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Full Length Research Paper

Impact of variable NPK source on water use efficiency and growth rates of winter grasses (cereals): Wheat, rye, barley and oats

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Growth analysis [absolute growth rate (AGR), crop growth rate (CGR), and net assimilation rate (NAR)] and water use efficiency (WUE) response of four cool season C_3-cereals viz. wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), barley (*Hordeum vulgare* L.) and oats (*Avena sativa* L.) at 30, 60 and 90 days after emergence (DAE) under eight NPK sources [S_1 = 20-20-20, S_2= 20-27-5, S_3 = 7-22-8, S_4 = 10-10-10-20S, S_5 = 11-15-11, S_6 = 31-11-11, S_7 = 24-8-16, and S_8 = 19-6-12] in pot experiment. The experiment was conducted in the green house of Dryland Agriculture Institute, West Texas A&M University, Texas, USA during winter 2009-10. The results confirmed significant variations in AGR, CGR, NAR and WUE among the four crops at different growth stages and NPK source. Barley and wheat were dominant crops under each NPK source in terms of higher AGR, CGR and WUE than rye and oats at 30 DAE. The AGR, CGR and WUE at 60 DAE decreased for each crop species with application of NPK 31:11:11 and 24:8:16 having more nitrogen content. At 90 DAE, both CGR and WUE ranked first for barley with NPK 20:20:20, for wheat with 24:8:16 and NPK 10:10:10 for oats. The increase in AGR and CGR had positive impact on WUE. Interestingly, the AGR, CGR and WUE increased whereas NAR decreased with the passage of time. The S_6 NPK fertilizer, known as an acid loving fertilizer had harmful effects on the growth and WUE of different crop species in this study.

Key words: *Triticum aestivum*, *Secale cereale*, *Hordeum vulgare*, *Avena sativa*, growth stages, NPK source, absolute growth rate (AGR), crop growth rate (CGR), net assimilation rate (NAR), water use efficiency (WUE).

INTRODUCTION

Plant growth analysis provides understanding of variation in crops growth (Lambers, 1987), total dry matter accumulation and yield (Khan et al., 2013; Amanullah et al., 2014), nutrients and water use efficiencies

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(Amanullah and Stewart, 2013; Amanullah, 2014a, 2015a). The mineral nutrients application exerts pronounced influences on photosynthates and dry matter accumulation (Costa et al., 2002; Amanullah et al., 2014). There are many NPK fertilizer sources, although, there is no reported research on crop growth analysis (AGR, CGR, NAR) and water use efficiency (WUE) response of crop species grown under different NPK sources. Imbalanced nutrients application adversely affects crop growth and WUE (Amanullah and Stewart, 2013; Amanullah, 2015b). Due to the current climate scenario and water shortage, raising WUE of both irrigated and rain-fed crop production is an urgent imperative (Hamdy et al., 2003). Several strategies will be required to improve the productivity of water use in irrigated and rain-fed agriculture (Wang et al., 2002). It is hypothesized that the use of nutrients (NPK) could be one strategy to improve crop growth and increase WUE. This research project was therefore designed with to investigate the impact of different NPK sources on AGR, CGR and NAR and their relationship with WUE of winter cereal crops in pot experiment. Four crops species studied in this experiment were: wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), barley (*Hordeum vulgare* L.) and oats (*Avena sativa* L.) under eight different NPK sources (S_1 = 20-20-20, S_2= 20-27-5, S_3 = 7-22-8, S_4 = 10-10-10-20S, S_5 = 11-15-11, S_6 = 31-11-11, S_7 = 24-8-16, S_8 = 19-6-12) in pot experiment at the green house of Dryland Agriculture Institute, WTAMU, Texas, USA. The part of this research published indicates that NPK source S_6 (31: 11: 11) known as an acid loving fertilizer had negative effects on the total aerial biomass (dry matter accumulation in shoots) and below ground biomass (dry matter accumulation in roots) in the four crops species (Amanullah et al., 2015). In another paper (Amanullah, 2015b), variations in specific leaf area and specific leaf weights of the four crops (wheat, rye, barley and oats) was also observed at various growth stages and NPK source. The current paper presents the results of different NPK source sources on AGR, CGR and NAR and their relationship with WUE at 30, 60 and 90 days after emergence (DAE).

MATERIALS AND METHODS

Growth rates [absolute growth rate (AGR), crop growth rate (CGR), net assimilation rate (NAR)] and WUE response in four cool season C_3-cereals (small grains) viz. wheat (*T. aestivum* L., cv. TAM III), rye (*S. cereale* L., cv. Elbon), barley (*H. vulgare* L., cv. P919) and oats (*A. sativa* L., cv. Walker) was investigated at 30, 60 and 90 DAE under eight NPK sources [S_1 = 20-20-20 (Peter Professional by Scotts), S_2= 20-27-5 (Starter Fertilizer by Scotts), S_3 = 7-22-8 (Bedding Plant Food by FertiLoam), S_4 = 10-10-10-20S (Shake in Feed by Miracle Grow), S_5 = 11-15-11 (Gardner's Special by FertiLoam), S_6 = 31-11-11 (Acid Loving by FertiLoam), S_7 = 24-8-16 (All Purpose Plant Food by Expert Gardner) and S_8 = 19-6-12 (Slow Release by Expert Gardner)]. Each NPK source was applied at the rate of 300 mg kg^{-1} of potting soil (organic soil know as *miracle grow*) in pot experiment at Dryland Agriculture Institute, West Texas A&M University, Canyon, Texas, USA during winter 2009-2010. The fertilizer was mixed in the potting soil and the pots were filled. The experiment was performed in completely randomized design (CRD) with three repeats. There were 32 pots (treatments) per repeats and a total of 96 pots in the whole experiment. Twenty seeds of each crop species were planted in each pot, and after one week of emergence, 15 plants were maintained per pot, and then five plants were uprooted at 30, 60 and 90 DAE.

The root were washed with tap water, and the plants were then divided into three parts, that is, roots, leaves and stems. The materials was put in paper bags and then put in an oven at 80°C for 24 h. The samples were weighed by electronic balance (Sartorius Basic, BA2105) and the average data on DM of root, leaf, and stem plant^{-1} was worked out. Shoot DM plant^{-1} was obtained by adding leaf DM + stem DM plant^{-1}. The sum of the shoot + root DM plant^{-1} was calculated as the total DM plant^{-1}. Absolute growth rate (AGR): dry matter accumulation per plant per unit time; crop growth rate (CGR): dry matter accumulation per unit pot area per unit time; and net assimilation rate (NAR): dry matter accumulation per unit leaf area per unit time, were determined using the following formulae:

$$AGR = W_2 - W_1 / t_2 - t_1 \text{ (g plant}^{-1}\text{ day}^{-1})$$

$$CGR = W_2 - W_1 / (PA)\ (t_2 - t_1) \text{ (g m}^{-2}\text{ day}^{-1})$$

$$NAR = CGR/LAI \text{ (g m}^{-2}\text{ day}^{-1})$$

Where, W_1 = dry weight per plant at the beginning of interval; W_2 = dry weight per plant at the end of interval; $t_2 - t_1$ = the time interval between the two consecutive samplings; PA = pot area occupied by plants at each sampling; LAI = leaf area index (leaf area per plant divided by ground area per plant).

A known amount of water in each pot was applied at 75% field capacity, and the total amount of water applied was calculated for the whole experimental period. WUE was then calculated (g L^{-1}) by dividing the total dry matter (shoot + root) produced (g) by the amount of water used (liters).

$$WUE = \text{Total dry matter produced} \div \text{Liters of water used (g L}^{-1})$$

Statistical analysis

Data were subjected to analysis of variance (ANNOVA) according to the methods described in Steel and Torrie (1980) and treatment means were compared using the least significant difference (LSD) at $P \leq 0.05$. The main effects of NPK sources and crop species at three growth stages are presented in tables. The interactive effect of NPK sources x crop species at different growth stages are presented in figures.

RESULTS

Absolute growth rate

AGR among the cool season cereals varied significantly ($P \leq 0.05$) at 30, 60 and 90 DAE as shown in Table 1. At 30 DAE, barley had the highest AGR (1.87 mg plant^{-1} day^{-1}), followed by wheat (1.75 mg plant^{-1} day^{-1}); while oats had the lowest AGR (0.98 mg plant^{-1} day^{-1}). At 60 DAE, barley had the highest AGR (41.1 mg plant^{-1} day^{-1}), followed by wheat (36.5 mg plant^{-1} day^{-1}); while oats had the lowest (22.0 mg plant^{-1} day^{-1}). At 90 DAE, barley had the highest AGR (70.77 mg plant^{-1} day^{-1}), being at par

Table 1. Absolute growth rate (mg plant^{-1} day^{-1}) response of cool season cereals to different NPK sources at 30, 60 and 90 days after emergence (DAE).

NPK source	**N-P_2O_5-K_2O**	**30 DAE**	**60 DAE**	**90 DAE**
S_1 = PF (Scotts)	20-20-20	1.52	44.3	68.32
S_2 = SF (Scotts)	20-27-5	1.49	39.1	86.85
S_3 = BPF (Ferti. Loam)	7-22-8	1.42	49.1	48.61
S_4 = SF (Miracle Grow)	10-10-10-20(S)	1.74	31.0	27.57
S_5 = GS (Ferti. Loam)	11-15-11	1.66	32.5	62.33
S_6 = AL (Ferti. Loam)	31-11-11	1.00	4.1	31.78
S_7 = AFPF (E. Gardner)	24-8-16	1.23	18.3	58.74
S_8 = SR (E. Gardner)	19-6-12	1.56	38.0	64.73
Crops species				
Wheat (*Triticum aestivum* L.)		1.75	36.5	69.73
Rye (*Secale cereale* L.)		1.21	28.6	31.25
Barley (*Hordeum vulgare* L.)		1.87	41.1	70.77
Oats (*Avena sativa* L.)		0.98	22.0	52.71
Least significant difference				
Crops ($P \leq 0.05$)		0.11	4.2	8.36
NPK Sources ($P \leq 0.05$)		0.15	6.0	11.83
Interaction ($P \leq 0.05$)		(Figure 1)*	(Figure 2)*	(Figure 2)*

*Indicates the data is significant at $P \leq 0.05$ using LSD test.

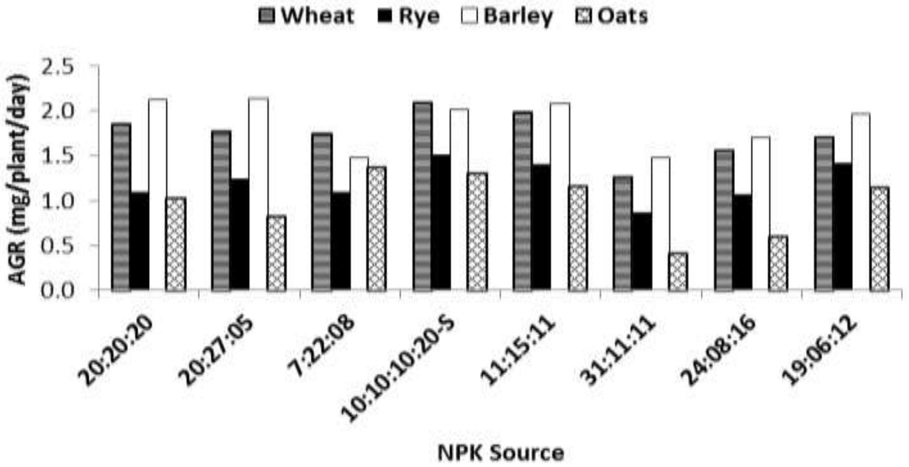

Figure 1. Absolute growth rate (mg plant^{-1} day^{-1}) response to interaction of cool season cereals with NPK sources at 30 days after emergence

with wheat (69.73 mg plant^{-1} day^{-1}); while rye had the lowest (31.25 mg plant^{-1} day^{-1}). The AGR at 30, 60 and 90 DAE among cool season cereals varied significantly ($P \leq 0.05$) when applied different NPK sources (Table 1).

At 30 DAE, the highest AGR (1.74 mg plant^{-1} day^{-1}) was noted when applied with S_4 being at par with S_5 (1.66 mg plant^{-1} day^{-1}); while the lowest AGR (1.00 mg plant^{-1} day^{-1}) was obtained when crops were grown with S_6. At 60 DAE, the highest AGR (49.1 mg plant^{-1} day^{-1}) was recorded when crops were applied S_3, being at par with S_1 (44.3 mg plant^{-1} day^{-1}); while the lowest (4.1 mg plant^{-1} day^{-1}) was obtained when the crops were applied S_6. At 90 DAE, the highest AGR (86.85 mg plant^{-1} day^{-1}) was recorded when crops were applied S_2, followed by S_1 (68.32 mg plant^{-1} day^{-1}); while the lowest (27.57 mg plant^{-1} day^{-1}) was obtained when crops were applied S_4. The interaction at 30 DAE (Figure 1) indicates that both barley and wheat are dominant crops in terms of AGR than rye and oats under different NPK sources. But at 60 DAE (Figure 2), barley growth was severely affected by the

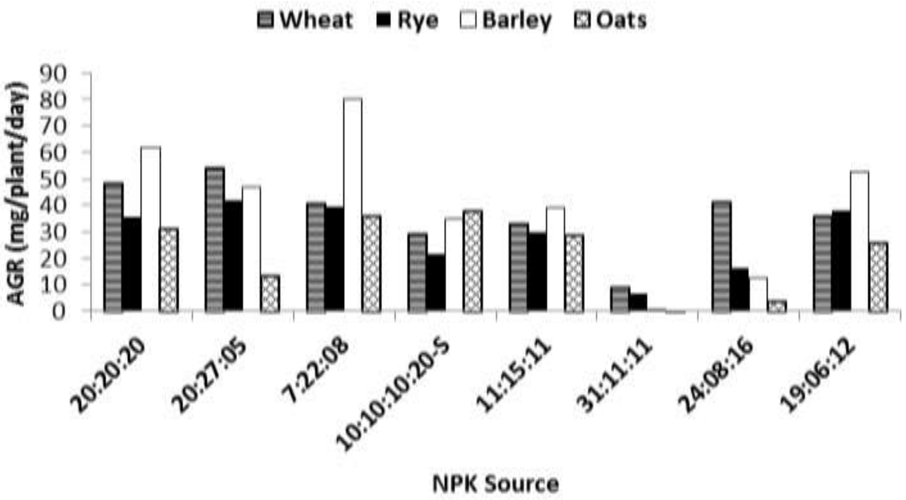

Figure 2. Absolute growth rate (mg $plant^{-1}$ day^{-1}) response to interaction of cool season cereals with NPK sources at 60 days after emergence.

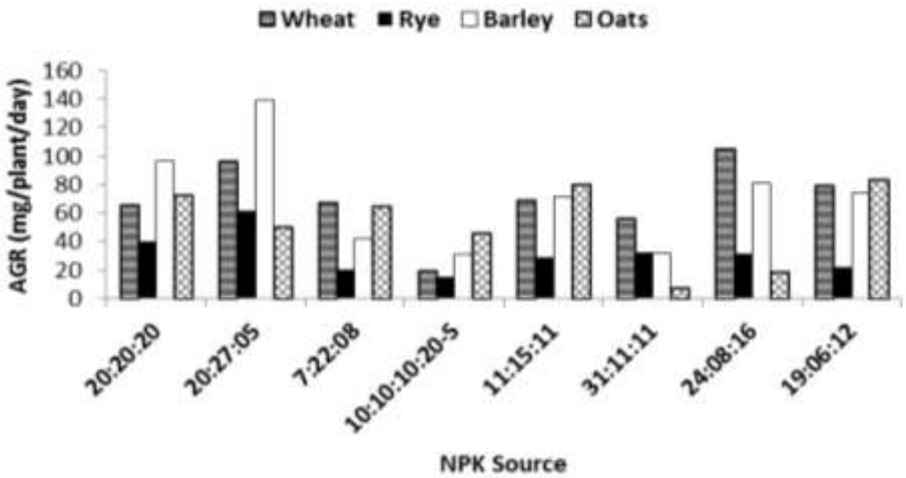

Figure 3. Absolute growth rate (mg $plant^{-1}$ day^{-1}) response to interaction of cool season cereals with NPK sources at 90 days after emergence.

two NPK sources (31:11:11 and 24:8:16) having more nitrogen. At these two sources, wheat AGR was higher than other crops. At later growth stage (Figure 3), oats show dominance in AGR than other crops under two NPK sources (11:15:11 and 19:6:12).

Crop growth rate

Crop growth rate (CGR) among the cool season cereals varied significantly ($P \leq 0.05$) at 30, 60 and 90 DAE (Table 2). At 30 DAE, barley had the highest CGR (0.84 g m^{-2} day^{-1}), followed by wheat (0.79 g m^{-2} day^{-1}); while oats had the lowest CGR (0.44 g m^{-2} day^{-1}). At 60 DAE, barley had the highest CGR (12.06 g m^{-2} day^{-1}), followed by wheat (10.68 g m^{-2} day^{-1}); while oats had the lowest (6.47 g m^{-2} day^{-1}). At 90 DAE, barley had the highest CGR (21.23 g m^{-2} day^{-1}), being at par with wheat (20.92 g m^{-2} day^{-1}); while rye had the lowest CGR (9.37 g m^{-2} day^{-1}). The CGR at 30, 60 and 90 DAE among cool season cereals varied significantly ($P \leq 0.05$) when applied different NPK sources (Table 2). At 30 DAE, the highest CGR (0.78 g m^{-2} day^{-1}) was obtained when crops were applied S_4, being at par with S_5 (0.75 g m^{-2} day^{-1}); while the lowest CGR (0.45 g m^{-2} day^{-1}) was obtained when crops received S_6. At 60 DAE, the highest CGR (14.51 g m^{-2} day^{-1}) was obtained when crops were applied S_3, being at far with S_1 (13.08 g m^{-2} day^{-1}); while the lowest CGR (1.13 g m^{-2} day^{-1}) was obtained when crops received S_6. At 90 DAE, the highest CGR (26.05 g m^{-2} day^{-1}) was calculated when crops were applied S_2, followed by S_1 (20.49 g m^{-2} day^{-1}); while the lowest CGR

Table 2. Crop growth rate (g m^{-2} day^{-1}) response of cool season cereals to different NPK sources at 30, 60 and 90 days after emergence (DAE).

NPK source	$N\text{-}P_2O_5\text{-}K_2O$	30 DAE	60 DAE	90 DAE
S_1 = PF (Scotts)	20-20-20	0.69	13.08	20.49
S_2 = SF (Scotts)	20-27-5	0.67	11.51	26.05
S_3 = BPF (Ferti. Loam)	7-22-8	0.64	14.51	14.58
S_4 = SF (Miracle Grow)	10-10-10-20(S)	0.78	9.04	8.27
S_5 = GS (Ferti. Loam)	11-15-11	0.75	9.52	18.70
S_6 = AL (Ferti. Loam)	31-11-11	0.45	1.13	9.53
S_7 = AFPF (E. Gardner)	24-8-16	0.55	5.31	17.62
S_8 = SR (E. Gardner)	19-6-12	0.70	11.16	19.42
Crops species				
Wheat (*Triticum aestivum* L.)		0.79	10.68	20.92
Rye (*Secale cereale* L.)		0.55	8.42	9.37
Barley (*Hordeum vulgare* L.)		0.84	12.06	21.23
Oats (*Avena sativa* L.)		0.44	6.47	15.81
Least significant difference				
Crops ($P \leq 0.05$)		0.05	1.27	2.51
NPK Sources ($P \leq 0.05$)		0.07	1.79	3.55
Interaction ($P \leq 0.05$)		(Figure 4)*	(Figure 5)*	(Figure 6)*

*Indicates the data is significant at $P \leq 0.05$ using LSD test.

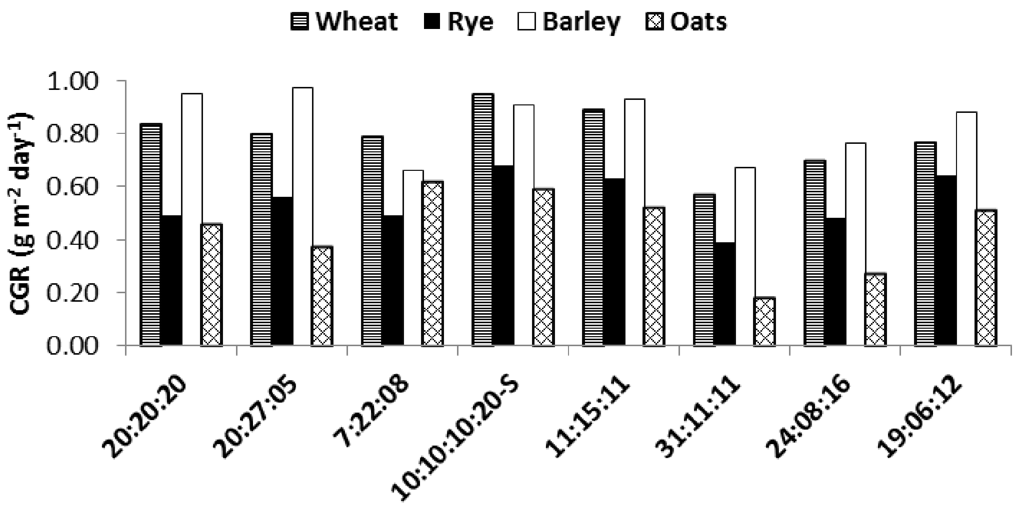

Figure 4. Crop growth rate (g m^{-2} day^{-1}) response to interaction of cool season cereals with NPK sources at 30 days after emergence.

(8.27 g m^{-2} day^{-1}) was calculated when crops received S_4. The interaction at 30 DAE (Figure 4) indicates that both barley and wheat are dominant crops in terms of CGR than rye and oats under different NPK sources. At 60 DAE (Figure 5), all crops CGR were severely affected under 31:11:11, while under 24:8:16, wheat CGR was significantly higher than other three crops. At 90 DAE (Figure 6), barley ranked first in CGR under 20:20:20 and 20:27:5; wheat ranked first under 31:11:11 and 24:8:16; oats ranked first under 11:15:11, 10:10:10 and 19:6:12. Wheat and oats had similar but more CGR than barley and rye under 7:22:8 and 19:6:12.

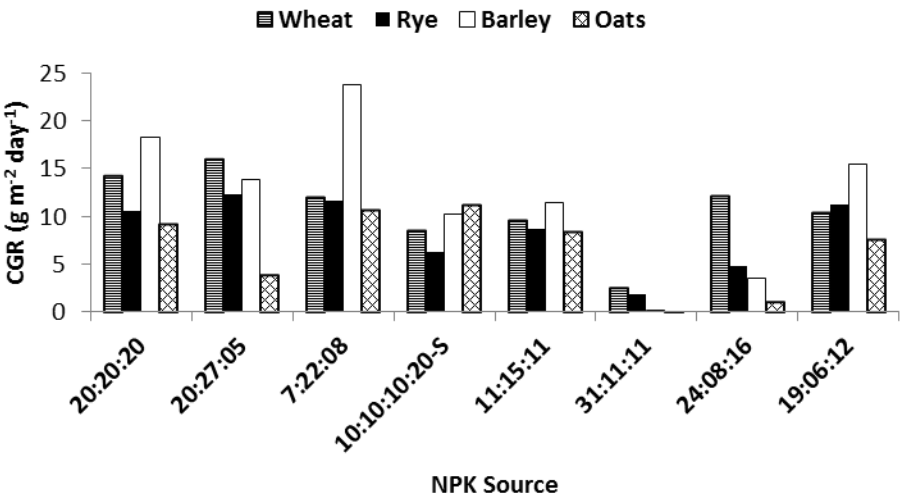

Figure 5. Crop growth rate (g m^{-2} day^{-1}) response to interaction of cool season cereals with NPK sources at 60 days after emergence.

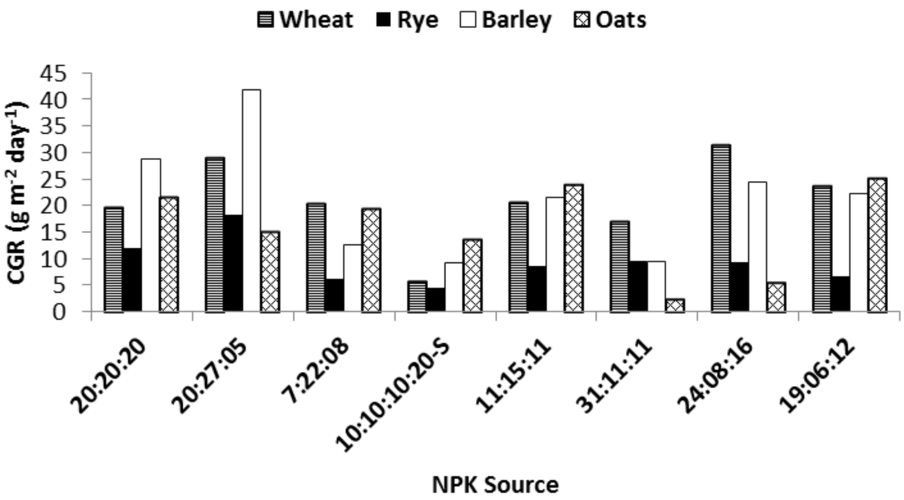

Figure 6. Crop growth rate (g m^{-2} day^{-1}) response to interaction of cool season cereals with NPK sources at 90 days after emergence.

Net assimilation rate

Net assimilation rate (NAR) among the cool season cereals varied significantly ($P \leq 0.05$) at 30 and 90 DAE, but had no significant differences at 60 DAE (Table 3). At 30 DAE, wheat had the highest NAR (22.72 g m^{-2} day^{-1}), being at par with rye (22.40 g m^{-2} day^{-1}); while oats had the lowest NAR (17.19 g m^{-2} day^{-1}). Although, the differences in NAR were not significant among the crops at 60 DAE, however, rye (16.70 g m^{-2} day^{-1}) and wheat (15.13 g m^{-2} day^{-1}) had the higher NAR as compared to barley (7.80 g m^{-2} day^{-1}) and oats (9.76 g m^{-2} day^{-1}). At 90 DAE, wheat had significantly, the highest NAR (8.83 g m^{-2} day^{-1}), followed by oats (4.46 g m^{-2} day^{-1}); while rye had the lowest NAR (3.41 g m^{-2} day^{-1}). The NAR at 30, 60 and 90 DAE among cool season cereals varied significantly ($P \leq 0.05$) when applied different NPK sources (Table 3). At 30 DAE, the highest NAR (25.38 g m^{-2} day^{-1}) was calculated when crops were applied S_6, followed by S_7 (21.67 g m^{-2} day^{-1}); while the lowest NAR (16.68 g m^{-2} day^{-1}) was calculated when crops received S_3. At 60 DAE, the highest NAR (36.28 g m^{-2} day^{-1}) was calculated when crops were applied S_6, followed by S_3 (13.87 g m^{-2} day^{-1}); while the lowest NAR (6.08 g m^{-2} day^{-1}) was obtained when crops received S_7. The NAR showed negative relationship with LAI and positive relationship with CGR. At 90 DAE, the highest NAR (9.36 g m^{-2} day^{-1}) was obtained when crops were applied S_5, followed by S_1 (6.12 g m^{-2} day^{-1}); while the lowest (3.51 g m^{-2} day^{-1}) was obtained when crops received S_8. The interaction at 30

Table 3. Net assimilation rate (g m^{-2} day^{-1}) response of cool season cereals to different NPK sources at 30, 60 and 90 days after emergence (DAE).

NPK source	N-P_2O_5-K_2O	30 DAE	60 DAE	90 DAE
S_1 = PF (Scotts)	20-20-20	21.09	8.47	6.12
S_2 = SF (Scotts)	20-27-5	21.26	8.25	4.93
S_3 = BPF (Ferti. Loam)	7-22-8	16.68	13.87	5.53
S_4 = SF (Miracle Grow)	10-10-10-20(S)	20.88	9.35	4.20
S_5 = GS (Ferti. Loam)	11-15-11	19.70	9.22	9.36
S_6 = AL (Ferti. Loam)	31-11-11	25.38	36.28	3.84
S_7 = AFPF (E. Gardner)	24-8-16	21.67	6.08	4.65
S_8 = SR (E. Gardner)	19-6-12	17.78	7.26	3.51
Crops species				
Wheat (*Triticum aestivum* L.)		22.72	15.13	8.83
Rye (*Secale cereale* L.)		22.40	16.70	3.41
Barley (*Hordeum vulgare* L.)		19.91	7.80	4.36
Oats (*Avena sativa* L.)		17.19	9.76	4.46
Least significant difference				
Crops ($P \leq 0.05$)		2.34	ns	1.03
NPK sources ($P \leq 0.05$)		3.30	14.63	1.46
Interaction ($P \leq 0.05$)		(Figure 7)*	(Figure 8)^{ns}	(Figure 9)*

*Indicates the data is significant at $P \leq 0.05$; ns indicates the data is not significant at $P \leq 0.05$ using LSD test.

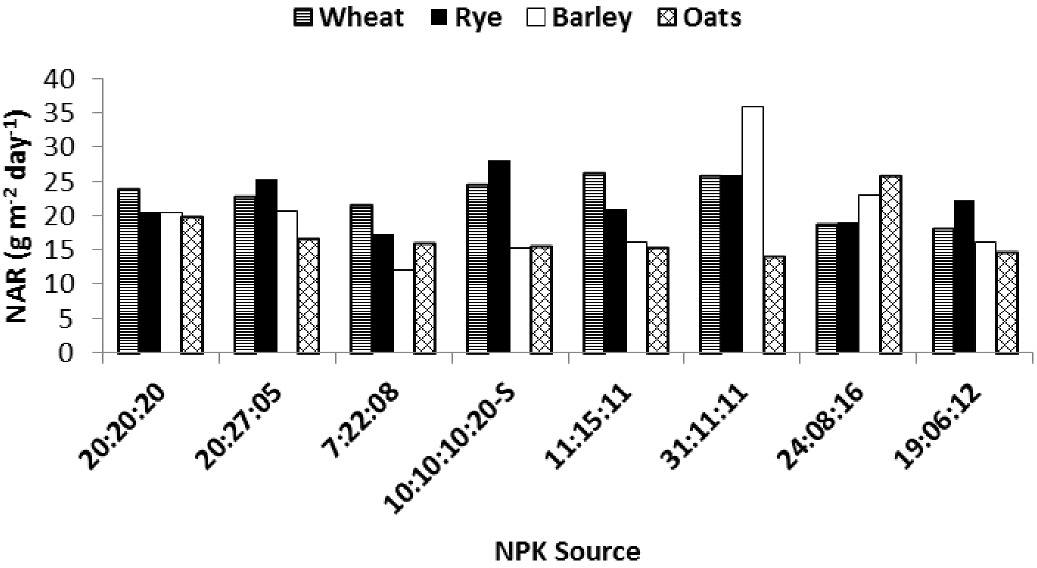

Figure 7. Net assimilation rate (g m^{-2} day^{-1}) response to interaction of cool season cereals into NPK sources at 30 days after emergence.

DAE (Figure 7) indicates that wheat had higher NAR than other crops under 20:20:20, 7:22:8, and 11:15:11; barley had higher NAR than other crops under 31:11:11; rye had higher NAR than crops under 20:27:5, 10:10:10 and 19:6:12, while oats had higher NAR under 24:8:16 than other three crops. The interaction at 60 DAE (Figure 8) indicates that except barley which had low NAR; the NAR of other three crops (wheat, rye and oats) was significantly higher with 31:11:11 (NPK). At 90 DAE (Figure 9), wheat ranked first in NAR under different NPK

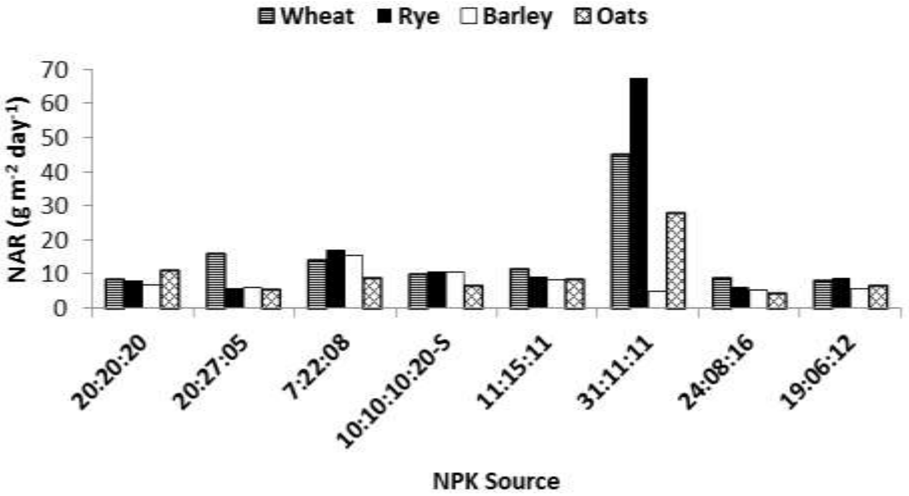

Figure 8. Net assimilation rate (g m^{-2} day^{-1}) response to interaction of cool season cereals with NPK sources at 60 days after emergence.

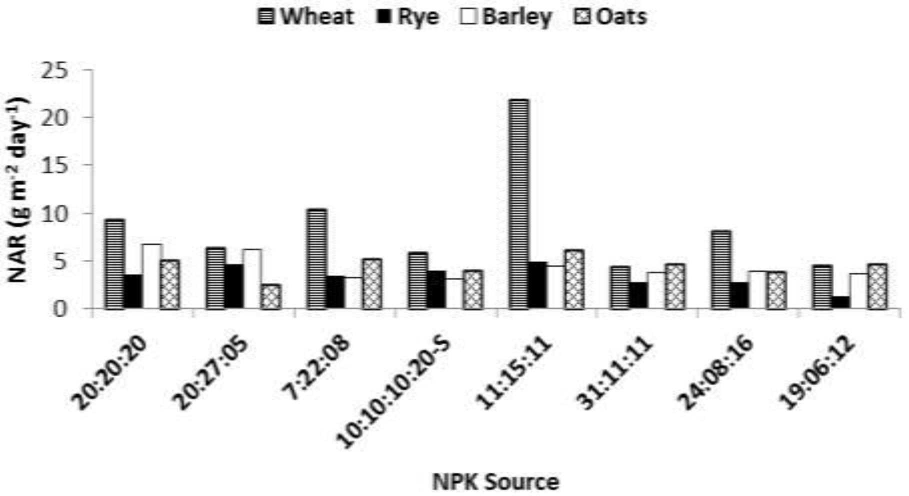

Figure 9. Net assimilation rate (g m^{-2} day^{-1}) response to interaction of cool season cereals with NPK sources at 90 days after emergence.

sources than other crops species.

Water use efficiency

WUE among cool season cereals varied significantly ($P \leq 0.05$) at 30, 60 and 90 DAE (Table 4). At 30 DAE, barley had the highest WUE (0.33 g L^{-1}), followed by wheat (0.31 g L^{-1}); while oats had the lowest WUE (0.16 g L^{-1}) at 30 DAE. Barley had the highest WUE (2.19 g L^{-1}), being at par with wheat (2.02 g L^{-1}); while oats had the lowest WUE (1.16 g L^{-1}) at 60 DAE; the highest WUE (2.54 g L^{-1}), being at par with wheat (2.50 g L^{-1}) and lowest WUE (1.35 g L^{-1}) at 90 DAE. The WUE of the crops also varied significantly when applied different NPK sources at 30, 60 and 90 DAE (Table 4). At 30 DAE, the highest WUE of 0.29 g L^{-1} each was obtained when crops were applied either S_4 or S_8, being at par with S_5 (0.28 g L^{-1}). The lowest WUE (0.17 g L^{-1}) was noted when crops were grown with S_6. At 60 DAE, the highest WUE of 2.48 g L^{-1} was calculated when crops were applied either S_8, being at par with S_1 (2.18 g L^{-1}) and S_3 (2.41 g L^{-1}). The lowest WUE (0.24 g L^{-1}) was noted when crops were grown with S_6. At 90 DAE, the highest WUE of 2.63 g L^{-1} was calculated when crops were applied S_8, being at par with S_2 (2.58 g L^{-1}) and S_7 (2.61 g L^{-1}). The lowest WUE (0.75 g L^{-1}) was noted when crops were grown with S_6. The interaction at 30 DAE (Figure 10) indicates that barley

Table 4. Water use efficiency (g L^{-1}) response of cool season cereals to different NPK sources at 30, 60 and 90 days after emergence (DAE).

NPK source	$N-P_2O_5-K_2O$	30 DAE	60 DAE	90 DAE
S_1= PF (Scotts)	20-20-20	0.26	2.18	2.31
S_2 = SF (Scotts)	20-27-5	0.25	1.93	2.58
S_3 = BPF (Ferti. Loam)	7-22-8	0.26	2.41	2.01
S_4 = SF (Miracle Grow)	10-10-10-20(S)	0.29	1.55	1.22
S_5 = GS (Ferti. Loam)	11-15-11	0.28	1.63	1.96
S_6 = AL (Ferti. Loam)	31-11-11	0.17	0.24	0.75
S_7 = AFPF (E. Gardner)	24-8-16	0.22	1.40	2.61
S_8 = SR (E. Gardner)	19-6-12	0.29	2.48	2.63
Crops species				
Wheat (*Triticum aestivum* L.)		0.31	2.02	2.50
Rye (*Secale cereale* L.)		0.20	1.54	1.35
Barley (*Hordeum vulgare* L.)		0.33	2.19	2.54
Oats (*Avena sativa* L.)		0.16	1.16	1.64
Least significant difference				
Crops ($P \leq 0.05$)		0.01	0.20	0.17
NPK sources ($P \leq 0.05$)		0.02	0.29	0.25
Interaction ($P \leq 0.05$)		(Figure 10)*	(Figure 11)*	(Figure 12)*

*Indicates the data is significant at ($P \leq 0.05$).

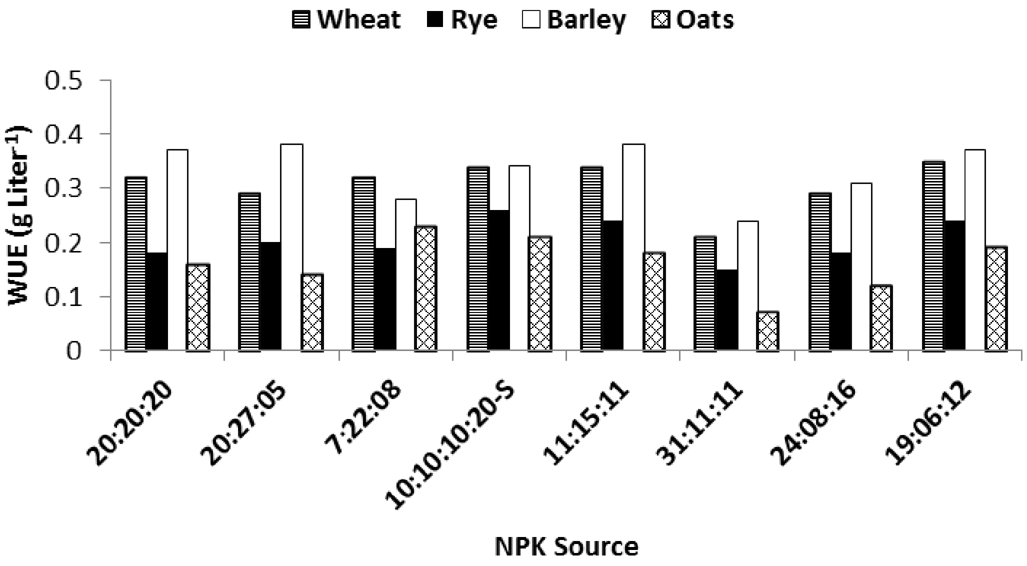

Figure 10. Water use efficiency (g $Liter^{-1}$) response to interaction of cool season cereals with NPK sources at 30 days after emergence.

and oats had higher WUE than oats and rye under different NPK sources The interaction at 60 DAE (Figure 11) indicates that barley had higher WUE than other crops under 20:20:20, 7:22:8, 11:15:11 and 19:6:12, while wheat was better in terms of WUE than other crops under 20:27:5 and 24:8:16. The WUE in all crops was significantly reduced under 31:11:11 (Figure 11). At 90 DAE (Figure 12), barley ranked first in CGR under 20:20:20, 20:27:5. 7:22:8 and 19:6:12; wheat ranked first under 31:11:11 and 24:8:16; oats ranked first under

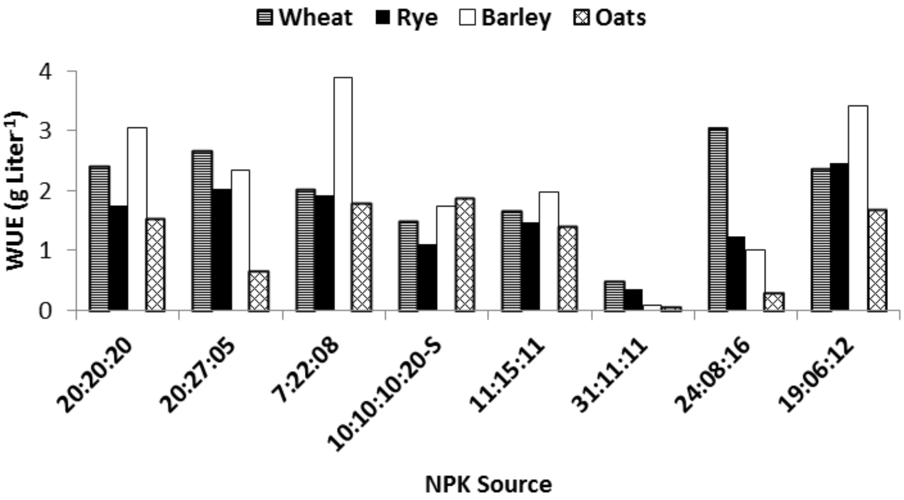

Figure 11. Water use efficiency (g L^{-1}) response to interaction of cool season cereals with NPK sources at 60 days after emergence.

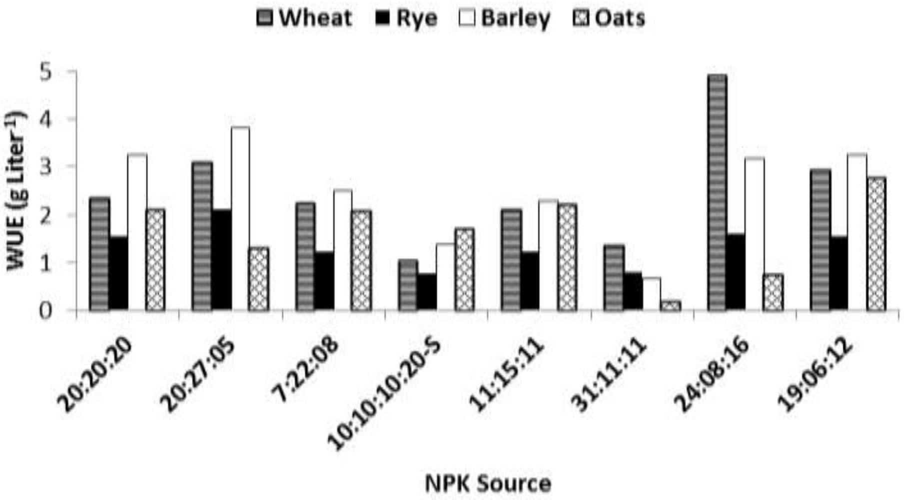

Figure 12. Water use efficiency (g L^{-1}) response to interaction of cool season cereals with NPK sources at 90 days after emergence.

10:10:10 (NPK).

DISCUSSION

Significant variations ($P \leq 0.05$) was observed in the AGR, CGR, NAR and WUE of four cool season small grains species (wheat, rye, barley and oats) at different growth stages (30, 60 and 90 DAE). The differences in the AGR, CGR, NAR and WUE of different crop species at different growth stages may be attributed to the difference in the genetic makeup of crop species (Bendichz and McCarthy, 1970). The number of chromosome in these four crops under study (wheat, barley, rye and oats) are different viz. 42, 14, 14 and 42, respectively (Dolezel et al., 2007) which may be responsible for variation in growth analysis of these crops. Variation in the growth analysis (AGR, CGR, and NAR) and WUE of different crop species depends on plant growth characteristics (leaf area, leaf area index, number of leaves, tillers and roots plant^{-1}, dry matter accumulation plant^{-1} and m^{-2}, dry matter partitioning into various plant parts, that is, roots, shoots, stems, leaf and reproductive parts, as well as root to shoot ratios etc.). Earlier, Amanullah et al. (2016) reported that C_3-cereals crops (wheat, rye, barley and oats) differ in root and shoot biomass (g plant^{-1}), root to shoot ratios and water use efficiency (g L^{-1}) when they were grown in various combinations (intercropping) and water levels. The results of Amanullah (2017) study found significant differences in these four species in terms of dry matter partitioning and accumulation at various growth stages. Differences in the WUE of wheat vs. rye was reported under different soil types (Amanullah, 2014a), and difference in the WUE was attributed to the significant variations in their shoot, root and total dry weights produced. Other research on maize genotypes (Amanullah et al., 2014) confirmed that variation in the total dry weights plant^{-1} of different genotypes was attributed to variation in mean single leaf area, number of leaves plant^{-1} and leaf area index. Differences in total biomass accumulation, root to shoot ratios (Amanullah et al., 2015), and leaf thickness (Amanullah, 2015b) in the four-crop species under different NPK sources was also reported.

Significant variations ($P \leq 0.05$) in the AGR, CGR, NAR and WUE were also observed at different growth stages (30, 60 and 90 DAE) with different NPK sources. The differences in the AGR, CGR, NAR and WUE while using different NPK fertilizers may probably be attributed to the differences in the leaf area, leaf area index, number of leaves and tillers plant^{-1}, root, shoot and total dry matter accumulation produced under different NPK sources. Amanullah (2017) found significant differences in dry matter partitioning and accumulation under different NPK sources. Increased plant growth with optimal N, P, K application provides vegetative cover, thus enhancing moisture retention, nutrient use efficiency and soil productivity (Bumb and Bannante, 1996). Hussein and Alva (2014) reported that water use efficiency responded favorably with increase in rates of N, P, K fertilizers. In previous research on maize response to different nitrogenous fertilizer sources (Amanullah et al., 2014), it was indicated that application of CAN (calcium ammonium nitrate) produced significantly higher mean single leaf area, leaves plant^{-1}, leaf area index and total dry matter accumulation than application of urea and ammonium sulphate (AS) in the first year of experiment. However, the differences in these parameters were not significant while using different N-fertilizers in the second year of experiment (Amanullah et al., 2014). Khan et al. (2013) reported that foliar application of various N-fertilizer sources (urea, CAN and AS) had produced significantly higher total biomass yield than control (water spray only). In another study, regarding maize response to phosphatic fertilizer sources (Amanullah et al., 2010), the mean single leaf area, number of leaves plant^{-1}, leaf area index and total biomass ha^{-1} was significantly higher either with application of di-ammonium phosphate (DAP) or single super phosphate (SSP) as compared to the application of nitrophos (NP) and control plots (P not applied). In the current experiment, the AGR showed positive relationship with increase in total dry weight (shoots + roots) plant^{-1}. Indicating that any NPK source that increased dry weight of shoots (leaf + stem) or roots or both (shoots + roots) resulted in higher AGR and vice versa. The increase in CGR in this experiment showed positive relationship with increase in AGR. Therefore, any NPK source that increased AGR/dry weight plant^{-1} resulted in higher CGR and vice versa. The increase in WUE showed positive relationship with increase in both AGR and CGR. This means that any NPK source which increased AGR/CGR resulted in higher WUE and vice versa. The result of Amanullah (2015) study indicated that two NPK sources viz. S_4 [(10-10-10-20(S] and S_6 (31-11-11) reduced the total weight plant^{-1} and therefore these NPK sources had negative impact on the AGR, CGR, NAR and WUE. In another greenhouse study, Amanullah (2014b) noted that higher WUE obtained under three organic soils (potting soils) was attributed to increase in shoot and root growth of wheat and rye. On the other hand, the less total dry weight per plant produced under inorganic soils (Canyon and Amarillo soils) adversely affected the growth and WUE of both wheat and rye (Amanullah, 2014b). The experiment on oats (Amanullah and Stewart, 2013) had also confirmed that increase in total dry matter accumulation per plant had positive impact on AGR, CGR, NAR and WUE. Differences in total biomass accumulation and root to shoot ratios (Amanullah et al., 2015), and leaf thickness (Amanullah, 2015b) at various growth stages under different NPK sources was also reported.

The AGR, CGR and WUE increased with the passage of time, that is, the values of all these parameters were less at the early growth stage than at the late growth stage (90 > 60 > 30 DAE). The increase in all these three parameters with advancement in crop age was attributed to the increase in the total dry matter accumulation plant^{-1} (Amanullah, 2015). Bagrintseva and Nosov (2012) reported that DM partitioning in both winter wheat and winter barley was more at grain filling > heading > tillering. Mut et al. (2006) found significant differences in the DM yield among triticale, wheat, rye and barley at early heading and dough stages. Research on maize crop (Amanullah et al., 2009) indicated that the total dry matter produced depends on plant height and leaf area plant^{-1}, and the total dry matter was more at the late (physiological maturity) than the early (silking) growth stage. In contrast, the NAR (CGR ÷ LAI) in this experiment decreased with the passage of time (90 < 60 < 30 DAE), and the decrease in NAR with advancement in crop age may be attributed to the increase in leaf area plant^{-1} and leaf area index. Earlier, Amanullah and Stewart (2013) suggested that NAR had negative relationship with increase in leaf area index and positive relationship with increase in CGR.

Conclusion

Considerable variation in AGR, CGR, NAR and WUE was observed in the four crop species at different growth stages when applied with different NPK sources. The increase in dry matter accumulation plant^{-1} was considered the best criteria to increase AGR, CGR and WUE in different crop species. The increase in AGR, CGR and WUE was observed with advancement in crop age, while on the other hand, NAR was reduced with the passage of time. The reduction in NAR with passage of time was due to the increase in leaf area index. Identification or development of crop species with higher AGR and CGR has higher WUE in different environments. Since growth rates and WUE values were determined on the average of five plants in pot experiment, more research is needed under field condition under different environmental conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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