water regimes (i.e. partial and full aerobic rice system) in terms of crop performance and water productivity.
2. To quantify the nitrogen response and nitrogen use efficiency of aerobic rice crop in response to different sources of nitrogenous fertilisers.

2. MATERIALS AND METHODS

A dedicated field trial was conducted during summer 2017 at the research farm, department of Agronomy, University of Agriculture, Faisalabad using a fine rice cultivar Super Basmati as experimental material. Two water regimes i.e. alternately submerged-nonsubmerged system (ASN) and continuously non-submerged system (CN) were tested against three different sources of nitrogenous fertilisers i.e. urea, ammonium sulphate and calcium ammonium nitrate each supplying nitrogen (N) at the rate of 120 kg ha^{-1}. To determine the indigenous N supply and to calculate apparent N recovery, a control plot was included with no fertiliser-N application. The ASN water regime was maintained by re-irrigation as soon as field water level reached 15 cm from soil surface. ASN was started 15 days after sowing (DAS) with installation of a plastic drain pipe. Irrigation scheduling was set when water level reached below 15 cm. This level of water is also termed “safe AWD’’ by IRRI (Bouman *et al.,* 2007). The CN water regime was maintained by re-irrigation as soon as the field water level reached 80% of drained upper limit (DUL). DUL was determined by wetting up soil profile of a representative site in the field until it is fully saturated and covering the site with the help of a plastic sheet of 4 m × 4 m. The free draining soil was allowed to drain for 2-3 days and then sampled for gravimetric water content in the top layer (0 to 30 cm). DUL was then calculated by multiplying the gravimetric water content with bulk density as described in Dalgliesh and Foale (2005). In this study, the experimental design was a randomized complete block design (RCBD laid out in a split-plot arrangement. To minimise the variability in results the experiment had three replications. Net plot size was 15 m^2 (i.e. 5 m × 3 m). Recommended dose of different sources of N fertilisers was applied in three splits i.e. 1/3rd at the time of sowing, 1/3rd at the active tillering stage, and 1/3rd at the panicle initiation stage in its respective plots. Recommended amounts of phosphorus i.e. 90 kg P_2O_5 ha^{-1} and potash i.e. 60 kg K_2O ha^{-1} were incorporated in the form of triple super phosphate and sulphate of potash at the time of seedbed land preparation. The crop was sown with a line spacing of 25 cm using seed rate of 60 kg ha^{-1}. Sowing was completed in the last week of June, 2017 using a manual single row drill. Weeds were managed to avoid the critical period of weed competition by manual weeding (i.e. pulling/hoeing) and spraying recommended herbicides. Experimental data pertaining to the following growth, development, resource-use, and yield parameters was recorded during this field study. The understudied characters were emergence count, number of tillers (m^{-2}), physiological maturity, plant height (cm), panicle length (cm), number of kernels, rooting depth (cm), 1000-kernel weight (g), biological yield (mg ha^{-1}), paddy yield (mg ha^{-1}), harvest index (%),water productivity (g grain kg^{-1}), agronomic N use efficiency and apparent N recovery.

3. RESULTS AND DISCUSSION

Emergence count

Data on emergence count showed no significant differences among plots. The emergence started 4 days after sowing (DAS) and was completed on 8 DAS. The plant population was uniform in all plots.

Table 1 Influence of irrigation regimes and source of fertilizer treatments on tillers (m^{-2}) of super basmati

Source	Tillers (m^{-2})	Days to Physiological maturity	PH	Panicle length	No. of kernels/panicle	1000 GW	Biological Yield	Paddy yield	HI	WP
Replication										
Irrigation	171.02*	5.92^{NS}	256.0**	95.37^{NS}	13.47^{NS}	97.25^{NS}	96.5*	1575*	51.7*	4298*
Error R * I										
		21.5**	218.48*	347.7*	321.28**	270.79*				
Fertilizer										
	1357.37**	6.81*	0.32*	51.3*	8.36*	4.28*	110.1**	502**	55.07**	218.27**
I * F	8.39*						3.5*	61.3**	3.57*	43*
Error										
R*I*F										
Total										

*= significant; **= highly significant

Number of tillers (m^{-2})

The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effects of the two factors were also significantly different (Table 1,2). Maximum number of tillers m^{-2} (393) was observed in the alternately submerged-nonsubmerged (ASN) treatment where ammonium sulphate was applied. Minimum number of tillers m^{-2} (203) was observed in the continuously submerged (CN) treatment where no nitrogenous fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.01$) increased the number of tillers as well as the higher water input in ASN regime ($P \leq 0.05$).

Table 2 Influence of irrigation regimes and source of fertilizer treatments on tillers (m^{-2}) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN[a]	CN[b]	
Control	210	203	206.33 d
Urea	340	331	335.33 c
Ammonium Sulphate	393	367	379.66 a
Calcium Ammonium Nitrate	371	340	355.66 b
Mean	328 a	310 b	319.25 Grand Mean

a= alternate submerged nonsubmerged system; b= continuously nonsubmerged system

Days to physiological maturity (DAS)

Table 1, 3 shows statistical analysis of data on days to physiological maturity (DAS). The interaction between irrigation regimes and source of nitrogenous fertilizer was non-significant ($P \geq 0.05$). The individual effect of the irrigation regimes was also significantly different (Table 1, 3). Maximum number of days to physiological maturity 137 was observed in the ASN treatment where no fertilizer was applied. Minimum number of days to flowering 118 was observed in ASN treatment where ammonium sulphate fertilizer was applied. Mean comparisons showed that irrigation regimes significantly ($P \leq 0.05$) decreased the number of days to physiological maturity.

Table 3 Influence of irrigation regimes and source of fertilizer treatments on days to physiological maturity of super basmati

Treatments	Irrigation Regimes		Mean
	ASN^a	CN^b	
Control	121	137	129 a
Urea	124	135	129 b
Ammonium Sulphate	118	133	126 c
Calcium Ammonium Nitrate	123	134	129 b
Mean	122 a	135 a	129 Grand Mean

a= alternate submerged nonsubmerged system, b= continuously nonsubmerged

Plant height (cm)

Table 1, 4 shows statistical analysis of data on plant height (cm). The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effects of the two factors were also significantly different (Table 1, 4). Maximum plant height 110 was observed in the ASN treatment where ammonium sulphate fertilizer was applied. Minimum plant height 71 was observed in the CN treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.05$) increased the plant height as well as the higher water input in ASN regime ($P \leq 0.01$).

Table 4 Influence of irrigation regimes and source of fertilizer treatments on plant height (cm) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN^a	CN^b	
Control	81.3	71.3	76.3 d
Urea	100	91.6	95.8 c
Ammonium Sulphate	110	101.3	105.6 a
Calcium Ammonium Nitrate	106.3	96	101.1 b
Mean	99.4 a	90 b	94.7 Grand Mean

a= alternate submerged nonsubmerged system**,** b=continuous nonsubmerged system

Panicle length (cm)

Table 1, 5 shows statistical analysis of data on panicle length (cm). The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effect of the source of fertilizer was significantly different (Table 1, 5). Maximum panicle length (26) was observed in the ASN treatment where ammonium sulphate fertilizer was applied. Minimum panicle lenght 16 was observed in the CN treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.05$) increased the panicle length.

Table 5 Influence of irrigation regimes and source of fertilizer treatments on panicle length (cm) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN^a	CN^b	
Control	17	16	17 c
Urea	20	19	19.8 bc
Ammonium Sulphate	26	21	24.2 a
Calcium Ammonium Nitrate	23	20	21.6 ab
Mean	21.8 a	19.5 a	20.6 Grand Mean

a=alternate submerged nonsubmerged system; b=continuous nonsubmerged system

Number of kernels per panicle

Table 1, 6 shows statistical analysis of data on number of kernels per panicle. The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effect of the fertilizers was also significantly different (Table 1, 6).

Maximum number of kernels per panicle (98) was observed in the ASN treatment where ammonium sulphate fertilizer was applied. Minimum number of kernels per panicle (58) was observed in the ASN treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.01$) increased the number of kernels per panicle.

Table 6 Influence of irrigation regimes and source of fertilizer treatments on number of kernels per panicle of super basmati

Treatments	Irrigation Regimes		Mean
	ASN[a]	CN[b]	
Control	58	60	59.1 d
Urea	74	69	71.8 c
Ammonium Sulphate	98	89	93.8 a
Calcium Ammonium Nitrate	82	77	80.1 b
Mean	78.2 a	74.2 a	76.2 Grand Mean

a=alternate submerged nonsubmerged system; b=continuously nonsubmerged system

1000 grain weight (g)

Table 1, 7 shows statistical analysis of data on 1000 grain weight (g). The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effect of the fertilizer application was also significantly different (Table 1, 7). Maximum 1000 grain weight (24.9) was observed in the ASN treatment where calcium ammonium nitrate was applied. Minimum 1000 grain weight (21) was observed in the continuous nonsubmerged (CN) treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.05$) increased the 1000 grain weight.

Table 7 Influence of irrigation regimes and source of fertilizer treatments on 1000 grain weight (g) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN[a]	CN[b]	
Control	21.8	21	21.4 b
Urea	22.3	21.7	22 b
Ammonium Sulphate	24.2	22.3	23.25 a
Calcium Ammonium Nitrate	24.9	21.7	23.3 a
Mean	23.3 a	22 a	22.4 Grand Mean

a=alternate submerged nonsubmergedsytem; b=continuous nonsubmerged system

Biological yield (Mg ha^{-1})

Table 1, 8 shows statistical analysis of data on biological yield (Mg ha^{-1}). The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effects of the two factors were also significantly different (Table 1, 8). Maximum biological yield (11.9) was observed in the ASN treatment where ammonium sulphate fertilizer was applied. Minimum biological yield (7.6) was observed in the CN treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.01$) increased the biological yield as well as the higher water input in ASN regime ($P \leq 0.05$).

Table 8 Influence of irrigation regimes and source of fertilizer treatments on biological yield (Mg ha^{-1}) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN[a]	CN[b]	
Control	7.9	7.5	7.73 d
Urea	10.4	9.3	9.85 c
Ammonium Sulphate	11.9	10.8	11.35 a
Calcium Ammonium Nitrate	11.6	9.8	10.7 b
Mean	10.45 a	9.35 b	9.32 Grand Mean

a=alternate submerged nonsubmerged system; b=continuously nonsubmerged system

Paddy yield (Mg ha^{-1})

Table 1, 9 shows statistical analysis of data on paddy yield (Mg ha^{-1}). The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.01$). The individual effects of the two factors were also significantly different (Table 1, 9). Maximum paddy yield Mg ha^{-1} (4.21) was observed in ASN treatment where ammonium sulphate fertilizer was applied. Minimum paddy yield Mg ha^{-1} (2.96) was observed in CN treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.01$) increased the paddy yield as well as the higher water input in ASN regime ($P \leq 0.05$).

Table 9 Influence of irrigation regimes and source of fertilizer treatments on paddy yield (Mg ha^{-1}) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN[a]	CN[b]	
Control	2.96	2.65	2.80 c
Urea	3.89	3.35	3.62 b
Ammonium Sulphate	4.21	3.58	3.89 a
Calcium Ammonium Nitrate	4.01	3.26	3.63 b
Mean	3.76 a	3.21 b	3.48 Grand Mean

a=alternate submerged nonsubmerged system; b=continuously nonsubmerged system

Harvest index (%)

Table 1, 10 shows statistical analysis of data on harvest index (%). The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effects of the two factors were also significantly different (Table 1, 10). Maximum harvest index (35.3) was observed in ASN treatment where ammonium sulphate fertilizer was applied. Minimum harvest index (28) was observed in CN treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.01$) increased the harvest index as well as the higher water input in ASN regime ($P \leq 0.05$).

Table 10 Influence of irrigation regimes and source of fertilizer treatments on harvest index (%) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN[a]	CN[b]	
Control	29.6	28	28.8 d
Urea	33.4	31.3	32.3 c
Ammonium Sulphate	35.3	33.4	34.3 a
Calcium Ammonium Nitrate	34.5	33.2	33.8 b
Mean	35.9 a	34.3 b	35.1 Grand Mean

a=alternate submerged nonsubmerged system; b=continuous nonsubmerged system

Water productivity (g kg^{-1})

Table 1, 11 shows statistical analysis of data on water productivity (g grain kg^{-1} water). The interaction between irrigation regimes and source of nitrogenous fertilizer was significant ($P \leq 0.05$). The individual effects of the two factors were also significantly different (Table 1, 11). Maximum water productivity (0.32) was observed in ASN treatment where ammonium sulphate fertilizer was applied. Minimum water productivity (0.14) was observed in the CN treatment where no fertilizer was applied. Mean comparisons showed that fertilizer application significantly ($P \leq 0.01$) increased the water productivity as well as the higher water input in ASN regime ($P \leq 0.05$).

Table 11 Influence of irrigation regimes and source of fertilizer treatments on water productivity (g grain kg^{-1} water) of super basmati

Treatments	Irrigation Regimes		Mean
	ASN[a]	CN[b]	
Control	0.22	0.14	0.18 d

Urea	0.30	0.20	0.25 c
Ammonium Sulphate	0.32	0.21	0.26 a
Calcium Ammonium Nitrate	0.30	0.18	0.24 b
Mean	0.28 a	0.18 b	0.23 Grand Mean

a=alternate submerged nonsubmerged system; b=continuous nonsubmerged system

Agronomic N use efficiency (AEN)

The interaction between irrigation regimes and source of nitrogenous fertilizer was significant. The individual effects of the two factors were also significantly different (12) Maximum agronomic N use efficiency (4.2) was observed in ASN treatment where ammonium sulphate fertilizer was applied. Minimum AEN (3.2) was observed in CN treatment where calcium ammonium nitrate fertilizer was applied. Mean comparisons showed that fertilizer application significantly increased the agronomic N use efficiency as well as the higher water input in ASN regime.

Table 12 Influence of irrigation regimes and source of fertilizer treatments on agronomic N use efficiency of super basmati

Treatments	**Irrigation Regimes**	
	ASN[a]	**CN[b]**
Control	**-**	**-**
Urea	**3.8**	**3.3**
Ammonium Sulphate	**4.22**	**3.5**
Calcium Ammonium Nitrate	**4**	**3.2**

a=alternate submerged nonsubmerged system; b=continuous nonsubmerged system

Apparent N recovery (ANR)

The interaction between irrigation regimes and source of nitrogenous fertilizer was significant. The individual effects of the two factors were also significantly different (Table 13). Maximum apparent N recovery (0.62) was observed in ASN treatment where ammonium sulphate fertilizer was applied. Minimum ANR (0.20) was observed in CN treatment where urea fertilizer was applied. Mean comparisons showed that fertilizer application significantly increased the apparent N recovery as well as the higher water input in ASN regime.

Table 13 Influence of irrigation regimes and source of fertilizer treatments on apparent N recovery of super basmati

Treatments	**Irrigation Regimes**	
	ASN[a]	**CN[b]**
Control	**-**	**-**
Urea	**0.22**	**0.20**
Ammonium Sulphate	**0.62**	**0.49**
Calcium Ammonium Nitrate	**0.44**	**0.39**

a=alternate submerged nonsubmerged system; b=continuous nonsubmerged system

4. DISCUSSION

The detailed experiment set out to examine the crop performance of aerobic rice under wide range of available fresh water and soil conditions. Under field conditions, unwanted rainfall made it difficult to maintain water stress in alternate submerged nonsubmerged (ASN) and continuous nonsubmerged treatments (Belder *et al.*, 2004). Relatively differences between ASN and CN replicates in crop performance. Aerobic rice yield components have a strong relationship to fully aerobic (CN) and partial aerobic (ASN) with N uptake by crop (Lampayan *et al.*, 2010). Among the treatments, emergence count remains same because treatmentregarding ASN and CN starts after 15 days after sowing (safe AWD). Among the irrigation regimes, the differences in days to physiological maturity confirmed water stress in continuous nonsubmerged (CN). Irrigation regimes and sources of fertilizers had a significant effect on crop performance related to grain yield and water productivity. Continuous use of nitrogenous fertilizer inputs to aerobic soils, generally reduce the soil pH due to conversion of ammonium into nitrate through nitrification and leaching of nitrate from root zone (Schwab., *et al* 1990). Higher N uptake in ASN treatment may be due to reduction in N losses or increased N from soil. This is also confirmed that safe AWD (ASN) having 34% more N uptake from indigenous supply than the continuous nonsubmerged irrigation regime (Reis *et al.*, 2018). Higher N mineralization associated with aerobic rice conditions than continuous submerged (Kader *et al.*, 2013). In the beginning of crop season fewer rainfall and higher temperature rate from mid-season onwards negatively impacted on rice development (Reis *et al.*, 2018). Difference in grain yield between ASN between partially and fully aerobic was associated with difference in values of panicle number m^{-2} and harvest index (Awan *et al.*, 2013). Flowering period is most sensitive to water stress resulting in low harvest index. Availability of water around flowering resulted high value of HI (Bouman *et al.*, 2005). With the decreasing water input in CN resulted in decreased HI value which is consistent with the findings of Xue *et al.*, (2008). Compared to the continuous submerged system, water productivity improved as water use declined. In CN irrigation regime grain yield decrease more than the amount of water saved, resulting in decreased value of water productivity (WP). Highest values of WP were associated with the highest values of panicle number m-2, spikelet fertility, 1000 grain weight and harvestindex. Panicle number m-2 is the main limiting factor for grain yield due reduction in emergence of tiller frequency and reduced number of productive tillers (Yan *et al.*, 2010). Transition to aerobic rice water use declined as compared continuous submerged rice system. Total water input in ASN treatment (1275mm) is less than requirement of 1600mm for rice in Pakistan. Decreasing water input results decrease in grain yield.

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