Dry Matter Partitioning, Growth Analysis and Water Use Efficiency Response of Oats (*Avena sativa* L.) to Excessive Nitrogen and Phosphorus Application

Jr. Amanullah¹,²* and B. A. Stewart²

**ABSTRACT**

Shoot:root ratio, dry matter partitioning, growth analysis, and water use efficiency of oat (*Avena sativa* L., cv. Walker) was investigated under excessive nitrogen (N) as 200 mg N kg⁻¹ \( (N_1P_0) \), excessive phosphorus as 200 mg P kg⁻¹ \( (N_0P_1) \), and combined 100 mg N+100 mg P kg⁻¹ \( (N_2P_2) \), and the control \( (N_0P_0) \) as check in a pot experiment at Dryland Agriculture Institute, West Texas A and M University, Canyon, Texas, USA, during winter 2009-2010. The experiment was performed in completely randomized design (CRD) with three replicates. One week after emergence, 15 plants were maintained per pot. Later, five plants were uprooted at 30, 60, and 90 days after emergence (DAE). The volume of each pot was 6,283 cm³, containing 2,000 g of potting mix (organic soil) pot⁻¹.

Excessive N applications had very negative effects on leaf, stem, and root and, consequently, on the total dry weight per plant of oat. The reduction in total plant dry weight with excessive N applications reduced crop growth rate. In contrast, excessive P applications had no negative effects on leaf, stem, root, and the total plant dry weight. Rather, excessive P applications had more favorable effects on leaf, stem, root, and total dry weight per plant at early growth stage. At later growth stages, combined N+P applied had more beneficial impact on leaf, stem, root and total dry weight per plant. The increase in total dry matter accumulation per plant showed positive relationship with absolute growth rate (AGR), crop growth rate (CGR), and net assimilation rate (NAR). The NAR showed negative relationship with increase in LAI and positive relationship with increase in CGR. Water use efficiency was increased with P application and showed positive relationship with increase in CGR.

**Keywords:** Growth analysis, N and P toxicity, Oats, Shoot-root ratio, Water use efficiency.

**INTRODUCTION**

Excessive nitrogen application had negative influence on root mass and/or root length (Welbank, *et al.*, 1974; Feil and Geisler, 1988). The stimulating effect of increased local concentration of nitrate-N on uptake and root proliferation may affect root distribution in a soil (Drew 1975; Robinson, 1994). Plants with too much N do not grow properly: high tissue N contents cause a very succulent growth high in water content but low in dry matter, and, therefore, the plants are very weak, because leaves high in N also respire -use up the food produced by photosynthesis- more rapidly (Plaster, 2009). When too much N is applied, excessive vegetative growth occurs; the cells of the plant stems become enlarged but relatively weak, and the top-heavy plants are prone to lodging with heavy rain or wind. High N applications may delay plant

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maturity and cause more susceptibility to diseases and to insects damages. These problems are especially noticeable if the other nutrients, such as P and potassium, are in relatively low supply (Braddy and Weil, 2002). Other studies have reported that reductions in root growth may occur at high N supplies (Anderson, 1987; Comfort et al., 1988). High N rates may reduce deep root penetration and decrease potential use of deep soil nutrients and water. Bosemark (1954) concluded that with high N supplies, root growth stopped completely. Cereal plants have been reported to respond to additional N nutrition through increase in growth of whole plant (Troughton, 1962).

Excessive use of phosphate fertilizer and manure may increase P loss from agricultural soils, posing environmental impact (Jian-ling et al., 2007). The buildup of P in lawns, gardens, pastures, and croplands can cause plants to grow poorly and even die. Excessive soil P reduces the plant’s ability to take up required micronutrients, particularly iron and zinc, even when soil tests show adequate amounts of those nutrients in the soil. Approaches for the diagnosis and management of crop nutrition often target individual nutrients; there is an increasing interest in integrated nutrient management (Sadras, 2006). Under high P condition, both Fe and Zn are converted into non-available forms (Plaster, 2009; Provin and Pitt, 2010). Therefore, plants grown under excessive P conditions need additional iron and zinc applications. However, simply adding iron and zinc will not work. Foliar Zn and Fe applications, however, work well (Provin and Pitt, 2010). Maximum root dry weight was noticed at 152 mg P kg⁻¹, whereas maximum root dry weight for common bean and cowpea were achieved at 130 and 159 mg kg⁻¹ soil, respectively. Root growth was reduced at higher P levels, but different crop species shown different response to P application. Fagaria et al., 1997). Both root and shoot growth vary similarly as P level increases, and above certain levels, further increase in P supply does not affect root or shoot growth (Troughton, 1962)

The mineral nutrients P and N exert pronounced influences on photosynthates and dry matter partitioning between shoots and roots (Costa et al., 2002). Phosphorus and N deficient plants usually have more dry matter partitioning to roots than shoots, probably as a result of higher export rates of photosynthates to roots (Fagaria et al., 2006). Studies on excessive N and P on the shoot-root, dry matter partitioning and growth analysis of oats are lacking. The objective of the present study was to investigate the impact of excess N and P applications on oats shoot-root ratio, dry matter partitioning, and growth.

**MATERIALS AND METHODS**

Shoot-root ratio (by weight), dry matter partitioning, and growth analysis of oats (Avena sativa L., cv. Walker) was investigated under excessive nitrogen (N) and phosphorus (P) applications in pot experiment at Dryland Agriculture Institute, West Texas A and M University, Canyon, Texas, USA, during winter 2009-10. The experiment was performed in completely randomized design with three replicates.

The four treatments were: \( T_1 = \text{Control (N}_0\text{P}_0 \) ), \( T_2 = 200 \text{mg N kg}^{-1} (\text{N}_1\text{P}_0) \), \( T_3 = 200 \text{mg P kg}^{-1} (\text{N}_0\text{P}_1) \), and \( T_4 = 100 \text{mg N}+100 \text{mg P kg}^{-1} (\text{N}_2\text{P}_2) \). Potting mix called Miracle Grow was used as a soil medium in each pot. Urea (46% N) and triple super phosphate (46% P₂O₅) were used as source of N and P, respectively (\( N_0 \) indicates no N was applied and \( P_0 \) indicates no P was applied).

**Characteristics of Miracle Grow**

Miracle Grow is a formulated soil medium from 50-60% sphagnum peat moss, coconut husk fibers (coir pith), composted bark fines, wetting agent, and fertilizer. The nitrogen, phosphorus and potassium sources have
been coated to provide 0.10% slow-release nitrogen (N), 0.10% slow-release phosphate (P2O5), and 0.10% potash (K2O). The ACGIH threshold Limit Values (TLV) for nuisance (inert) dust containing less than 1% crystalline silica and no abestas are: 10 mg m⁻³ inhalable particulates and 3 mg m⁻³ respirable particulate. The bulk density (0.32 g cm⁻³) and porosity (88 %) for miracle grow was calculated in the green house.

Twenty seeds of oat were planted in each pot, and three pots of the same treatment were separately placed per tub. Water was applied in the tub, and the pots took water from the tub. The pots were maintained at field capacity in the whole growing season. One week after emergence, plants were thinned to 10 plants per pot. Separate pots (treatments) were maintained for the three growth stages i.e. 30, 60, and 90 days after emergence (DAE). All the 10 plants were uprooted from each pot at 30, 60, and 90 DAE and the data was recorded as the average of five plants. The roots were washed with tap water and the plants were dried on paper bags and kept in oven at 80ºC for about 20 hours. The samples were weighed by electronic balance (Sartorius Basic, BA2105) and the average dry weight of root, leaf, and stem per plant was determined. Shoot dry weight per plant was obtained by adding leaf and stem dry weight per plant. The sum of the shoot and root dry weight was taken as the total dry weight per plant. Shoot dry weight was divided by root dry weight to get data on shoot-root ratio. Absolute growth rate (AGR), defined as dry matter accumulation per plant per unit time; crop growth rate (CGR), defined as dry matter accumulation per unit ground area per unit time; and net assimilation rate (NAR), defined as dry matter accumulation per unit leaf area per unit time, were determined using the following formulae:

\[ AGR = \frac{W_2 - W_1}{t_2 - t_1} \]  \hspace{1cm} (mg plant⁻¹ day⁻¹) \hspace{1cm} (1)

\[ CGR = \frac{W_2 - W_1}{GA(t_2 - t_1)} \]  \hspace{1cm} (g m⁻² day⁻¹) \hspace{1cm} (2)

\[ NAR = \frac{CGR}{LAI} \]  \hspace{1cm} (3)

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; \( GA \) = Ground area occupied by the plant at each sampling, and \( LAI \) = Leaf area index.

Water use efficiency was measured using the following formula:

\[ \text{Water use efficiency} = \frac{\text{Total dry matter produced}}{\text{Liters of water used}} \]  \hspace{1cm} (g Lit⁻¹) \hspace{1cm} (4)

Canopy temperature was measured with the help of infra red thermometer and carbon exchange rate (CER) was measured with the help of leaf porometer at 90 DAE.

**Statistical Analysis**

Data were subjected to analysis of variance (ANOVA) according to the methods described in Steel and Torrie (1980) and treatment means were compared using the least significant difference (LSD) at \( P \leq 0.05 \) using MSTAT-C software.

**RESULTS AND DISCUSSION**

**Shoot-root Ratio (By Weight)**

The relationship between root growth and whole plant growth is called allometry or relative growth (Fagaria et al., 2006). Shoot (S): root(R) ratio varied significantly (\( P \leq 0.05 \)) among different treatments at 60 and 90 DAE, but the differences were not significant at 30 DAE (Table 1). However, at 30 DAE, S:R ratio varied from minimum (1.2) with 100 mg N+100 mg P kg⁻¹ (T3) to maximum (2.1) with 0 mg N+200 mg P kg⁻¹ (T1). At 60 DAE, oats had higher S:R ratio in T3 (6.7), followed by T4 (3.5), and the lowest S:R ratio (2.0) was recorded for 200 mg N+00 mg P kg⁻¹ (T2). At 90 DAE, oats had the highest S:R ratio in T1 (6.2) being statistically the same with T2 (4.7) and T3 (4.6), and the lowest S:R ratio (2.1) was
Table 1. Shoot dry weight (mg plant\(^{-1}\)), root dry weight (mg plant\(^{-1}\)), and shoot:root ratio of oat in response to N and P treatments.

<table>
<thead>
<tr>
<th>Treatments(\text{a})</th>
<th>Shoot dry weight plant(^{-1})</th>
<th>Roots dry weight plant(^{-1})</th>
<th>Shoot: Root ratio by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 DAE</td>
<td>60 DAE</td>
<td>90 DAE</td>
</tr>
<tr>
<td>(\text{T}_1 = N_0 P_0)</td>
<td>27.1</td>
<td>160.2</td>
<td>336.7</td>
</tr>
<tr>
<td>(\text{T}_2 = N_0 P_0)</td>
<td>14.2</td>
<td>40.5</td>
<td>378.1</td>
</tr>
<tr>
<td>(\text{T}_3 = N_1 P_1)</td>
<td>30.8</td>
<td>352.6</td>
<td>954.8</td>
</tr>
<tr>
<td>(\text{T}_4 = N_2 P_2)</td>
<td>16.8</td>
<td>230.9</td>
<td>1702.1</td>
</tr>
<tr>
<td>LSD(_{0.05})</td>
<td>6.1</td>
<td>113.0</td>
<td>560.8</td>
</tr>
</tbody>
</table>

\(\text{a} \ N_0 = \text{N not applied}, P_0 = \text{P not applied}; N_1 = 200 \text{ mg N kg}\(^{-1}\), P_1 = 200 \text{ mg P kg}\(^{-1}\); N_2 = 100 \text{ mg N kg}\(^{-1}\), P_2 = 100 \text{ mg P kg}\(^{-1}\); \(b\) Days after emergence. 

Not significant.

Nitrogen deficiency plants often have a low S:R ratio, and they mature more quickly than healthy plants (Braddy and Weil, 2002). Fagaria (1992) reported increase in S:R ratios of common bean, rice, wheat, and cowpea as plants advanced in age. Shoot:root ratio increased from minimum at 30 DAE to maximum at 60 DAE in control or when P was applied alone, and then decreased at later growth stage (90 DAE). Evans and Wardlaw (1976) and Emam and Shekoofa (2009) also reported that dry matter partitioning in roots is higher during the seedling stages of crop growth and steadily declines throughout development. In hydroponic, pot and field experiments with wheat and other cereals, increasing N supply enhanced both shoot and root growth, but usually shoot growth more than root growth, leading to increased S:R dry weight ratio with increase in N supply (Robinson et al., 1994; Marschner, 1995; Lucas et al., 2000).

Dry Matter Partitioning

Shoot dry weight (SHDW) varied significantly (P\(\leq 0.05\)) among different treatments at 30, 60, and 90 DAE (Table 1). At 30 DAE, SHDW reached the maximum (30.8 mg plant\(^{-1}\)) in \(\text{T}_1\), being statistically the same as \(\text{T}_1\) (27.1 mg plant\(^{-1}\)), and the lowest SHDW (14.2 mg plant\(^{-1}\)) was noted in \(\text{T}_2\) (excess of N). The lowest SHDW at \(\text{T}_2\) was attributed to the toxic effects of N at the early growth stage and the growth of young seedlings was affected adversely. At 60 DAE, SHDW reached maximum (352.6 mg plant\(^{-1}\)) in \(\text{T}_3\), followed by \(\text{T}_4\) (230.9 mg plant\(^{-1}\)), and the lowest SHDW (40.5 mg plant\(^{-1}\)) was noted in \(\text{T}_2\). At 90 DAE, oats had the higher SHDW in \(\text{T}_3\) (1702.1 mg plant\(^{-1}\)), followed by \(\text{T}_1\) (954.8 mg plant\(^{-1}\)), and the lowest SHDW (336.7 mg plant\(^{-1}\)) was noted for \(\text{T}_1\). Root development varies with stages of plant growth and development (Fagaria et al., 2006). However, the increase in weight was more in \(\text{T}_3\) and \(\text{T}_4\) as compared with \(\text{T}_1\) and \(\text{T}_2\). The increase in the last 30 days was more than the first 60 days. Excess P had positive while excess N had negative impacts on oats shoot dry weight as compared with control. Costa et al. (2002) reported that the mineral nutrients P and N exerted pronounced influences on assimilates production and dry matter partitioning between shoots and roots. Phosphorus and N deficient plants usually have more dry matter partitioning to roots than shoots, probably as a result of higher export rates of assimilates to roots (Fagaria et al., 2006).

Root dry weight (RDW) varied significantly (P\(\leq 0.05\)) among different treatments at 90 DAE, but the differences were not significant at 30 and 60 DAE (Table 1). At 90 DAE, oats had higher RDW in \(\text{T}_4\) (271.8 mg plant\(^{-1}\)), followed by \(\text{T}_3\) (219.0 mg plant\(^{-1}\)), and the lowest RDW
(87.8 mg plant\(^{-1}\)) was noted for T\(_2\). Root dry weight increased with passage of time in all treatments. However, the increase in weight was more in T\(_4\) and T\(_6\) as compared with T\(_1\) and T\(_2\). Reduction in RDW for T\(_2\) was attributed to the toxic effects of N and the root dry matter accumulation in oats was negatively affected. Baligar et al. (1998) reported that relative dry weights of roots due to absence of N in rice, common bean, maize, and soybean was, respectively, 62\%, 44\%, 65\%, and 89 percent less than that of treatments where N, P, and K nutrients were adequate. The increase in root weight in the last 30 days was more than the first 60 days. Excess P had positive and excess N had negative impacts on the leaf dry weight of oats, particularly at the lowest LDW (22.9 mg plant\(^{-1}\)). At 60 DAE, LDW reached maximum (265.9 mg plant\(^{-1}\)) in T\(_3\), followed by T\(_1\) (19.5 mg plant\(^{-1}\)), and the lowest LDW (10.0 mg plant\(^{-1}\)) was noted in T\(_2\). At 90 DAE, oats had the higher LDW in T\(_2\) (875.1 mg plant\(^{-1}\)), followed by T\(_3\) (581.4 mg plant\(^{-1}\)), and the lowest LDW (22.9 mg plant\(^{-1}\)) was noted in T\(_2\). At 90 DAE, oats had the higher LDW in T\(_2\) (875.1 mg plant\(^{-1}\)), followed by T\(_3\) (581.4 mg plant\(^{-1}\)), and the lowest LDW (197.1 mg plant\(^{-1}\)) was noted for T\(_2\). Excessive N applications had greater negative impacts on the leaf dry weight of oats, particularly at the lowest LDW (22.9 mg plant\(^{-1}\)).

Table 2. Leaf dry weight, stem dry weight, and total plant dry weight of oat in response to N and P treatments.

<table>
<thead>
<tr>
<th>Treatments(^a)</th>
<th>Leaf dry weight, mg plant(^{-1})</th>
<th>Stem dry weight, mg plant(^{-1})</th>
<th>Total dry weight, mg plant(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 DAE</td>
<td>60 DAE</td>
<td>90 DAE</td>
</tr>
<tr>
<td>T(_1) = N(_0) P(_0)</td>
<td>19.5</td>
<td>122.2</td>
<td>210.1</td>
</tr>
<tr>
<td>T(_2) = N(_0) P(_1)</td>
<td>10.0</td>
<td>22.9</td>
<td>197.1</td>
</tr>
<tr>
<td>T(_3) = N(_1) P(_0)</td>
<td>24.8</td>
<td>265.9</td>
<td>581.4</td>
</tr>
<tr>
<td>T(_4) = N(_1) P(_1)</td>
<td>12.0</td>
<td>173.7</td>
<td>875.1</td>
</tr>
<tr>
<td>LSD(_{0.05})</td>
<td>4.9</td>
<td>91.5</td>
<td>402.7</td>
</tr>
</tbody>
</table>

\(^a\) N\(_0\) = N not applied, P\(_0\) = P not applied; N\(_1\) = 200 mg N kg\(^{-1}\); P\(_1\) = 200 mg P kg\(^{-1}\); N\(_2\) = 100 mg N kg\(^{-1}\), P\(_2\) = 100 mg P kg\(^{-1}\), \(^b\) Days after emergence.
two early growth stages (30 and 60 DAE), than at the later growth stage (90 DAE). At the early growth stages (30 and 60 DAE), combined applications of N and P (T₄) also had inhibiting effect on leaf dry weight as compared with excessive applications of P when applied alone (T₃). Combined applications of N and P had relatively higher leaf dry weight than the control at 60 DAE, but the differences were not significant. However, at 90 DAE, the combined applications of N+P had more favorable effects on leaf dry weight as compared with excessive N and P applied alone. The study indicated that application of 200 mg N kg⁻¹ alone had negative effects while combined application of 100 mg N+100 mg P kg⁻¹ of soil had favorable impact on the leaf growth of oats.

Stem dry weight (STDW) varied significantly (P< 0.05) among different treatments at 30, 60, and 90 DAE (Table 2). At 30 DAE, STDW reached maximum (7.6 mg plant⁻¹) in T₁ being statistically the same as T₃ (6.0 mg plant⁻¹), and the lowest STDW (4.2 mg plant⁻¹) was noted in T₂. At 60 DAE, STDW reached maximum (86.7 mg plant⁻¹) in T₃, followed by T₄ (57.2 mg plant⁻¹), and the lowest STDW (17.5 mg plant⁻¹) was noted in T₂. At 90 DAE, oats had the higher STDW in T₄ (827.0 mg plant⁻¹), followed by T₃ (373.3 mg plant⁻¹), and the lowest STDW (126.6 mg plant⁻¹) was noted for T₁. Excessive N applications had very negative effects on the STDW of oats at the two early growth stages (30 and 60 DAE). At the later growth stage (90 DAE), excessive N applications had higher STDW than the control. At the early growth stages (30 and 60 DAE), combined applications of N and P (T₄) also had inhibiting effect on STDW as compared with excessive applications of P when applied alone (T₃). Combined applications of N and P had relatively higher stem dry weight than the control at 60 DAE, but the differences were not significant. However, at 90 DAE, the combined applications of N+P had more favorable effects on STDW as compared with all other three treatments. Excessive P applications alone had positive impacts on STDW than control and excessive N applied alone.

Total dry weight plant⁻¹ (TDWP) varied significantly (P≤ 0.05) among different treatments at 30, 60, and 90 DAE (Table 2). At 30 DAE, TDWP reached maximum (45.8 mg plant⁻¹) in T₃, being statistically the same as T₁ (42.7 mg plant⁻¹), and the lowest TDWP (24.7 mg plant⁻¹) was noted in T₂. At 60 DAE, TDWP reached maximum (414.5 mg plant⁻¹) in T₃, followed by T₄ (297.5 mg plant⁻¹), and the lowest TDWP (62.6 mg plant⁻¹) was noted in T₂. At 90 DAE, oats had the higher TDWP in T₄ (1,973.9 mg plant⁻¹), followed by T₃ (1,173.8 mg plant⁻¹), and the lowest TDWP (465.9 mg plant⁻¹) was noted in T₂. Excessive N applications had very negative effects on the total (shoot+root) dry weight per plant of oats at the two early growth stages (30 and 60 DAE). At the later growth stage (90 DAE); excessive N applications had almost the same TDWP as compared with the control. High N applications may delay plant maturity and cause the plants to be more susceptible to diseases and insect pests. These problems are especially noticeable if the other nutrients, such as P and potassium, are in relatively low supply (Braddy and Weil, 2002). Plaster (2009) reported that plants with too much N did not grow properly. High tissue N contents cause a very succulent growth, that is, growth that is high in water content but low in dry matter and, therefore, the plants are very weak. Leaves high in N also respire -use up the food produced by photosynthesis- more rapidly. Ayed and Mashhady (1984) reported that urea application greater than 83 mg N kg⁻¹ in one experiment and 130 mg N kg⁻¹ in another experiment caused severe toxicity to the Proso grass seedlings. At the early growth stages (30 and 60 DAE), excessive P applications alone (T₃) had higher TDWP as compared with other treatments. Combined applications of N+P had higher TDWP than excessive P applications alone at the later growth stage (90 DAE). Plaster (2009) reported that in many ways, P acts to balance N. While N
Oats Response to Excess N and P

Growth Analysis (AGR, CGR, and NAR)

Absolute growth rate (AGR) varied significantly (P≤ 0.05) among different treatments at 30, 60 and 90 DAE (Table 3). At 30 DAE, AGR reached maximum (1.88 mg plant⁻¹ day⁻¹) in T₃ being statistically the same with T₁ (1.67 mg plant⁻¹ day⁻¹), and the lowest AGR (1.00 mg plant⁻¹ day⁻¹) was noted in T₂. At 60 DAE, AGR reached maximum (12.29 mg plant⁻¹ day⁻¹) in T₃, followed by T₄ (8.84 mg plant⁻¹ day⁻¹), and the lowest AGR (1.26 mg plant⁻¹ day⁻¹) was noted in T₃. At 90 DAE, oats had the higher AGR in T₄ (55.88 mg plant⁻¹ day⁻¹), followed by T₃ (25.31 mg plant⁻¹ day⁻¹), and the lowest AGR (9.56 mg plant⁻¹ day⁻¹) was noted for T₁. The higher N applications alone had negative effects on the AGR at the two early growth stages (30 and 60 DAE). At the later growth stage (90 DAE), excessive N applications had more AGR than control but the differences were statistically not significant. Nitrogen is the most important nutrient required for growth, development, and achievement of higher yield (Fagaria et al., 2006). The decline in AGR at 30 and 60 DAE with excessive N application showed positive relationship with shoot (leaf+stem) and root dry weight per plant. At 90 DAE, the relatively higher AGR with higher N applications than the control was mainly attributed to the lesser total dry weight per plant produced at 60 DAE with higher N applications than control. At the early growth stages (30 and 60 DAE), excessive P applications alone (T₃) had higher AGR probably due to the higher total plant dry weight as compared with the other treatments. However, at later growth stage, combined applications of N+P had higher AGR than excessive P applications because of higher total dry matter accumulation (1,973.9 mg plant⁻¹ day⁻¹). The excessive P application alone had more favorable effects on AGR than the control and excessive N applications.

Crop growth rate (CGR) varied significantly (P≤ 0.05) among different treatments at 30, 60 and 90 DAE. At 30 DAE, CGR reached maximum (0.84 g m⁻² day⁻¹) in T₃ being statistically the same as T₁ (0.75 g m⁻² day⁻¹), and the lowest CGR (0.45 g m⁻² day⁻¹) was noted in case of T₂. At 60

Table 3. Absolute growth rate, crop growth rate, and net assimilation rate of oat in response to N and P treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Absolute growth rate (mg plant⁻¹ day⁻¹)</th>
<th>Crop growth rate (g m⁻² day⁻¹)</th>
<th>Net assimilation rate (g m⁻³ day⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 DAE</td>
<td>60 DAE</td>
<td>90 DAE</td>
</tr>
<tr>
<td>T₁=N₀P₀</td>
<td>1.67</td>
<td>5.62</td>
<td>9.56</td>
</tr>
<tr>
<td>T₂=N₁P₀</td>
<td>1.00</td>
<td>1.26</td>
<td>13.44</td>
</tr>
<tr>
<td>T₃=N₀P₁</td>
<td>1.88</td>
<td>12.29</td>
<td>25.31</td>
</tr>
<tr>
<td>T₄=N₂P₂</td>
<td>1.27</td>
<td>8.84</td>
<td>55.88</td>
</tr>
<tr>
<td>LSD₀.₀₅</td>
<td>0.36</td>
<td>4.61</td>
<td>19.83</td>
</tr>
</tbody>
</table>

a N₀= N not applied, P₀ = P not applied; N₁= 200 mg N kg⁻¹, P₁= 200 mg P kg⁻¹; N₂= 100 mg N kg⁻¹, P₂= 100 mg P kg⁻¹; b Days after emergence, * Not significant.

delays maturity, P hastens it. Nitrogen aids vegetative growth; P aids blooming and fruiting. Nitrogen and P must both be sufficient for both vegetative and reproductive growth, and supplying more P than necessary does not stimulate more bloom. However, at 90 DAE, the excessive P application alone had more favorable effects on TDWP than the control and excessive N applications alone. Jian-ling et al. (2007) reported that P applied from fertilizer and manure was important in increasing crop yield and soil fertility; however, excessive uses of phosphate fertilizer and manure may also increase P loss from agricultural soils, posing environmental impact.
DAE, \(g R\) reached maximum \((3.46 \, \text{g m}^{-2} \, \text{day}^{-1})\) in \(T_3\), followed by \(T_4\) \((2.49 \, \text{g m}^{-2} \, \text{day}^{-1})\), and the lowest \(g R\) \((0.26 \, \text{g m}^{-2} \, \text{day}^{-1})\) was noted in \(T_2\). At 90 DAE, oats had the higher \(g R\) in \(T_4\) \((6.89 \, \text{g m}^{-2} \, \text{day}^{-1})\), followed by \(T_3\) \((1.72 \, \text{g m}^{-2} \, \text{day}^{-1})\) being statistically the same as \(T_2\) \((1.70 \, \text{g m}^{-2} \, \text{day}^{-1})\), and the lowest \(g R\) \((0.38 \, \text{g m}^{-2} \, \text{day}^{-1})\) was noted in \(T_1\). The higher N applications alone, compared to the other treatments, had negative effects on the \(g R\) at the two early growth stages (30 and 60 DAE). The reduction in \(g R\) at these two stages with excessive N applications was due to the lowest total dry weight per plant produced by oat plants. At the later growth stage (90 DAE), excessive N applications had higher \(g R\) than the control, but almost equal \(g R\) was obtained when compared with excessive P applications. The increase in \(g R\) at 90 DAE with excessive N applications was attributed to the lesser total dry weight per plant produced by oat plants at 60 DAE. Slow growth and stunting are the most obvious signs of N shortage (Plaster, 2009). At the early growth stages (30 and 60 DAE), excessive P applications alone \((T_3)\) had higher \(g R\) because of the higher total plant dry weight as compared with other treatments. At later growth stage, combined applications of N+P had higher \(g R\) than excessive P applications because of higher total dry matter accumulation. Excessive P application probably reduced the plant’s ability to take up the required micronutrients, particularly iron and zinc, which resulted in lower \(A R\) and \(g R\) than combined N+P applications (Plaster, 2009; Provin and Pitt, 2010). Therefore, plants grown under excessive P conditions need additional iron and zinc applications. Shallow-rooted and perennial plants frequently have iron and zinc deficiencies caused by excessive P. However, simply adding of Zn and Fe will not work. Foliar Zn and Fe applications, however, work well (Provin and Pitt, 2010).

Net assimilation rate (\(NAR\)) is the ratio of \(g R\) to LAI, and varied significantly \((P \leq 0.05)\) among different treatments at 30 and 90 DAE, and the differences at 60 DAE were not significant. At 30 DAE, \(NAR\) reached maximum \((100.01 \, \text{g m}^{-2} \, \text{day}^{-1})\) in \(T_3\), followed by \(T_1\) \((54.92 \, \text{g m}^{-2} \, \text{day}^{-1})\), and the lowest \(NAR\) \((33.19 \, \text{g m}^{-2} \, \text{day}^{-1})\) was noted in \(T_1\). At 90 DAE, oats had the higher \(NAR\) in \(T_2\) \((8.61 \, \text{g m}^{-2} \, \text{day}^{-1})\), followed by \(T_1\) \((2.14 \, \text{g m}^{-2} \, \text{day}^{-1})\), and the lowest \(NAR\) \((0.45 \, \text{g m}^{-2} \, \text{day}^{-1})\) was noted for \(T_1\). The \(NAR\) was reduced with advancement in oat plants age. The higher N applications alone, compared with the other treatments, had positive effects on \(NAR\) at 30 and 90 DAE. The increase in \(NAR\) at these two stages with excessive N applications was due to the lowest LAI (data not shown) produced by oat plants. The relationship of \(NAR\) was positive with \(g R\) and negative with LAI.

**Water Use Efficiency, Leaf Temperature and Carbon Exchange Rate**

Water use efficiency (WUE) varied significantly \((P \leq 0.05)\) among different treatments at 60 and 90 DAE, but the differences were not significant at 30 DAE (Table4). At 60 DAE, WUE reached maximum \((0.50 \, \text{g L}^{-1})\) in case of \(T_3\), being close to \(T_4\) \((0.43 \, \text{g L}^{-1})\), and the lowest WUE \((0.09 \, \text{g L}^{-1})\) was noted in case of \(T_2\). At 90 DAE, oats had the higher WUE in case of \(T_4\) \((0.89 \, \text{g L}^{-1})\), followed by \(T_3\) \((0.46 \, \text{g L}^{-1})\), and the lowest WUE \((0.23 \, \text{g L}^{-1})\) was noted for \(T_1\), being close to \(T_2\) \((0.25 \, \text{g L}^{-1})\). The excessive N application alone had negative impacts on the WUE at 60 and 90 DAE. The increase and decrease in WUE under different treatments showed positive relationship with increase in crop growth rate. Leaf temperature at 90 DAE varied significantly \((P \leq 0.05)\) among different treatments at 5.00 PM only, but the differences were not significant at 9.00 am and 1.00 PM. At 5.00 PM, the temperature reached maximum \((30.3^\circ \text{C})\) in case of \(T_4\), followed by \(T_3\) \((29.3^\circ \text{C})\), and the lowest leaf temperature \((28.4^\circ \text{C})\) was noted in case of \(T_2\). The differences in the carbon exchange rate (CER) recorded at different timings at
Table 4. Water use efficiency, leaf temperature, and carbon exchange rate of oat in response to N and P treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Water use efficiency (g L⁻¹)</th>
<th>Leaf temperature (°C)</th>
<th>Carbon exchange rate (mmol m⁻² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 DAE</td>
<td>60 DAE</td>
<td>90 DAE</td>
</tr>
<tr>
<td>T₁ = N₀ P₀</td>
<td>0.13</td>
<td>0.26</td>
<td>0.23</td>
</tr>
<tr>
<td>T₂ = N₁ P₀</td>
<td>0.11</td>
<td>0.09</td>
<td>0.25</td>
</tr>
<tr>
<td>T₃ = P₀ P₁</td>
<td>0.18</td>
<td>0.50</td>
<td>0.46</td>
</tr>
<tr>
<td>T₄ = N₂ P₂</td>
<td>0.12</td>
<td>0.43</td>
<td>0.89</td>
</tr>
</tbody>
</table>

LSD₀.₀₅ | ns | 0.19 | 0.29 | ns | ns | 0.80 | ns | ns | ns |

₃N₀ = N not applied, P₀ = P not applied; N₁ = 200 mg N kg⁻¹, P₁ = 200 mg P kg⁻¹; N₂ = 100 mg N kg⁻¹, P₂ = 100 mg P kg⁻¹. Days after emergence, ' Not significant.

90 DAE were not significant (P ≤ 0.05) among different treatments. However, there were huge differences among the treatments at each time. It ranged between 39.2 to 122.7, 51.3 to 116.8, and 20.1 to 82.5 mmol m⁻² s⁻¹ at 9.0 AM, 1.0 and 5.0 PM, respectively.

CONCLUSIONS

Excessive N applications had negative effects on leaf, stem, and root and, consequently, on total dry weight per plant of oat. The reduction in total plant dry weight per plant with excessive N applications decreased crop growth rate. Excessive P applications had no negative effects on leaf, stem, root, and total plant dry weight. Rather, excessive P applications had more favorable effects on leaf, stem, root, and total dry weight per plant at early growth stage. At later growth stages, combined N and P application had more beneficial impact on leaf, stem, root, and, consequently, total dry weight per plant. The increase in total dry matter accumulation per plant showed positive relationship with AGR, CGR and NAR. The NAR showed negative relationship with increase in LAI, and positive relationship with increase in CGR. Application of P alone or in combination with N had positive impacts on water use efficiency of oats at the two later growth stages (60 and 90 DAE).

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REFERENCES

Amanullah and Stewart


واکنش یولاف (Avena sativa L.)، cv. Walker، به مصرف زیاد نیتروژن (N) و فسفر (P) شامل مقدار 100 mg N + 100 mg P kg⁻¹ (N₀P₀) و مصرف نمایشگری یولاف (Na₀P₀) در سه روز بعد از بذری اجرای تکرار اجرا شد. یک هفته بعد از سبزی شدن، ۱۵ بونه در هر گلدان نگهداری شد. مسیر، در فاصله ۳۰، ۶۰ و ۹۰ روز بعد از سبزی شدن ۵ بونه از گلدان هر گلدان خارج شد. حجم هر گلدان ۲۸۳ سانتی متر مکعب و حاوی ۱۰۰۰ گرم خاک مخلوط (خاک آلفا) بود. نیتروژن زیاد روي رشد برگ، ساقه و ریشه و در نتیجه روی وزن خشک کل یولاف اثر مثبتی داشت. کاهش وزن خشک کل یولاف در اثر مصرف زیاد نیتروژن منجر به کم شدن رشد یولاف گردید. اما، مصرف زیاد فسفر هیچگونه اثر مثبتی روی رشد برگ و ساقه و ریشه و وزن خشک کل یولاف نداشت. در واقع، اثر مصرف زیاد فسفر در مراحل اولیه رشد روی پارامترهای زیست‌پزشکی بود. در مراحل بعدی رشد، مصرف توم نیتروژن و فسفر اثرات مثبتی روی رشد برگ، ساقه، ریشه و کل ماده خشک نشان داد. رابطه افزایش ماده خشک کل در هر بونه با سرعت رشد NAR، سرعت رشد گیاه (AGR)، مطلوک (CGR) و سرعت خاص جذب سنگین (MGR) بود. رابطه سرعت خاص جذب و ساخت با افزایش شاخص مساحت برگ منفی بود ولی با افزایش سرعت رشد گیاهی رابطه ای مثبت داشت. کار آبی مصرف آب با کار برد فسفر افزایش یافت و رابطه ای منفی با افزایش سرعت رشد یولاف نشان داد.