

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

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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 (N₁P₀), excessive phosphorus as 200 mg P kg⁻¹ (N₀P₁), and combined 100 mg N+100 mg P kg⁻¹ (N₂P₂), and the control (N₀P₀) 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 of Zn and Fe 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: T₁= Control (N₀P₀), T₂= 200 mg N kg⁻¹ (N₁P₀), T₃= 200 mg P kg⁻¹ (N₀P₁), and T₄= 100 mg N+100 mg P kg⁻¹ (N₂P₂). 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 (N₀ indicates no N was applied and P₀ 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

**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.

Treatments ^a	Shoot dry weight plant ⁻¹			Roots dry weight plant ⁻¹			Shoot: Root ratio by weight		
	30 DAE ^b	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
T ₁ = N ₀ P ₀	27.1	160.2	336.7	15.6	51.0	161.3	1.8	3.2	2.1
T ₂ = N ₁ P ₀	14.2	40.5	378.1	10.5	22.1	87.8	1.3	2.0	4.7
T ₃ = N ₀ P ₁	30.8	352.6	954.8	15.0	61.9	219.0	2.1	6.7	4.6
T ₄ = N ₂ P ₂	16.8	230.9	1702.1	15.4	66.5	271.8	1.2	3.5	6.2
LSD _{0.05}	6.1	113.0	560.8	ns ^c	ns	107.7	ns	3.1	2.3

^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, ^c Not significant.

noted with 00 mg N+00 mg P kg⁻¹ (T₁) i.e. control. Nitrogen applied alone (T₂) or mixed with P (T₄) increased S:R ratio in oats. Nitrogen deficient plants often have a low S:R ratio, and they mature more quickly than healthy plans (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 T₃, being statistically the same as T₁ (27.1 mg plant⁻¹), and the lowest SHDW (14.2 mg plant⁻¹) was noted in T₂

(excess of N). The lowest SHDW at T₂ 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 T₃, followed by T₄ (230.9 mg plant⁻¹), and the lowest SHDW (40.5 mg plant⁻¹) was noted in T₂. At 90 DAE, oats had the higher SHDW in T₄ (1702.1 mg plant⁻¹), followed by T₃ (954.8 mg plant⁻¹), and the lowest SHDW (336.7 mg plant⁻¹) was noted for T₁. Root development varies with stages of plant growth and development (Fagaria *et al.*, 2006). However, the increase in weight was more in T₃ and T₄ as compared with T₁ and T₂. 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 assimilate 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 T₄ (271.8 mg plant⁻¹), followed by T₃ (219.0 mg plant⁻¹), and the lowest RDW

(87.8 mg plant⁻¹) was noted for T₂. Root dry weight increased with passage of time in all treatments. However, the increase in weight was more in T₃ and T₄ as compared with T₁ and T₂. Reduction in RDW for T₂ 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 oats root dry weight as compared with control. At high N rates inhibition of root mass and/or length was observed (Welbank *et al.*, 1974; Feil and Geisler, 1988). 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. Fagaria *et al.* (1997) reported maximum root dry weight for wheat 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. These results indicated that increasing P levels increased root growth, but root growth was reduced at higher P levels, and crop species had different P requirements to achieve maximum growth

potentials. Overall, root growth of cereals and legumes crops was reduced if P was deficient. Troughton (1962) reported that both root and shoot varied similarly as P level increased and, above certain levels, further increase in P supply did not affect root or shoot growth. Because P is needed for root growth, it is often a major element in starter fertilizers. However, there is no evidence that amounts of P greater than 'adequate' encourage heavier rooting. In fact, at low P levels, plants tend to favor roots over shoots to improve uptake, and in green house production of bedding plants, At low P levels, plants tends to favor roots growth over shoots, thus root system improve under low P rates. Many greenhouse growers, in fact, grow crops under low P regimes, because high P levels cause greenhouse plants to stretch undesirably (Plaster, 2009).

Leaf dry weight (LDW) varied significantly ($P \leq 0.05$) among different treatments at 30, 60, and 90 DAE (Table 2). At 30 DAE, LDW reached maximum (24.8 mg plant⁻¹) in T₃, followed by T₁ (19.5 mg plant⁻¹), and the lowest LDW (10.0 mg plant⁻¹) was noted in T₂. At 60 DAE, LDW reached maximum (265.9 mg plant⁻¹) in T₃, followed by T₄ (173.7 mg plant⁻¹), and the lowest LDW (22.9 mg plant⁻¹) was noted in T₂. At 90 DAE, oats had the higher LDW in T₄ (875.1 mg plant⁻¹), followed by T₃ (581.4 mg plant⁻¹), and the lowest LDW (197.1 mg plant⁻¹) was noted for T₂. Excessive N applications had greater negative impacts on the leaf dry weight of oats, particularly at the

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

Treatments ^a	Leaf dry weight, mg plant ⁻¹			Stem dry weight, mg plant ⁻¹			Total dry weight, mg plant ⁻¹		
	30 DAE ^b	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
T ₁ = N ₀ P ₀	19.5	122.2	210.1	7.6	38.0	126.6	42.7	211.2	498.0
T ₂ = N ₁ P ₀	10.0	22.9	197.1	4.2	17.5	181.0	24.7	62.6	465.9
T ₃ = N ₀ P ₁	24.8	265.9	581.4	6.0	86.7	373.3	45.8	414.5	1173.8
T ₄ = N ₂ P ₂	12.0	173.7	875.1	4.7	57.2	827.0	32.2	297.5	1973.9
LSD _{0.05}	4.9	91.5	402.7	1.8	27.7	288.5	8.6	142.2	642.8

^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.



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 (T_4) also had inhibiting effect on leaf dry weight as compared with excessive applications of P when applied alone (T_3). 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 ($P \leq 0.05$) among different treatments at 30, 60, and 90 DAE (Table 2). At 30 DAE, STDW reached maximum (7.6 mg $plant^{-1}$) in T_1 being statistically the same as T_3 (6.0 mg $plant^{-1}$), and the lowest STDW (4.2 mg $plant^{-1}$) was noted in T_2 . At 60 DAE, STDW reached maximum (86.7 mg $plant^{-1}$) in T_3 , followed by T_4 (57.2 mg $plant^{-1}$), and the lowest STDW (17.5 mg $plant^{-1}$) was noted in T_2 . At 90 DAE, oats had the higher STDW in T_4 (827.0 mg $plant^{-1}$), followed by T_3 (373.3 mg $plant^{-1}$), and the lowest STDW (126.6 mg $plant^{-1}$) was noted for T_1 . 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 (T_4) also had inhibiting effect on STDW as compared with excessive applications of P when applied alone (T_3). 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 ($P \leq 0.05$) among different treatments at 30, 60, and 90 DAE (Table 2). At 30 DAE, TDWP reached maximum (45.8 mg $plant^{-1}$) in T_3 , being statistically the same as T_1 (42.7 mg $plant^{-1}$), and the lowest TDWP (24.7 mg $plant^{-1}$) was noted in T_2 . At 60 DAE, TDWP reached maximum (414.5 mg $plant^{-1}$) in T_3 , followed by T_4 (297.5 mg $plant^{-1}$), and the lowest TDWP (62.6 mg $plant^{-1}$) was noted in T_2 . At 90 DAE, oats had the higher TDWP in T_4 (1,973.9 mg $plant^{-1}$), followed by T_3 (1,173.8 mg $plant^{-1}$), and the lowest TDWP (465.9 mg $plant^{-1}$) was noted in T_2 . 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 (T_3) 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

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.

Growth Analysis (AGR, CGR, and NAR)

Absolute growth rate (AGR) varied significantly ($P \leq 0.05$) among different treatments at 30, 60 and 90 DAE (Table 3). At 30 DAE, AGR reached maximum ($1.88 \text{ mg plant}^{-1} \text{ day}^{-1}$) in T₃ being statistically the same with T₁ ($1.67 \text{ mg plant}^{-1} \text{ day}^{-1}$), and the lowest AGR ($1.00 \text{ mg plant}^{-1} \text{ day}^{-1}$) was noted in T₂. At 60 DAE, AGR reached maximum ($12.29 \text{ mg plant}^{-1} \text{ day}^{-1}$) in T₃, followed by T₄ ($8.84 \text{ mg plant}^{-1} \text{ day}^{-1}$), and the lowest AGR ($1.26 \text{ mg plant}^{-1} \text{ day}^{-1}$) was noted in T₂. At 90 DAE, oats had the higher AGR in T₄ ($55.88 \text{ mg plant}^{-1} \text{ day}^{-1}$), followed by T₃ ($25.31 \text{ mg plant}^{-1} \text{ day}^{-1}$), and the lowest AGR ($9.56 \text{ mg plant}^{-1} \text{ day}^{-1}$) 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 ($1,973.9 \text{ mg plant}^{-1} \text{ day}^{-1}$). The excessive P application alone had more favorable effects on AGR than the control and excessive N applications.

Crop growth rate (CGR) varied significantly ($P \leq 0.05$) among different treatments at 30, 60 and 90 DAE. At 30 DAE, CGR reached maximum ($0.84 \text{ g m}^{-2} \text{ day}^{-1}$) in T₃ being statistically the same as T₁ ($0.75 \text{ g m}^{-2} \text{ day}^{-1}$), and the lowest CGR ($0.45 \text{ g m}^{-2} \text{ day}^{-1}$) 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.

Treatments ^a	Absolute growth rate ($\text{mg plant}^{-1} \text{ day}^{-1}$)			Crop growth rate ($\text{g m}^{-2} \text{ day}^{-1}$)			Net assimilation rate ($\text{g m}^{-2} \text{ day}^{-1}$)		
	30 DAE ^b	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
T ₁ = N ₀ P ₀	1.67	5.62	9.56	0.75	1.47	0.38	33.19	9.44	0.45
T ₂ = N ₁ P ₀	1.00	1.26	13.44	0.45	0.26	1.70	100.0	6.79	8.61
T ₃ = N ₀ P ₁	1.88	12.29	25.31	0.84	3.46	1.72	54.92	8.25	0.85
T ₄ = N ₂ P ₂	1.27	8.84	55.88	0.57	2.49	6.89	38.09	3.91	2.14
LSD _{0.05}	0.36	4.61	19.83	0.16	1.37	2.89	34.42	ns ^c	4.70

^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, ^c Not significant.



DAE, *CGR* 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 *CGR* ($0.26 \text{ g m}^{-2} \text{ day}^{-1}$) was noted in T_2 . At 90 DAE, oats had the higher *CGR* 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 *CGR* ($0.38 \text{ g m}^{-2} \text{ day}^{-1}$) was noted in T_1 . The higher N applications alone, compared to the other treatments, had negative effects on the *CGR* at the two early growth stages (30 and 60 DAE). The reduction in *CGR* 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 *CGR* than the control, but almost equal *CGR* was obtained when compared with excessive P applications. The increase in *CGR* 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 *CGR* because of the higher total plant dry weight as compared with other treatments. At later growth stage, combined applications of N+P had higher *CGR* 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 *AGR* and *CGR* 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 *CGR* 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_2 , followed by T_3 ($54.92 \text{ g m}^{-2} \text{ day}^{-1}$), 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_4 ($2.14 \text{ g m}^{-2} \text{ day}^{-1}$), 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 *CGR* 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 (Table 4). At 60 DAE, *WUE* reached maximum (0.50 g L^{-1}) in case of T_3 , being close to T_4 (0.43 g L^{-1}), and the lowest *WUE* (0.09 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 g L^{-1}), followed by T_3 (0.46 g L^{-1}), and the lowest *WUE* (0.23 g L^{-1}) was noted for T_1 , being close to T_2 (0.25 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°C) in case of T_4 , followed by T_3 (29.3°C), and the lowest leaf temperature (28.4°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.

Treatments ^a	Water use efficiency(g L ⁻¹)			Leaf temperature(°C)			Carbon exchange rate (m mol m ⁻² s ⁻¹)		
	30	60	90	9:0	1:0	5:0	9:0	1:0	5:0
	DAE ^b	DAE	DAE	am	pm	pm	am	pm	pm
T ₁ = N ₀ P ₀	0.13	0.26	0.23	23.9	30.6	28.6	86.2	116.8	34.0
T ₂ = N ₁ P ₀	0.11	0.09	0.25	24.5	32.0	28.4	70.0	51.3	20.1
T ₃ = P ₀ P ₁	0.18	0.50	0.46	24.5	30.2	29.3	122.7	86.3	82.5
T ₄ = N ₂ P ₂	0.12	0.43	0.89	23.6	30.3	30.3	39.2	101.3	34.1
LSD _{0.05}	ns ^c	0.19	0.29	ns	ns	0.80	ns	ns	ns

^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, ^c Not significant.

90 DAE were not significant ($P \leq 0.05$) 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 m mol 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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واکنش یولاف (*Avena sativa* L.) از نظر تسهیم ماده خشک، تجزیه رشد و کارآیی مصرف آب در اثر کاربرد بیش از حد نیتروژن و فسفر

ج. امان اله، ب. ا. استوارت

چکیده

در یک آزمون گلخانه ای در موسسه تحقیقات کشاورزی مناطق خشک (دیم) در دانشگاه تگزاس غربی A&M در امریکا و در زمستان ۲۰۱۰-۲۰۰۹، واکنش یولاف (*Avena sativa* L., cv. Walker) از نظر نسبت شاخساره به ریشه، توزیع ماده خشک، تحلیل رشد، و کارآیی مصرف آب در واکنش به مصرف بیش از حد نیتروژن (N) به مقدار 200 mg N kg^{-1} (N_1P_0) و فسفر 200 mg P kg^{-1} (N_0P_1) و مصرف توام $100 \text{ mg N} + 100 \text{ mg P kg}^{-1}$ (N_2P_2)، و تیمار شاهد (N_0P_0) بررسی شد. آزمایش در طرح آماری کاملاً تصادفی با سه تکرار اجرا شد. یک هفته بعد از سبز شدن، ۱۵ بوته در هر گلدان نگهداری شد. سپس، در فواصل ۳۰، ۶۰، و ۹۰ روز بعد از سبز شدن ۵ بوته از خاک هر گلدان خارج شد. حجم هر گلدان ۶۲۸۳ سانتی متر مکعب و حاوی ۲۰۰۰ گرم خاک مخلوط (خاک آلی) بود. نیتروژن زیاد روی رشد برگ، ساقه و ریشه و، در نتیجه، روی وزن خشک کل گیاه یولاف اثر منفی زیادی داشت. کاهش وزن خشک کل گیاه در اثر مصرف زیاد نیتروژن منجر به کم شدن رشد گیاه گردید. اما، مصرف زیاد فسفر هیچگونه اثر منفی روی رشد برگ و ساقه و ریشه و وزن خشک کل گیاه نداشت. در واقع، اثر مصرف زیاد فسفر در مراحل اولیه رشد روی پارامترهای مزبور مثبت بود. در مراحل بعدی رشد، مصرف توام نیتروژن و فسفر اثرات مفید تری روی برگ، ساقه، ریشه و کل ماده خشک نشان داد. رابطه افزایش ماده خشک کل در هر بوته با سرعت رشد مطلق (AGR)، سرعت رشد گیاه (CGR)، و سرعت خالص جذب و ساخت (NAR) مثبت بود. رابطه سرعت خالص جذب و ساخت با افزایش شاخص مساحت برگ منفی بود ولی با افزایش سرعت رشد گیاه رابطه ای مثبت داشت. کارآیی مصرف آب با کاربرد فسفر افزایش یافت و رابطه ای مثبت با افزایش سرعت رشد گیاه نشان داد.