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Leaf Growth Analysis of Cool Season Cereals "Wheat, Rye, Barley, and Oats" under Different NPK Sources

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Abstract

Plant growth analysis is generally expressed as indexes of growth such as crop growth rate, relative growth rate, net assimilation rate, leaf area ratio, and leaf area index that provide the first clue toward an understanding of variation in growth rates among genotypes or species. The objective of this research was to investigate leaf growth analysis viz. Mean Single Leaf Area (MSLA), Leaf Area Plant^{-1} (LAPP), Leaf Area Ratio (LAR) and Leaf Area Index (LAI) of four winter cereals [wheat (*Triticum aestivum L.*), rye (*Secale cereale L.*), barley (*Hordeum vulgare L.*) and oats (*Avena sativa L.*)] at different growth stages and NPK source. Different leaf parameters were investigated at one month interval [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). The experiment was conducted in pots at the green house of the Dryland Agriculture Institute, West Texas A&M University, Canyon (Texas), USA during winter 2009-2010. The results revealed that increase in both leaf lengths and widths were considered important leaf characteristics for increasing or decreasing MSLA and LAPP. The increase in LAPP showed positive relationship with increase in both LAR and LAI in the four crop species. Application of S_6 (an acidic fertilizer) had negative effects on MSLA, LAPP, LAI and total dry weight plant^{-1}. Wheat and rye showed relatively high tolerance to S_6 as compared to barley and oats.

Keywords: *Triticum aestivum*; *Secale cereal*; *Hordeum vulgare*; *Avena sativa*; Growth stages; NPK source; LAR and LAI

Abbreviations: MSLA: Mean Single Leaf Area; LAPP: Leaf Area Plant^{-1}; LAR: Leaf Area Ratio; LAI: Leaf Area Index; DAE: Days After Emergence

Introduction

Plant growth analysis is generally expressed as indexes of growth such as crop growth rate, relative growth rate, net assimilation rate, leaf area ratio, and leaf area index Fageria et al. [1] that provide the first clue toward an understanding of variation in growth rates among genotypes or species (Lambers, 1987). The mineral nutrients exert pronounced influences on photosynthates and dry matter partitioning between shoots and roots Costa et al. [2]. Oscar and Tollenaar [3] reported that LAI increased with the application of higher N rate, while Pandey et al. [4] noticed that maize crop differs in its ability to maintain LAI and above ground dry matter production at different levels of N supply. High tissue N contents cause a very succulent growth, that is high in water content but low in dry matter, and so the plants are very weak, and leaves with high N consents respire-use up the food produced by photosynthesis-more rapidly Plaster [5]. Breadth of the area per leaf profile decreases under high soil N level and high plant density Oscar and Tollenaar [3]. Increase in number of leaves plant^{-1} was reported by Arya and Singh [6], and increase in leaf area was reported by Hamdi and Woodard [7] that soils low in P will adsorb large amounts of P leaving little for plants and higher P dose increased its availability allowing less adsorption and so improved maize growth [8,9].

Our earlier published research work on maize (*Zea mays L*) indicated that increase in N rate and number of splits increased LAI and LAR Amanullah et al. [10], increased interception of solar radiation Amanullah et al. [9], grain yield Amanullah et al. [10], leaves plant^{-1} and biomass Amanullah et al. [11] and dry matter partitioning Amanullah and Shah [12]. The published paper from the same study Amanullah et al. [13] indicated that the NPK fertilizer S6 (31: 11: 11), an acid loving fertilizer had negative effects on the shoot and root development of cool season cereals, but among these cereals under study, barley and oats roots were affected more than wheat and rye. In another recent study we found considerable variations in growth analysis and water use efficiency for the four crop species viz. wheat, rye, barley, and oat was observed under different crop combinations and water levels Amanullah et al. [14] a. The increase in LAI of rice crop with proper phosphorus and zinc nutrition showed a positive impact on crop growth rate, dry matter, and yield Amanullah et al. [15] b. Amanullah [16] noticed a considerable variation in dry matter (DM) partitioning into various plant parts was observed in the four crop species at different growth stages when applied with different NPK sources.

At 30 DAE (days after emergence), more DM was portioned into leaf 54% > roots 27% > stems 19%. At 60 DAE, the distribution of DM into leaf was 66% > stems 18% > roots 16. Similarly, at 90 DAE, more DM accumulated in leaf 38% > stems 33% > roots 29%. Maize plants applied with different phosphatic fertilizers i.e. di-ammonium phosphate (DAP) or single super phosphate (SSP) had the highest crop growth rate, LAI, leaf expansion rate (LER), dry matter and grain yields than application of nitrophos (NP) and with zero-P control plots Amanullah et al. [17]. There are many NPK sources available all over the world, yet not a single published research work is there to indicate impact of NPK sources on various leaf characteristics of cool season cereals. The main objective of this experiment was to investigate whether there is any difference in the LAR and LAI of cool season C_3 cereals at various NPK sources or not?

Materials and Methods

Leaf dynamics including mean single leaf area, leaf area plant^{-1}, leaf area ratio and leaf area index of four cool season C_3-species(cereals, grasses) viz. wheat (*Triticum aestivum L*., cv. TAM III), rye (*Secale cereale L*., cv. Elbon), barley (*Hordeum vulgare L*., cv. P919) and oats (*Avena sativa L*., cv. Walker) was investigated 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 2009-10. The fertilizer was mixed in the potting soil and then 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 was 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 days after emergence (DAE).

The root were washed with tap water, and the plants were then divided into three parts i.e. roots, leaves and stems. The materials was put in paper bags and then put in an oven at 80 ^{0}C for 24 hours. The samples were weighing by electronic balance (*Sartorius Basic*, BA2105) and the average data on dry weight of root, leaf, and stem plant^{-1} was worked out. Shoot dry weight plant^{-1} was obtained by adding leaf dry weight with stem dry weight plant^{-1}. The sum of the shoot and root dry weight plant^{-1} was calculated as the total dry weight plant^{-1}. Mean single leaf area (MSLA), leaf area plant^{-1} (LAPP) and leaf area index (LAI) was measured on the fresh samples before drying, while leaf area ratio (LAR) were calculated after drying the samples on the average of the five plants at 30, 60 and 90 DAE using the following formulae:

$$MSLA = Leaf\ length\ x\ leaf\ width\ x\ 0.65\ \left(cm^2\right)$$
$$LAPP = MSLA\ x\ number\ of\ leaves\ plant^{-1}\left(cm^2\right)$$
$$LAR = LAPP \div total\ weight\ plant^{-1}\left(cm^2 mg^{-1}\right)$$
$$LAI = LAPP \div ground\ \left(pot\right)\ area\ plant^{-1}$$

Statistical Analysis

Data were subjected to analysis of variance (ANNOVA) according to the methods described in Steel and Torrie [18] and treatment means were compared using the least significant difference (LSD) at $P \le 0.05$.

Results

Mean Single Leaf Area

The differences in mean single leaf area (MSLA) of the cool season cereals were significant ($P \le 0.05$) for the crops, NPK sources and crops x NPK sources at 30, 60 and 90 days after emergence (Tables 1-3). Among the crops, barley ranked first (7.03 cm^2), followed by wheat (5.33 cm^2), and rye had the smallest MSLA (3.83 cm^2) being at par with that of oats at 30 DAE (Table 1). Among NPK sources, the highest MSLA (6.11 cm^2) was obtained with S_8, being at par with S_3 (6.03 cm^2), S_4 (6.09 cm^2) and S_5 (5.91 cm^2), and the smallest MSLA (2.58 cm^2) was produced with S_6. At 60 DAE (Table 2), barley ranked first again with the highest MSLA (18.0 cm^2), followed by oats this time (16.4 cm^2); while rye had the smallest MSLA (10.0 cm^2). Among NPK sources, the highest MSLA (19.7 cm^2) was obtained with S_8, being at par with S_2 (17.8 cm^2); while the smallest MSLA (2.3 cm^2) was recorded with S_6. At 90 DAE (Table 3), oats ranked first with maximum MSLA (20.8 cm^2), followed by barley (18.2 cm^2); while rye had the smallest MSLA (8.8 cm^2). Among NPK sources, the highest MSLA (17.2 cm^2) was obtained with S_2, being at par with S_1 (16.5 cm^2), S_5 (15.5 cm^2) and S_8 (17.0 cm^2); while the smallest MSLA (9.7 cm^2) was recorded when crops were applied with S_6.

Table 1: Mean single leaf area (cm^2) response of cool season cereals to different NPK sources at 30 days after emergence.

NPK Sources	N-P_2O_5-K_2O	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	5.36	3.79	7.12	3.49	4.94
S_2 = SF (Scotts)	20-27-5	5.32	3.41	7.10	3.33	4.79

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S_3= BPF (Ferti. Loam)	7-22-8	5.60	4.42	8.29	5.81	6.03
S_4= SF (Miracle Grow)	10-10-10-20(S)	5.85	3.81	9.01	5.69	6.09
S_5= GS (Ferti. Loam)	11-15-11	5.20	4.66	8.67	5.13	5.91
S_6= AL (Ferti. Loam)	31-11-11	3.32	2.28	2.80	1.95	2.58
S_7= AFPF (E. Gardner)	24-8-16	5.59	3.80	4.99	1.56	3.99
S_8= SR (E. Gardner)	19-6-12	6.44	4.43	8.29	5.28	6.11
	Mean	**5.33**	**3.83**	**7.03**	**4.03**	
$LSD_{0.05}$						
Crops		0.40				
NPK Sources		0.57				
Interaction		1.14				

Table 2: Mean single leaf area (cm²) response of cool season cereals to different NPK sources at 60 days after emergence.

NPK Sources	N-P$_2$O$_5$-K$_2$O	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	12.3	11.0	23.7	16.4	15.8
S_2 = SF (Scotts)	20-27-5	13.7	15.7	24.8	17.1	17.8
S_3= BPF (Ferti. Loam)	7-22-8	10.7	9.4	18.8	19.5	14.6
S_4= SF (Miracle Grow)	10-10-10-20(S)	10.4	9.4	15.7	22.8	14.6
S_5= GS (Ferti. Loam)	11-15-11	12.3	10.8	19.2	19.3	15.4
S_6= AL (Ferti. Loam)	31-11-11	3.7	2.8	1.8	0.7	2.3
S_7= AFPF (E. Gardner)	24-8-16	12.9	9.0	13.8	8.8	11.2
S_8= SR (E. Gardner)	19-6-12	13.7	12.2	26.3	26.8	19.7
	Mean	**11.2**	**10.0**	**18.0**	**16.4**	
$LSD_{0.05}$						
Crops		61.1				
NPK Sources		86.4				
Interaction		172.8				

Table 3: Mean single leaf area (cm²) response of cool season cereals to different NPK sources at 90 days after emergence.

NPK Sources	N-P$_2$O$_5$-K$_2$O	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	10.6	9.9	17.2	28.3	16.5
S_2 = SF (Scotts)	20-27-5	13.7	9.7	20.6	24.8	17.2
S_3= BPF (Ferti. Loam)	7-22-8	8.3	7.9	15.9	20.2	13.1
S_4= SF (Miracle Grow)	10-10-10-20(S)	7.0	7.2	17.0	21.6	13.2
S_5= GS (Ferti. Loam)	11-15-11	7.0	8.1	20.5	26.2	15.5
S_6= AL (Ferti. Loam)	31-11-11	11.2	9.1	13.3	5.3	9.7
S_7= AFPF (E. Gardner)	24-8-16	12.2	7.7	20.1	16.6	14.2
S_8= SR (E. Gardner)	19-6-12	13.1	10.7	21.1	23.1	17.0
	Mean	**10.4**	**8.8**	**18.2**	**20.8**	
$LSD_{0.05}$						
Crops		1.6				
NPK Sources		2.2				
Interaction		4.4				

Leaf Area Plant

In case of LAPP, the barley ranked first (21.10 cm²), followed by wheat (16.00 cm²), and rye had the smallest LAPP (11.48 cm²) at 30 DAE (Table 4). Among NPK sources, the highest LAPP (18.33 cm²) was obtained with S_8, being at par with S_3 (18.09 cm²), S_4 (18.27 cm²) and S_5 (17.74 cm²), and the smallest LAPP (7.75 cm²) was noted with S_6. At 60 DAE (Table 5), barley ranked first again with maximum LAPP (478.3 cm²), followed by wheat (315.6 cm²); while oats had the smallest LAPP (271.0 cm²). Among NPK

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sources, crops had the highest LAPP (520.9 cm^2) when applied with S_8, being at par with S_1 (506.6 cm^2); while the smallest LAPP (24.3 cm^2) was recorded when crops were applied with S_6. At 90 DAE (Table 6), barley ranked first with the highest LAPP (752.3 cm^2), followed by oats (566.8 cm^2); while wheat had the smallest LAPP (450.2 cm^2). Among NPK sources, the highest LAPP (839.8 cm^2) was produced with S_2, being at par with S_8 (827.3 cm^2); while the smallest LAPP (383.4 cm^2) was recorded with S_6.

Table 4: Leaf area plant^{-1} (cm^2) response of cool season cereals to different NPK sources at 30 days after emergence.

NPK Sources	N-P_2O_5-K_2O	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	16.09	11.38	21.35	10.47	14.82
S_2 = SF (Scotts)	20-27-5	15.96	10.24	21.29	9.99	14.37
S_3= BPF (Ferti. Loam)	7-22-8	16.80	13.26	24.86	17.44	18.09
S_4= SF (Miracle Grow)	10-10-10-20(S)	17.55	11.44	27.04	17.06	18.27
S_5= GS (Ferti. Loam)	11-15-11	15.60	13.98	26.00	15.39	17.74
S_6= AL (Ferti. Loam)	31-11-11	9.95	6.83	8.39	5.85	7.75
S_7= AFPF (E. Gardner)	24-8-16	16.77	11.41	14.98	4.68	11.96
S_8= SR (E. Gardner)	19-6-12	19.31	13.29	24.86	15.84	18.33
	Mean	**16.00**	**11.48**	**21.10**	**12.09**	
$LSD_{0.05}$						
Crops		1.21				
NPK Sources		1.71				
Interaction		3.42				

Table 5: Leaf area plant^{-1} (cm^2) response of cool season cereals to different NPK sources at 60 days after emergence.

NPK Sources	N-P_2O_5-K_2O	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	514.8	402.1	828.6	281.0	506.6
S_2 = SF (Scotts)	20-27-5	328.7	676.2	703.8	240.4	487.3
S_3= BPF (Ferti. Loam)	7-22-8	255.5	216.8	465.3	371.4	327.2
S_4= SF (Miracle Grow)	10-10-10-20(S)	277.3	180.0	308.1	521.1	321.6
S_5= GS (Ferti. Loam)	11-15-11	258.8	282.9	423.3	311.3	319.1
S_6= AL (Ferti. Loam)	31-11-11	59.2	31.9	4.5	1.9	24.3
S_7= AFPF (E. Gardner)	24-8-16	435.2	234.7	209.4	88.3	241.9
S_8= SR (E. Gardner)	19-6-12	395.1	452.4	883.7	352.5	520.9
	Mean	**315.6**	**309.6**	**478.3**	**271.0**	
$LSD_{0.05}$						
Crops		61.1				
NPK Sources		86.4				
Interaction		172.8				

Table 6: Leaf area plant^{-1} (cm^2) response of cool season cereals to different NPK sources at 90 days after emergence.

NPK Sources	N-P_2O_5-K_2O	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	322.2	574.4	658.1	726.1	570.2
S_2 = SF (Scotts)	20-27-5	699.1	620.1	1108.6	931.6	839.8
S_3= BPF (Ferti. Loam)	7-22-8	339.3	300.7	630.6	648.8	479.8
S_4= SF (Miracle Grow)	10-10-10-20(S)	161.9	184.3	474.7	518.7	334.9
S_5= GS (Ferti. Loam)	11-15-11	140.4	274.4	800.8	588.4	451.0
S_6= AL (Ferti. Loam)	31-11-11	557.2	483.0	418.8	74.6	383.4
S_7= AFPF (E. Gardner)	24-8-16	585.0	502.6	975.2	222.3	571.3
S_8= SR (E. Gardner)	19-6-12	796.2	737.9	951.6	823.7	827.3

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	Mean	450.2	459.7	752.3	566.8	
$LSD_{0.05}$						
Crops		91.0				
NPK Sources		128.6				
Interaction		257.3				

Leaf Area Ratio

At 30 DAE, oats ranked first in terms of LAR (0.43 $cm^2\ mg^{-1}$), followed by barley (0.37 $cm^2\ mg^{-1}$), and wheat had the lowest LAR (0.30 $cm^2\ mg^{-1}$) as shown in Table 7. The highest LAR (0.42 $cm^2\ mg^{-1}$) was calculated with S_3, being at par with S_4 (0.38 $cm^2\ mg^{-1}$), S_5 (0.38 $cm^2\ mg^{-1}$) and S_8 (0.39 $cm^2\ mg^{-1}$); while the lowest LAR (0.31 $cm^2\ mg^{-1}$) was recorded with either S_6 or S7. At 60 DAE, oats ranked first in terms of LAR (406.6 $cm^2\ g^{-1}$), followed by barley (357.8 $cm^2\ g^{-1}$); while wheat had the lowest LAR (265.5 $cm^2\ g^{-1}$) as shown in Table 8. The highest LAR (524.0 $cm^2\ g^{-1}$) was calculated when crops were applied with S_7, being at par with S_2 (430.7 $cm^2\ g^{-1}$) and S_8 (426.1 $cm^2\ g^{-1}$); while the lowest LAR (102.8 $cm^2\ g^{-1}$) was recorded with S_6 (Table 8). Oats ranked first in terms of LAR (275.5 $cm^2\ g^{-1}$), being at par with rye (263.1 $cm^2\ g^{-1}$) and barley (248.7 $cm^2\ g^{-1}$); while wheat had the lowest LAR (148.1 $cm^2\ g^{-1}$) at 90 DAE (Table 9). The highest LAR (365.1 $cm^2\ g^{-1}$) was obtained with S_6, followed by S_7 (284.0 $cm^2\ g^{-1}$) and S_8 (280.4 $cm^2\ g^{-1}$); while the lowest LAR (159.0 $cm^2\ g^{-1}$) was recorded with S_5.

Table 7: Leaf area ratio ($cm^2\ mg^{-1}$) response of cool season cereals to different NPK sources at 30 days after emergence.

NPK Sources	$N-P_2O_5-K_2O$	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	0.30	0.39	0.34	0.39	0.36
S_2 = SF (Scotts)	20-27-5	0.32	0.30	0.34	0.45	0.35
S_3= BPF (Ferti. Loam)	7-22-8	0.31	0.42	0.52	0.45	0.42
S_4= SF (Miracle Grow)	10-10-10-20(S)	0.30	0.26	0.47	0.48	0.38
S_5= GS (Ferti. Loam)	11-15-11	0.27	0.35	0.40	0.50	0.38
S_6= AL (Ferti. Loam)	31-11-11	0.28	0.28	0.21	0.47	0.31
S_7= AFPF (E. Gardner)	24-8-16	0.34	0.38	0.29	0.23	0.31
S_8= SR (E. Gardner)	19-6-12	0.33	0.32	0.40	0.50	0.39
	Mean	**0.30**	**0.34**	**0.37**	**0.43**	
$LSD_{0.05}$						
Crops		0.04				
NPK Sources		0.05				
Interaction		0.10				

Table 8: Leaf area ratio ($cm^2\ g^{-1}$) response of cool season cereals to different NPK sources at 60 days after emergence.

NPK Sources	$N-P_2O5-K_2O$	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	341.0	363.9	429.9	284.9	354.9
S_2 = SF (Scotts)	20-27-5	201.0	505.3	477.9	538.6	430.7
S_3= BPF (Ferti. Loam)	7-22-8	198.8	196.1	224.4	330.1	237.4
S_4= SF (Miracle Grow)	10-10-10-20(S)	288.9	257.2	283.3	443.5	318.2
S_5= GS (Ferti. Loam)	11-15-11	246.6	304.2	340.0	349.7	310.1
S_6= AL (Ferti. Loam)	31-11-11	161.7	113.0	78.9	57.8	102.8
S_7= AFPF (E. Gardner)	24-8-16	336.1	463.4	484.6	811.9	524.0
S_8= SR (E. Gardner)	19-6-12	350.1	374.3	543.5	436.5	426.1
	Mean	**265.5**	**322.2**	**357.8**	**406.6**	
$LSD_{0.05}$						
Crops		78.3				
NPK Sources		110.7				
Interaction		ns				

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Table 9: Leaf area ratio ($cm^2\ mg^{-1}$) response of cool season cereals to different NPK sources at 90 days after emergence.

NPK Sources	$N\text{-}P_2O_5\text{-}K_2O$	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	90.8	252.1	134.7	237.6	178.8
S_2 = SF (Scotts)	20-27-5	152.7	197.3	201.3	514.5	266.5
S_3= BPF (Ferti. Loam)	7-22-8	104.0	160.1	168.7	213.0	161.5
S_4= SF (Miracle Grow)	10-10-10-20(S)	106.1	160.3	232.0	204.3	175.7
S_5= GS (Ferti. Loam)	11-15-11	45.6	151.6	260.8	178.1	159.0
S_6= AL (Ferti. Loam)	31-11-11	327.8	436.0	409.6	286.9	365.1
S_7= AFPF (E. Gardner)	24-8-16	132.2	346.0	334.9	322.9	284.0
S_8= SR (E. Gardner)	19-6-12	225.5	401.4	247.6	247.0	280.4
	Mean	**148.1**	**263.1**	**248.7**	**275.5**	
$LSD_{0.05}$						
Crops		41.2				
NPK Sources		58.2				
Interaction		116.5				

Leaf Area Index

At 30 DAE, barley ranked first in terms of LAI (0.047), followed by wheat (0.036); while rye had the smallest LAI (0.026) being at par with oats (0.027) as shown in Table 10. The highest LAI of 0.041 was calculated each with S_4 and $S_{8,}$ being at par with S_3 (0.040) and S_5 (0.039); while the lowest LAI (0.017) was recorded when crops were applied with S_6 (Table 10). At 60 DAE (Table 11), barley ranked first in terms of LAI (1.59), followed by wheat (1.05) being at par with rye (1.03); while oats had the smallest LAI (0.90). The highest LAI of 1.74 was calculated with $S_{8,}$ being at par with S_1 (1.69) and S_2 (1.62); while the lowest LAI (0.08) was recorded when crops were applied with S_6 (Table 11). At 90 DAE, barley ranked first in terms of LAI (5.0), followed by oats (3.8); while wheat had the lowest LAI (3.0) being at par with rye (3.1) as shown in Table 12. The highest LAI (5.6) was calculated for $S_{2,}$ being at par with S_8 (5.5); while the lowest LAI (2.2) was recorded when crops were applied with S_4 (Table 12).

Table 10: Leaf area index (LAI) response of cool season cereals to different NPK sources at 30 days after emergence.

NPK Sources	$N\text{-}P_2O_5\text{-}K_2O$	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	0.036	0.025	0.047	0.023	0.033
S_2 = SF (Scotts)	20-27-5	0.035	0.023	0.047	0.022	0.032
S_3= BPF (Ferti. Loam)	7-22-8	0.037	0.029	0.055	0.039	0.040
S_4= SF (Miracle Grow)	10-10-10-20(S)	0.039	0.025	0.060	0.038	0.041
S_5= GS (Ferti. Loam)	11-15-11	0.035	0.031	0.058	0.034	0.039
S_6= AL (Ferti. Loam)	31-11-11	0.022	0.015	0.019	0.013	0.017
S_7= AFPF (E. Gardner)	24-8-16	0.037	0.025	0.033	0.010	0.027
S_8= SR (E. Gardner)	19-6-12	0.043	0.030	0.055	0.035	0.041
	Mean	**0.036**	**0.026**	**0.047**	**0.027**	
$LSD_{0.05}$						
Crops		0.003				
NPK Sources		0.004				
Interaction		0.008				

Table 11: Leaf area index (LAI) response of cool season cereals to different NPK sources at 60 days after emergence.

NPK Sources	$N\text{-}P_2O_5\text{-}K_2O$	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	1.72	1.34	2.76	0.94	1.69
S_2 = SF (Scotts)	20-27-5	1.10	2.25	2.35	0.80	1.62
S_3= BPF (Ferti. Loam)	7-22-8	0.85	0.72	1.55	1.24	1.09
S_4= SF (Miracle Grow)	10-10-10-20(S)	0.92	0.60	1.03	1.74	1.07

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S_5= GS (Ferti. Loam)	11-15-11	0.86	0.94	1.41	1.04	1.06
S_6= AL (Ferti. Loam)	31-11-11	0.20	0.11	0.01	0.01	0.08
S_7= AFPF (E. Gardner)	24-8-16	1.45	0.78	0.70	0.29	0.81
S_8= SR (E. Gardner)	19-6-12	1.32	1.51	2.95	1.17	1.74
	Mean	**1.05**	**1.03**	**1.59**	**0.90**	
$LSD_{0.05}$						
Crops		0.20				
NPK Sources		0.29				
Interaction		0.58				

Table 12: Leaf area index (LAI) response of cool season cereals to different NPK sources at 90 days after emergence.

NPK Sources	N-P_2O_5-K2O	Wheat	Rye	Barley	Oats	Mean
S_1= PF (Scotts)	20-20-20	2.1	3.8	4.4	4.8	3.8
S_2 = SF (Scotts)	20-27-5	4.7	4.1	7.4	6.2	5.6
S_3= BPF (Ferti. Loam)	7-22-8	2.3	2.0	4.2	4.3	3.2
S_4= SF (Miracle Grow)	10-10-10-20(S)	1.1	1.2	3.2	3.5	2.2
S_5= GS (Ferti. Loam)	11-15-11	0.9	1.8	5.3	3.9	3.0
S_6= AL (Ferti. Loam)	31-11-11	3.7	3.2	2.8	0.5	2.6
S_7= AFPF (E. Gardner)	24-8-16	3.9	3.4	6.5	1.5	3.8
S_8= SR (E. Gardner)	19-6-12	5.3	4.9	6.3	5.5	5.5
	Mean	**3.0**	**3.1**	**5.0**	**3.8**	
$LSD_{0.05}$						
Crops		0.6				
NPK Sources		0.9				
Interaction		1.7				

Discussion

30 Days After Emergence

The MSLA, LAPP and LAI in the four crop species ranked in the order: barley > wheat > oats > rye at the early growth stage. The increase in MSLA, LAPP and LAI in barley and wheat was attributed to the increase in leaf lengths and widths, and increase in leaf and tillers number plant^{-1} (data not shown). Increase in leaf area and leaf expansion rate with increase in leaf number tiller^{-1} was earlier reported by Bultynck et al. [19]. The less MSLA, LAPP and LAI in oats were attributed to its slow growth at the early stage. The decrease in MSLA, LAPP and LAI in rye was attributed to its narrow leaves as compared with other crop species. The less LAR in wheat than other crop species (barley > rye > oats > wheat) was attributed to the production of more total dry weight plant^{-1}. The highest LAPP in barley was the major cause to increased LAR to the maximum level than other crop species. Application of S_6 reduced the MSLA, LAPP and LAI, but increased LAR than other NPK sources. The significant decline in leaf lengths and widths, leaf and tillers number plant^{-1} (data not shown) with S_6 resulted in reduction in MSLA, LAPP and LAI. Plenet et al. [20] found that LAI in maize decreased due to the consequence of reduction in the leaf area plant^{-1}. The highest LAR with S_6 was attributed to the significant reduction in the total dry weight plant^{-1} produced. The association of LAR was positive with LAPP but negative with total dry weight plant^{-1}.

60 Days After Emergence

The higher MSLA in barley and oats (barley > oats > wheat > rye) and was attributed to the increase in leaf lengths and widths, as compared to the short and narrow leaves in wheat and rye that resulted in less MSLA. Leaf lengths and widths of oats at this stage increased tremendously than at the first stage, and therefore MSLA increased in oats with advancement in crop age. Gardner et al. [21] reported that leaf lengths, widths, and area generally increase progressively with ontogeny up to the point; then in certain species it decreased progressively with ontogeny so that the largest leaves are near the centre of the plant, such as on a maize plant. The increase in leaf number per tiller increased LAPP in barley, followed by both wheat and rye; while less number of leaves tiller^{-1} and leaves plant^{-1} in oats decreased significantly its total LAPP (barley > rye > wheat > oats) and LAI (barley > wheat > rye > oats) than other crop species. Because of less number of leaves tiller^{-1} and plant^{-1} in oats reduced its dry weight plant^{-1} as a result the LAR in oats reached to the maximum level (oats > barley > rye > wheat) as compared with crop species. Van den Boogaard et al. [22] showed, in a controlled-environment study, that a fast leaf area expansion rate in wheat was positively correlated with

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above-ground biomass and grain yield. Aapplication of S_6 reduced the MSLA, LAPP and LAI, but increased the LAR than other NPK sources. The significant decline in leaf lengths and widths, leaf and tillers number plant^{-1} (data not shown) with S_6 resulted in reduction in MSLA, LAPP and LAI. On the other hand, application of S_2, S_7 and S_8 improved the growth of plants and therefore increased MSLA, LAPP and LAI. The highest LAR with S_6 was attributed to the significant reduction in the total dry weight plant^{-1} produced, but the highest dry weight plant^{-1} with S_2, S_7 and S_8 reduced the LAR in crop species. Jennings et al. [23] reported that association between leaf lengths and dry matter accumulation plant^{-1} was positive.

90 Days After Emergence

Oats had the higher MSLA with S_1, S_2, S_3, S_4, S_5 and S_8 but had the lowest MSLA with S_6 than other crops. Barley and oats produced similar MSLA with S_7 but was higher than that of wheat and rye. Barley had the higher LAPP with S_2, S_5, S_7, and S_8, while oats produced the highest LAPP with S_1 and the lowest LAPP with S_6 and S_7. Both barley and oats produced similar but higher LAPP with S_3 and S_4 but higher than that of wheat and rye. The higher MSLA (oats > barley > wheat > rye) and LAPP (barley > oats > wheat > rye) in both barley and oats at 90 DAE was attributed to the increase in leaf lengths and widths than wheat and rye. Oats had the highest LAR with S_2; application of S_1, S_6, S_7 and S_8 increased LAR in rye, while application of S_3, S_4 and S_5 reduced LAR in all crops especially in wheat crop. The increase in LAR in oats and barley was due to the increase in LAPP, but the increase in LAR of rye was attributed to the reduction in total dry weight plant^{-1}. The decline in LAR of wheat with different NPK sources was attributed to its lower LAPP but higher dry weight plant^{-1}. Barley had the highest LAI with S_2, S_5, S_6 and S_8 than other crop species, while application of S_1, S_3 and S_4 increased LAI in oats being at par with barley. As compared with other crops, application of S_6 increased LAI in wheat but decreased LAI in oats. The species with more rapidly elongating leaves showed a faster increase with leaf position in leaf expansion rate (LER), leaf width and leaf area, higher relative leaf area expansion rates, and more biomass allocation to leaf sheaths and less to roots Bultynck et al. [19] . The NPK source S_6 known as acidic fertilizer had adversely affected both oats and barley than wheat and rye. Therefore, LAI in oats was less with S_6 than other crop species (oats < barley < rye < wheat). Differential response of maize genotypes regarding leaf area index has also been reported earlier by Azadgoleh Kazmi [24] and Luque et al. [25]. Increasing LAI increases dry mater production, but net canopy photosynthesis cannot increase indefinitely because of increased mutual shading of leaves Fageria et al. [1].

The results of this study confirmed that increase in leaf lengths and widths, and leaf and tillers number plant^{-1} at different growth stages (data not shown) was the important characteristics that increased both MSLA and LAPP in the small grains. Increase in leaf area and leaf expansion with increase in leaf number on a tiller was earlier reported by Bultynck et al. [19]. Barley ranked first, wheat second, followed by oats and rye in terms of MSLA and LAPP. Barley and wheat with rapid leaf area expansion could benefit water conservation in the soil because of reduction in evaporation at the early growth stage. Amanullah et al. [26] found that combined application of N + P or sole application of P had more favorable influence to increase number of leaf and leaf area per plant that resulted in higher LAI at the later growth stages (60 and 90 days after emergence) of oats than at the early growth stage (30 days after emergence) when compared with control (P and N not applied). According to Richards et al. [27], rapid leaf area expansion leads to rapid canopy closure, thereby reducing the evaporation from the soil surface, and thus increasing crop water-use efficiency. The species with more rapidly elongating leaves showed a faster increase with leaf position in leaf expansion rate (LER), leaf width and leaf area, higher relative leaf area expansion rates, and more biomass allocation to leaf sheaths and less to roots Bultynck et al. [19].

The increase in LAPP had positive impact on both LAR and LAI; and the association between LAI and total dry matter accumulation plant^{-1} (data not shown) was positive. Fageria et al. [1] reported that LAI is one of the most important plant growth indexes for determining dry matter yields, and increasing LAI values increases dry matter production. The increase in N rate and number of splits increased LAI Amanullah et al [8], light interception Amanullah et al. [9] and consequently increase dry matter accumulation and partitioning Amanullah et al. [12] and grain yield Amanullah et al. [10]. Van den Boogaard et al. [22] reported that a fast leaf area expansion rate in wheat was positively correlated with above-ground biomass and grain yield. The increase in the total dry weight plant^{-1} showed negative relationship with LAR but the response was different among the four crop species. Baligar et al. [28] reported that efficiency of acquisition, transport and utilization of nutrients varies with crop species and genotype/cultivar within species, and their interactions with the environment [29].

Conclusions

Study of different leaf characteristics (dynamics) and their relationship with each other are very important for canopy photosynthesis, plant growth, dry matter accumulation and partitioning. Application of S_6 known as acidic fertilizer has adverse effects on MSLA, LAPP, LAI and total dry weight plant^{-1}. Wheat and rye showed relatively high tolerance to this acidic fertilizer (S_6) as compared with barley and oats. Application of S_2, S_7, and S_8 improved the MSLA, LAPP and LAI that resulted in more number of tillers and roots plant^{-1}, increased total dry weight plant^{-1} and water use efficiency in the all crops under study (data not shown). The increase in leaf lengths and widths were considered very important for increasing MSLA and LAPP. Positive relationship was found between LAPP and LAR, and between LAPP and LAI. The increase in total dry weight plant^{-1} decreased LAR in the crop species. Since the values on different leaf characteristics were

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determined on the average of five plants at each growth stage in pot experiment under organic soil. Therefore, more research is needed on various crop species/varieties in field experiments under different environmental conditions.

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