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GROWTH DYNAMICS AND LEAF CHARACTERISTICS IN OATS (*AVENA SATIVA* L.) DIFFER AT EXCESSIVE NITROGEN AND PHOSPHORUS APPLICATION

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Abstract

Shoot-root ratio (by length), number of roots plant^{-1} (NRPP), number of tillers plant^{-1} (NTPP), and leaf characteristics [number of leaves plant^{-1} (NLPP), leaf length (LL), mean single leaf area (MSLA), leaf area plant^{-1} (LAPP), leaf elongation rate (LER), leaf area index (LAI), specific leaf area (SLA), specific leaf weight (SLW), and leaf area ratio (LAR)] response of oats (*Avena sativa* L., cv. Walker) was investigated under excessive nitrogen (N) as 200 mg N kg^{-1} (N_1P_0), excessive phosphorus (P) as 200 mg P kg^{-1} (N_0P_1), and combine 100 mg N + 100 mg P kg^{-1} of potting mix (N_2P_2) and control (N_0P_0) as check in pot experiment at Dryland Agriculture Institute, West Texas A&M University, Canyon, Texas, USA during winter 2009-10. The experiment was performed in completely randomized design (CRD) with three replicates. Shoot-root ratio increased with excessive N, excessive P and combined N + P applications due to the decline in root lengths. The lower shoot-root ratio in control was mainly attributed to the longer roots produced by oats. Phosphorus alone or combined application with N (N_2P_2) increased NRPP over control. At the early stages, control had more NRPP than N alone. With advancement in crop growth, combined N + P applications had more favorable effects on NTPP than other treatments. Excessive P had more but excessive N had less NTPP than control. Except SLW, all other parameters viz. NLPP, LL, LER, MSLA, LAPP, LAI, SLA, and LAR decreased due the toxic effects of excessive N. Excessive P alone or combined N + P applications had beneficial effects on various leaf characteristics of oats viz. NLPP, LL, LER, MSLA, LAPP, LAI, SLA, and LAR.

Introduction

The relationship between root growth and whole plant growth is called allometry or relative growth (Fageria *et al*., 2006), and root dry weight is generally related to total plant dry weight (Yoshida, 1981). Shoot-root relationship by weights gives an estimate of root mass that remains in soil if shoot weight is known. In contrast to shoot, dry matter partitioning in roots is high during the seedling stages of crop growth and steadily declines throughout development (Evans & Wardlaw, 1976). Fageria (1992) reported increase in shoot-root ratios of common bean, rice, wheat, and cowpea as plants advanced in age. The decrease in shoot-root ratios with time indicating roots have preferential utilization of photosynthates under the existing plant growth conditions. Environmental stresses increase relative weights of roots compared to shoots (Eghball & Maranville, 1993). Davidson (1969) reported that availability of N, P, or water increased root-shoot ratios of perennial ryegrass. When plants are nitrogen deficient, relatively more photosynthates is used by roots as they develop greater length to aid the plants in obtaining more N (Fageria *et al*., 2006). Champigny & Talouizte (1981) reported that under N deprivation, translocation of photoassimilates from shoots to roots increased because of increased sink strength of roots compared to shoot sinks. Root-shoot ratios of maize plants were higher when grown with low soil N compared to adequate N (Eghball & Maranville, 1993). The mineral nutrients P and N exerted 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 (Fageria *et al*., 2006). Root development varies with stages of plant growth and development (Fageria *et al*., 2006). The most rapid development of maize roots occurs during the first eight weeks after planting (Anderson, 1987). After silking, maize root length declines (Mengal & Barber, 1974) indicating high C demand of grain, resulting in enhanced translocation of C and N to grain, including some C and N that roots would normally obtain (Wiesler & Horst, 1993). Techniques used to quantify components of crop growth are collectively known as growth analysis. 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*., 2006). Functional growth analysis, based on experiments in which plants are grown under standard conditions and harvested at regular intervals, can provide the first clues toward an understanding of variation in growth rates among genotypes or species (Lambers, 1987).

Nitrogen is the most important nutrient required for growth, development, and achievement of higher yield (Fageria *et al*., 2006; Iftikhar *et al*., 2010; Babar *et al*., 2011). Nitrogen use efficiency (NUE), defined as grain yield per unit N applied, depends on the extent and effectiveness of roots for N uptake (Jackson *et al*., 1986). Durieux *et al*., (1994) reported stimulated maize root length in area of N application without affecting total root length. Other studies also noted localized total root stimulation of root growth in response to N placement (Granato & Raper, 1989) and N source (Teyker & Hobbs, 1992). Anderson (1987) found that N additions appeared to stimulate root growth close to soil surface 7cm under field conditions. Addition of N fertilizer also created longer roots without changing weight, which resulted in finer roots. Durieux *et al*., (1994) found that root weight was less affected by N than root length, and the effects may have depended on plant maturity. Mackay and Barber (1986) concluded that field applications of N did not affect root length and root surface area of the maize hybrid “Pioneer-3732”, but increased root growth of the hybrid "B73XM017". In addition, B73M017 gave higher grain yield than Pioneer-3732. In grren house experiments, Hatlitligil *et al*., (1984) noted greater root dry matter for "B73XM017" compared to two other maize hybrids. Baligar *et al*., (1998) reported that relative dry weights of roots due to absence of N in rice, common bean, maize, and soybean was 62, 44, 65, and 89 percent less than that of treatments where N, P, and K nutrients were applied in adequate levels. Sharratt & Cochran (1993) reported that barley roots in the upper 10 cm of soil was more prolific where N fertilizer was banded rather than broadcast, but total N uptake was no different among treatments. Under moderate N fertilization and water stress conditions, maize developed greater root masses and lengths than under normal non-stressful conditions. Under severe N stress, maize roots appear to develop less branching than where plants receive adequate N. Root branching can be useful when nutrients are applied in localized zones, but maize roots seem to develop less branching when entire soils are N deficient (Eghball *et al*., 1993). Other studies have reported that reductions in root growth may occur at high N supplies (Anderson, 1987; Comport *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 growth of whole plant (Troughton, 1962). However, growth of shoots increased to a greater extent than roots. In herbage grasses, each increasing increment in level of N supply produced smaller increases in growth and resulted in retardation of growth at high levels (Troughton, 1957).

Phosphorus is a key nutrient essential for root development in highly weathered tropical soils (Fageria *et al*., 2006). Fageria *et al*., (1997) reported that root dry weight was reduced 62% in rice, 74% in common bean, 50% in maize, and 21% in soybean without added soil P compared to adequate P in Brazilian Oxisol. In other study by Fageria *et al*., (1997) reported maximum root dry weight for weight at 152 mg P/kg, whereas maximum root dry weight for common bean and cowpea were achieved at 130 and 159 mg/kg soil, respectively. Indicating that increasing P levels increased root growth, but root growth was reduced at higher P levels, and crop species have 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 vary similarly as P level increases, and above certain levels, further increase in P supply do not affect root or shoot growth. Crop yield is frequently constrained by the excess availability of major nutrients, including N and P. 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 shoot/root dry weight ratio with increase in N supply (Robinson *et al*., 1994; Marschner 1995; Lucas *et al*., 2000; Ahmad *et al*., 2012). At high N rates inhibition of root mass and/or length was observed (Welbank *et al*., 1974; Feil & Geisler, 1988). Further, 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 1996). Urea application greater than 83mg N kg^{-1} in one experiment and 130mg N kg^{-1} in another experiment caused severe toxicity to the Proso grass seedlings (Ayed & Mashhady, 1984). Plaster (2009) reported that plants with too much N do 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 so the plants are very weak. Leaves high in N also respire-use up the food produced by photosynthesis-more rapidly. In lowlight situations, where photosynthesis is light limited, high N merely depletes food more quickly. Plants growing under low light, such as shady turf or indoor plants should be fertilized more lightly than plants grown in the sun (Plaster, 2009). In general, N promotes vegetative growth-stems and leaves-more than the reproductive growth of flowers and fruit. Also, while N aids growth in root and shoot, shoot growth tends to be favored. This can be a problem in turf, where high N fertilization can yield lush growth with an inadequate root system to support it during times of stress (Plaster, 2009). Excess N may reduce quality measures such as flavor components or sweetness in a wide range of crops. Also in some plants, high nitrate levels in plants tissue may present health problems for animals and humans that consume them (Plaster, 2009). Excess of some N compounds in soils can adversely affect human and animal health and can denigrate the quality of the environment. High nitrate level in soils can lead to sufficiently high nitrates in drinking water as to endanger the health of human and ruminant animals. The movement of soluble N compounds from soils to aquatic systems can disrupt the balance of those systems, leading to eutripication, decline in oxygen content of the water, and the subsequent death of fish and other aquatic species (Braddy & Weil, 2002). 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 maturity and cause the plants to more susceptible to diseases and to insect pests. These problems are especially noticeable if the other nutrients, such as P and potassium, are in relatively low supply. An oversupply of N degrades crop quality, resulting in undesirable color and flavor of fruits, and low sugar and vitamin levels of leafy vegetables (Braddy & Weil, 2002). Growth disorders and mortality of apical buds in Scots pine are observed under high ammonium supply and these have been attributed to decreased frost tolerance of the trees (Ferm *et al*., 1990, Pietila *et al*., 1991). Reports concerning the effect of nitrogen on frost resistance vary depending on the species and the form of nitrogen (NOx, NH_3). Nitrogen-rich fertilization is known to prolong the growing period of plants and thus increase the susceptibility of trees to late and/or early frosts (Bobbink *et al*., 1992). Excess nitrogen, either as fertilization or ammonium deposition, has also caused frost-drought-type injuries in plants (Gordon *et al*., 1999). Extra nitrogen supply alters the metabolism of nitrogenous compounds in plants and an increased concentration of amino acids (Nasholm *et al*., 1994), soluble proteins (Zedler *et al*., 1986; Ferm *et al*., 1990), and polyamines (Taulavuori *et al*., 1999) have been reported. The activities of enzymes involved in N uptake are also induced in nitrogen-supplied Scots pine (Perez-Soba *et al*., 1994). Excess nitrogen also changes protein patterns in Scots pine needles during acclimation and deacclimation (Pietila *et al*., 1991). Because proteins play an important role in the development of freezing tolerance, it has been suggested that the observed changes may affect the frost hardiness of nitrogen-supplied trees.

Phosphorus availability is essential for plant growth and survival and in the natural ecosystem is probably the most limiting mineral. This is due in part to the low concentration of P in the soil, typically 10µM or less, in combination with its low solubility and high sorption capacity. To overcome this limitation, plants have evolved a variety of strategies to increase the uptake of P from the soil, including alteration of root structure and function as well as modification of the rhizosphere (Grennan, 2008). 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 flower growth, and supplying more P than necessary does not stimulate more bloom (Plaster, 2009). Phosphorus applied from fertilizer and manure is 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 (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 there are 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). N: P ratios have been proposed as a diagnostic tool for nutrient limitations in natural vegetation (Gu sewell & Koerselman, 2002; Gu ewell *et al*., 2003). 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, the root systems are achieved 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). Under high P condition, both Fe and Zn are converted into non-available forms (Plaster, 2009; Provin & 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 & Pitt, 2010).

A good supply of N stimulates root growth and development, as well as the uptake of other nutrients. Nitrogen can dramatically stimulate plant productivity, whether measured in tons of grain, volume of lumber, carrying capacity pasture, or thickness of lawn. The world's ecosystems are probably influenced more by deficiencies or excess of nitrogen (N) than by those of any other essential element. Plants deficient in N tend to have a pale yellowish green color (chlorosis), have a stunted appearance, and develop thin, spindly stems. Nitrogen deficient plants often have a low shoot-root ratio, and they mature more quickly than healthy plans (Braddy & Weil, 2002). Slow growth and stunting are the most obvious signs of N shortage (Plaster, 2009). Neither plants nor animals can grow without P. Adequate P nutrition enhances many aspects of plant physiology, including the fundamentals processes of photosynthesis, N fixation, flowering, fruiting, and maturation. Root growth, particularly development of lateral roots and fibrous rootlets, is encouraged by P. In cereal crops, good P nutrition strengthens structural tissues such as those found in straw or stalks, thus helping to prevent lodging. Improvement of crop quality, especially in forages and vegetables, is another benefit attributed to P (Braddy & Weil, 2002). A shortage of P can cause stunting and fewer, smaller leaves. A P shortage may delay maturity of several crops, including corn, cotton, soybean, and others. Some crops, such as carrots, develop poor root systems (Plaster, 2009). A P-deficient plant is usually stunted and spindly. In severe cases, P deficiency can cause yellowing and senescence of leaves. Phosphorus is needed in especially large amounts in meristematic tissues, where cells are rapidly dividing and enlarging (Braddy & Weil, 2002). Better understanding of root architecture and growth dynamics of annual crops may lead to more efficient use of applied nutrients and water by crops. The study of plant roots is one of the most promising but least explored areas of research related to plant growth (Fageria *et al*., 2006). Studies on excessive N and P applications on the shoot-root ratio, growth dynamics and leaf characteristics of oats are lacking. This study was therefore performed with an objective to investigate whether excess of N and P applications influence shoot-root ratio, growth dynamics and leaf characteristics of oats or not?

Materials and Methods

Shoot-root ratio (by length), growth dynamics **[**shoot length, root length, number of roots plant^{-1}(NRPP) and number of tiller plant^{-1}(NTPP)**,** and leaf characteristics **[**number of leaves plant^{-1} (NLPP), leaf length (LL), mean single leaf area (MSLA), and leaf area plant^{-1} (LAPP), leaf elongation rate (LER), leaf area index (LAI), specific leaf area (SLA), specific leaf weight (SLW), and leaf area ratio (LAR)**]** 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&M University, Canyon, Texas, USA during winter 2009-10. The experiment was performed in completely randomized design (CRD) using three replicates. There were four pots (treatments) per replicate and the size of each pot was 6283 cm^3 containing 2 kg (2000 g) of potting mix (organic soil known as Miracle Grow) pot^{-1}. The four treatments were: T_1 = control (N_0P_0 ; N_0 = N not applied & P_0 = not applied), T_2 =

200 mg N kg^{-1} (N_1P_0; N_1 = 200 mg N & & P_0 = P not applied), T_3 = 200 mg P kg^{-1} (N_0P_1; N_0 = N not applied & P_1 = 200 mg P), and T_4 = 100 mg N + 100 mg P kg^{-1} of potting mix (N_2P_2; N_2 = 100 mg N & & P_2 = 100 mg P). Miracle Grow is formulated from 50-60% sphagnum peat moss, coconut husk fibers (coir pith), composted bark fines, wetting agent, and fertilizer. The N, P and potassium (K) sources have been coated to provide 0.10 % slow-release N, 0.10 % slow-release phosphate (P_2O_5), and 0.10 % potash (K_2O). 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.

Urea (46% N) and triple super phosphate (46% P_2O_5) were used as source of N and P, respectively. Twenty seeds of oats 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. After one week of 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 taken on the average of five plants. The roots were washed with tap water, and the plants were then divided into three parts i.e. roots, leaves and stems at each growth stage. Number of leaves, tillers and roots per five plants was counted and the average was worked out. Root length, shoot length (plant height), leaf length and width were measured by measuring tape and then averaged. Mean single leaf area was obtained by multiplying the average leaf length x leaf width x 0.67. Leaf area per plant was obtained by multiplying mean single leaf area into number of leaves per plant. The materials was then put in paper bags and then in oven at 80^0C for about 15-20 hours. The dry samples were weighing by electronic balance (*Sartorius Basic, BA2105*) and the average data on dry weight of root, leaf, and stem per plant was worked out. Shoot dry weight per plant was obtained by adding leaf dry weight with stem dry weight per plant. The sum of the shoot and root dry weight was called as total dry weight per plant. Shoot length (plant height) was divided by root length to get data on shoot-root ratio (by length). The SLE (stem elongation rate), LER (leaf elongation rate), LAI (leaf area index), SLA (specific leaf area), SLW (specific leaf weight) and LAR (leaf area ratio) were determined using the following formulae:

$SER = H_2 - H_1 / t_2 - t_1 \ldots\ldots (cm\ day^{-1})$
$LER = LL_2 - LL_1 / t_2 - t_1 \ldots\ldots (cm\ day^{-1})$
$LAI = LAPP\ x\ plants\ m^{-2} \ldots\ldots (g\ m^{-2}\ day^{-1})$
$SLA = LAPP / LWPP \ldots\ldots (cm^2\ mg^{-1})$
$SLW = LWPP / LAPP \ldots\ldots (mg\ cm^{-2})$
$LAR = LAPP / total\ plant\ dry\ weight \ldots\ldots (cm^2\ mg^{-1})$

where:
H_1 = plant height (cm) at the beginning of interval
H_2 = plant height (cm) at the end of interval
LL_1 = leaf length (cm) at the beginning of interval
LL_2 = leaf length (cm) at the end of interval
$t_2 – t_1$ = the time interval between the two consecutive samplings

Statistical analysis: Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel & 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

Plant height: Plant height (shoot height), root length, and shoot-root ratio (by length) varied significantly ($p \leq 0.05$) among different treatments at 30, 60 and 90 days after emergence (DAE) as shown in Table 1. At 30 DAE, oats ranked first in heights (22.7cm) in T_1 (control, N and P not applied) being statistically the same with 21.7 cm in T_3 (P applied only), and the shortest plants of 13.3 cm heights were observed in case of T_2 (N applied only). Applications of N alone or in combination with P had toxic effects on the plant height up to 30 DAE. With passage of time combined application of N + P had no negative impacts on plant height rather it had maximum plant height at 60 and 90 DAE. At 60 DAE, oats ranked first in heights (53.0 cm) in T_4 (half of both N and P applied), followed by T_3 (45.7 cm), and the shortest plants (19.7 cm) were observed in T_2. At 90 DAE, oats had taller plants in T_1, T_3 and T_4 (55.7-69.7 cm), and the shortest plants (41.0 cm) were observed in T_2. The toxic effects of half of N + P recovered with passage of time; on the other hand, the negative impacts of excessive N applications did not recover as the plants aged. Plant height showed positive association with number of leaves and leaf area per plant. Cross & Zuber (1973) reported that plant height and maturity of maize are highly correlated to leaf number.

Table 1. Plant height (cm), root length (cm), and shoot: root (by length) response of oats (*Avena sativa* L.) to excessive nitrogen and phosphorus application.

Treatments	Plant height (cm)			Root length (cm)			Shoot/root by length		
	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
$T_1 = N_o P_o$	22.7	37.0	55.7	12.3	16.0	22.7	1.9	2.4	2.5
$T_2 = N_1 P_o$	13.3	19.7	41.0	2.3	4.0	9.0	6.0	5.1	4.6
$T_3 = N_o P_1$	21.7	45.7	65.0	6.0	8.0	17.7	3.6	5.8	3.7
$T_4 = N_2 P_2$	16.3	53.0	69.7	7.0	9.3	19.7	2.3	5.7	3.5
$LSD_{0.05}$	3.6	5.4	14.1	1.8	2.9	3.6	1.9	1.6	1.0

where:
N_o = N not applied, P_o = 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}, ns = not significant and DAE = days after emergence

Root length: Root length is better parameter to relate absorption of water and nutrients. Oats ranked first in root length in T_1, followed by T_4, and the shortest roots length was observed in T_2 at 30, 60 and 90 DAE (Table 1). In contrast to shoot length, excessive P applications had negative or toxic impacts on root length. But the roots length recovered at the later growth stage (90 DAE) with excessive P applications. According to Isensee *et al*., (1966), roots that contact a fertilizer band may become injured, exhibit deformities, and be shorter than untreated roots. Apparently, seminal roots and first order branches are deformed or killed in a fertilizer band, or by other chemicals in sufficient concentration to be toxic, but higher orders of roots may proliferate more as the fertilizer concentration in the band declines with time (Gardner *et al*., 1985). Fageria *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 159mg P kg^{-1} soil, respectively. Indicating that increasing P levels increased root growth, but root growth was reduced at higher P levels, and crop species have different P requirements to achieve maximum growth potentials. Overall, root growth of cereals and legumes crops was reduced if P was deficient. Root length varied with stages of plant growth and development, and it increased with passage of time. In a review of depth development of roots with time for 55 crop species, maximum rooting depth for most crop species generally achieved at physiological maturity (Jaffar *et al*., 1993). Anderson (1987) reported that rapid development of maize roots occurs during the first 8 weeks after planting. Excessive N applications had the most adverse impacts on the root length and the toxic effect continued till the last sampling (90 DAE). High N rates may have reduced deep root penetration and decreased potential use of water and soil nutrients. Wilkinson and Ohlrogge (1962) attributed the decrease in root length with a greater N supply due to the increase in auxin level. Inhibition of root mass and length at high N rates was earlier observed by several researchers (Welbank *et al*., 1974; Anderson, 1987; Comport *et al*., 1988; Feil & Geisler, 1988). Durieux *et al*., (1994) found that root weight was less affected by N than root length, but Bosemark (1954) concluded that with high N supplies, root growth stopped completely. No significant differences were observed between the root lengths with excessive P alone or applied combined N + P at different growth stages, indicating that the amount of P greater than adequate do not encourage deeper rooting in oats. Troughton (1962) reported that both root and shoot vary similarly as P level increases, and above certain levels, further increase in P supply do not affect root or shoot growth. In fact, at low P levels, plants tend to favor roots over shoots to improve uptake, and in green house production of bedding plants, the root systems are achieved 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).

Shoot to root ratio: At 30, 60 and 90 DAE, oats had higher shoot-root ratio (by length) in the fertilized treatments as compared with control. At 30 and 90 DAE, T_2 ranked first by producing maximum shoot-root ratio of 6.0 and 4.6, respectively, at each stage followed by T_3 (3.6 and 3.7, respectively (Table 1). At 60 DAE, oats ranked first in shoot-root ratio (5.8) in T_3 being statistically the same with T_4 (5.7) and T_2 (5.1), and the lowest shoot-root ratio (2.4) was observed in T_1. Amanullah & Stewart (2013) found that with advancement in crop age, increase in shoot biomass was more than root biomass, and therefore, reduction in S:R was observed. Costa *et al*., (2002) reported that mineral nutrients P and N exerted pronounced influences on photosynthates and dry matter partitioning between shoots and roots. Braddy & Weil (2002) reported that N deficient plants often have a low shoot-root ratio, and they mature more quickly than healthy plants. The higher shoot-root ratio of fertilized treatments than control was due to the shorter roots produced by oats plants in the fertilized treatments, indicating the toxic effects of the applied fertilizer on the root length. On the other hand, the less shoot-root ratio in the control treatments was attributed to the longer roots that resulted in higher shoot-root ratio at all growth stages. Gardner *et al*., (1985) reported that as roots are closer to nutrients, and so nutrients deficiency generally affects roots less than shoots and therefore decreasing shoot-root ratio. In general, N aids growth in both root and shoot, shoot growth tends to be favored resulting in an inadequate root system in turf to support it during times of stress (Plaster, 2009). Evans & Wardlaw (1976) reported that dry matter partitioning in roots is high 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 shoot/root dry weight ratio with increase in N supply (Robinson *et al*., 1994; Marschner 1995; Lucas *et al*., 2000). Gardner *et al*., (1985) reported that increasing N level favors top growth in relation to root growth and so shoot-root ratio increases.

Stem elongation rate: Stem elongation rate (SER) varied significantly ($p \leq 0.05$) among different treatments at 30, 60 and 90 DAE (Table 2). At 30 DAE, SER ranked first (0.8 cm day^{-1}) in T_1 and T_3 (0.7 cm day^{-1}), and the lowest SER was calculated for T_2 (0.4 cm day^{-1}). At 60 DAE, SER reached maximum (0.9 cm day^{-1}) in T_4 and T_3 (0.8 cm day^{-1}), and the lowest SER (0.3 cm day^{-1}) was noted in case of T_2. At 90 DAE, oats had the higher SER in T_4 (0.8 cm day^{-1}) and lowest (0.5 cm day^{-1}) in T_2. The SER showed positive relationship with plant height and leaf area per plant. The higher leaf area per plant may have produced more photosynthates that have positive impacts on plant height as well as SER in oats. Number of roots $plant^{-1}$ (NRPP) varied significantly ($p \leq 0.05$) among different treatments at 30, 60 and 90 DAE. At 30 DAE, NRPP reached maximum (4.3 each) in case of T_1 and T_4, being statistically the same with T_3 (3.7), and the lowest NRPP (3.0) was noted in T_2. At 60 DAE, NRPP reached maximum (9.3) in T_4 and T_3 (8.0), and the lowest NRPP (3.7) were noted in T_2. At 90 DAE, oats had the higher 24.3 NRPP each in T_3 and T_4, followed by T_2 (11.3), and the lowest NRPP (9.7) were observed in T_1 (control). Although P alone or combined N + P decreased root length than control; but interestingly the increase in number of roots per plant over control was remarkable particularly at the later growth stages. Gardner *et al*., (1985) reported that P-fertilized plants develop more roots than do unfertilized plants, due to increase in photosynthesis, which in turn increases root growth. Also, P applied roots had less auxin activity and theoretically less inhibition than N-fertilized roots (Wilkinson & Ohlrogge, 1962). Root growth, particularly development of lateral roots and fibrous rootlets, is encouraged by P applications (Braddy & Weil, 2002). Fageria *et al*., (2006) reported that P is a key nutrient essential for root development in highly weathered tropical soils. Fageria *et al*., (1997) reported maximum root dry weight for wheat at 152 mg P/kg, whereas maximum root dry weight for common bean and cowpea were achieved at 130 and 159 mg/kg soil, respectively. Indicating that increasing P levels increased root growth, but root growth was reduced at higher P levels, and crop species have different P requirements to achieve maximum growth potentials. At the early stages control had more roots per plant than N alone; however, the number of roots per plant relatively increased with N alone when compared with control. At high N supplies the reduction in root growth was observed by Anderson (1987). In contrast, Eghball *et al*., (1993) reported less number of roots branching when N was deficient in the soil. At high N rates inhibition of root mass and/or length was observed (Welbank *et al*., 1974; Feil & 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 1996).

Table 2. Stem elongation rate (cm day^{-1}), number of roots and tillers plant^{-1} response of oats (*Avena sativa* L.) to excessive nitrogen and phosphorus application.

Treatments	Stem elongation rate			Roots plant^{-1}			Tillers plant^{-1}		
	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
$T_1 = N_o P_o$	0.8	0.6	0.6	4.3	4.7	9.7	1.0	2.3	3.3
$T_2 = N_1 P_o$	0.4	0.3	0.5	3.0	3.7	11.3	1.0	1.7	2.3
$T_3 = N_o P_1$	0.7	0.8	0.7	3.7	8.0	24.3	1.0	3.7	4.7
$T_4 = N_2 P_2$	0.5	0.9	0.8	4.3	9.3	24.3	1.0	3.7	7.0
$LSD_{0.05}$	0.1	0.1	0.2	0.9	3.3	11.1	ns	ns	2.1

where:

N_o = N not applied, P_o = 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}, ns = not significant and DAE = days after emergence

Number of tillers plant^{-1}: Number of tillers plant^{-1} (NTPP) varied significantly ($p \leq 0.05$) among different treatments at 90 DAE (Table 2). At 30 and 60 DAE, differences in NTPP were not significant among different treatments. There was no difference in tillers per plant among different treatments at the growth stages. At 90 DAE, oats had the higher NTPP in T_4 (7.0), followed by T_3 (4.7), and the lowest NTPP (2.3) were observed in case of T_2. With passage of time the combined N + P applications had more favorable impacts on number of tiller per plant than other treatments. Excessive P had more but excessive N had less number of tillers per plant when compared with control. Fageria *et al*., (1997) reported that application of N and P increased tillering in upland, as well as lowland rice. Tillers per plant in oats showed positive relationship with increase in NLPP, LAPP and LAI. The full expression of tillering is determined predominantly by the supply of mineral nutrients and photoassimilates (Fageria *et al*., 2006). Tillers per plant in oats increased as the plants aged. In wheat and rice, Fageria *et al*., (2006) reported increase in tillering as plants develop until a maximum values is reached, after which it decreases. Decrease in tillering after reaching a maximum has been attributed to the death of later tillers because of the inability to complete for light and nutrients (Fageria *et al*., 1997). Amanullah *et al*., (2011) found that under water stress condition, total plant biomass of barley (average of 2 cultivars) was more than wheat (average of 6 cultivars) because of higher tillers m^{-2} in barley (285) than wheat (224).

Number of leaves plant^{-1}: Number of leaves plant^{-1} (NLPP) varied significantly ($p \leq 0.05$) among different treatments at 60 and 90 DAE (Table 3). At 30 DAE, the differences in leaves plant^{-1} were not significant among different treatments, indicating that fertilizer application had no influence on NLPP. At 60 and 90 DAE, NLPP reached to maximum in T_4 (17.7 and 26.0, respectively), followed by T_3 (12.0 and 20.3, respectively), and the lowest NLPP as 6.3 and 9.7 were noted in T_2 at 60 and 90 DAE, respectively. Plaster (2009) reported that a shortage of P can cause stunting and fewer, smaller leaves. Excessive N application had negative impacts on the NLPP as compared with control. Leaf length (LL) and leaf elongation rate (LER) varied significantly ($p \leq 0.05$) among different treatments at 30, 60 and 90 DAE. At 30 DAE, oats ranked first in terms of LL (15.0 cm) in T_1 and T_3 (14.0 cm), and the smallest LL (7.0 cm) was observed in T_2 (Table 3). At the early growth stage, control and excessive P application had the same LL but statistically greater than other treatments. The shorter LL with combine application of N + P or excessive N alone was indicating that N probably may not help the plants to increase its LL at the early growth stage. At 60 DAE, oats ranked first in LL (34.3 cm) in T_3 and T_4 (34.0 cm), and the shortest LL (10.7 cm) was observed in T_2. At 90 DAE, oats had longer LL in T_4 (42.7 cm), followed by T_3 (40.7 cm), and the smaller LL (14.3 cm) was observed in T_2. At later growth stage, excessive P application alone or in combination with N had positive impacts on LL of oats than control indicating the importance of both N and P.

However, excessive N application had negative impacts on the LL at all growth stages as compared with control. The LL of oats showed positive relationship with leaf elongation rate (LER). Leaf length increased with passage of time and the maximum length was recorded at 90 DAE in all treatments. Bultynck *et al*., (2004) reported that *Aegilops tauschii*, the *Aegilops* species with the more rapidly elongating leaves, tended to have a lower leaf N concentration but a similar rate of photosynthesis per unit leaf area than the *Aegilops* species with the slowly elongating leaves. Gardner *et al*., (1985) reported that leaf length, width, and area generally increase progressively with ontogeny up to the point; then in certain species it decrease progressively with ontogeny so that the largest leaves are near the centre of the plant, such as on a maize plant. But in barley, the length of the lamina decreased with flower initiation but the width increased, resulting in a broad flag leaf (Goodin, 1972). Likewise LL, the LER at all growth stages reduced significantly with excessive N application as compared with other treatments. Humphries and Wheeler (1963) reported that N fertilization had a pronounced effect on leaf expansion, especially on leaf width and area. Excessive P application or combine N + P application had positive effects on the LER particularly at the later growth stages than control. Leaf length showed positive association with increase in plant height. Jennings *et al*., (1979) reported that strong associations between leaf length and plant height indicate that leaf length in both dwarf and tall cultivars is a pleiotrophic effect of genes for plant height. The association between leaf length and dry matter accumulation per plant was positive. Rhodes (1975) reported that yield in perennial rye grass was positively associated with leaf length. Leaf elongation rate (LER) was strongly and positively correlated with leaf width but not with leaf elongation duration (Bultynck *et al*., 2004).

Table 3. Number of leaves, leaf length and leaf elongation rate response of oats (*Avena sativa* L.) to excessive nitrogen and phosphorus application.

Treatments	Number of leaves plant^{-1}			Leaf length (cm)			Leaf elongation rate (cm day^{-1})		
	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
$T_1 = N_o P_o$	3.0	9.0	12.3	15.0	17.3	24.7	0.5	0.3	0.3
$T_2 = N_1 P_o$	2.3	6.3	9.7	7.0	10.7	14.3	0.2	0.2	0.2
$T_3 = N_o P_1$	2.3	12.0	20.3	14.0	34.3	40.7	0.5	0.6	0.5
$T_4 = N_2 P_2$	3.0	17.7	26.0	12.3	34.0	42.7	0.4	0.6	0.5
$LSD_{0.05}$	ns	2.8	3.5	1.7	4.0	2.0	0.1	0.1	0.1

where:

N_o = N not applied, P_o = 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}, ns = not significant and DAE = days after emergence

Mean single leaf area and leaf area plant^{-1}: Mean single leaf area (MSLA), leaf area plant^{-1} (Mean single leaf area (MSLA) and leaf area plant^{-1} (LAPP) varied significantly ($p \leq 0.05$) among different treatments at 30, 60 and 90 DAE (Table 4). At 30 DAE, MSLA reached maximum (3.4 cm^2) in T_1 being statistically the same with T_3 (3.0 cm^2), and the lowest MSLA (0.9 cm^2) was noted in T_2. At 60 DAE, MSLA reached maximum (11.1 cm^2) in T_4 being statistically the same with T_3 (10.4 cm^2), and the lowest MSLA (1.6 cm^2) was noted in T_2. At 90 DAE, oats had the higher MSLA in T_4 (18.5 cm^2), followed by T_3 (15.9 cm^2), and the lowest MSLA (3.4 cm^2) was noted in T_2. Mean single leaf area showed positive relationship with increase in leaf length. Excessive N applications decreased leaf length significantly and therefore resulted in the lowest MSLA at different growth stages. Excessive P applications alone or combine application of N + P had favorable influence on leaf length and MSLA. The influence of combine N + P applications was more pronounced on MSLA at the later growth stages of oats than at the early growth stage when compared with control. At 30 DAE, LAPP reached maximum (10.2 cm^2) in T_1, followed by T_3 (7.0 cm^2), and the lowest LAPP (2.1 cm^2) was noted in T_2 (Table 4). At 60 DAE, LAPP reached maximum (194.1 cm^2) in T_4, followed by T_3 (124.2 cm^2), and the lowest LAPP (9.9 cm^2) was noted in T_2. At 90 DAE, oats had the higher LAPP in T_4 (479.9 cm^2), followed by T_3 (322.9 cm^2), and the lowest LAPP (33.2 cm^2) was noted in T_2. Leaf area per plant showed positive relationship with increase in MSLA and number of leaves per plant (NLPP). Excessive N applications decreased MSLA and NLPP at different growth stages and therefore resulted in the lowest LAPP as compared with other treatments. Excessive P applications alone or combine application of N + P had favorable impacts on LAPP at the later growth stages as compared with control probably may be due to the increase in nutrients uptake with passage of time. In contrast, the control had more LAPP at the early growth stage than excessive P or combined N + P applications. The influence of combined N + P or excessive P applications was more favorable on LAPP the later growth stages of oats than at the early growth stage than control. The increase in LAPP at the later growth stages with N + P or P applications was attributed to the remarkable increase in the NLPP. Leaf area and leaf expansion rate increased with leaf number on a tiller (Bultynck *et al*., 2004). Richards *et al*., (2002) reported that 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*., 2004).

Table 4. Mean single leaf area, leaf area plant^{-1}, and leaf area index response of oats (*Avena sativa* L.) to excessive nitrogen and phosphorus application.

Treatments	Mean single leaf area (cm^2)			Leaf area plant^{-1} (cm^2)			Leaf area index		
	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
$T_1 = N_o P_o$	3.4	5.2	9.6	10.2	47.0	118.7	0.023	0.157	0.79
$T_2 = N_1 P_o$	0.9	1.6	3.4	2.1	9.9	33.2	0.005	0.033	0.22
$T_3 = N_o P_1$	3.0	10.4	15.9	7.0	124.2	322.9	0.016	0.414	2.15
$T_4 = N_2 P_2$	2.3	11.1	18.5	6.8	194.1	479.9	0.015	0.647	3.20
$LSD_{0.05}$	0.4	1.4	1.7	1.8	16.2	52.5	0.004	0.054	0.35

where:

N_o = N not applied, P_o = 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}, ns = not significant and DAE = days after emergence

Leaf area index: Leaf area index is an important yield-determining factor for field grown crops because LAI is a major determinant of light interception and transpiration (Fageria *et al*., 2006). At 30 DAE, LAI reached maximum (0.023) in T_1, followed by T_3 (0.016) being statistically the same with T_4 (0.015), and the lowest LAI (0.005) was noted in T_2 (Table 4). At 60 DAE, LAI reached maximum (0.647) in T_4, followed by T_3 (0.414), and the lowest LAI (0.033) was noted in T_2. At 90 DAE, oats had the higher LAI in T_4 (3.20), followed by T_3 (2.15), and the lowest LAI (0.22) was noted in T_2. Leaf area index showed positive relationship with increase in LAPP. As excessive N applications decreased LAPP at different growth stages and therefore resulted in the lowest LAI as compared with other treatments. Excessive P applications alone or combined application of N + P had favorable impacts on LAI at the later growth stages as compared with control. In contrast, the control had more LAI at the early growth stage than excessive P or combined N + P applications. The combined N + P or excessive P applications had more favorable influence to increase NLPP and LAPP that resulted in higher LAI at the later growth stages of oats than at the early growth stage when compared with control. Moosavi (2012) found that N deficiency decreased the LAI due to decreased leaf area expansion and leaf area duration. Jan *et al*., (2011) reported that in barley, LAI of increased with the application of higher rate of N. The total dry matter accumulation per plant in this study (data not shown) showed positive relationship with increase in LAI. Rhodes (1975) reported that yield in perennial rye grass was positively associated with LAI. Likewise, dry matter production LAI in oats also increased as plants aged i.e. the LAI at the later stage was higher than at the early growth stages. Fageria *et al*., (2006) 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. Increasing LAI increases dry mater production, but net canopy photosynthesis cannot increase indefinitely because of increased mutual shading of leaves (Fageria *et al*., 2006). Irradiance is lower for leaves within a canopy, which leads to decreased photosynthesis rates per unit leaf area (Yoshida, 1972).

Leaf thickness (SLA & SLW): Leaf thickness is expressed as specific leaf area (area per mass) or specific leaf weight (mass per area). Thick leaves are associated with high yielding capacities of crop cultivars (Fageria *et al*., 2006). Specific leaf area (SLA) varied significantly ($p \leq 0.05$) among different treatments at 30 and 60 DAE (Table 5). At 30 DAE, SLA reached maximum (0.58 cm^2 mg^{-1}) in T_4 being statistically the same with T_1 (0.53 cm^2 mg^{-1}), and the lowest SLA (0.23 cm^2 mg^{-1}) was noted in T_2. At 60 DAE, SLA reached maximum (1.24 cm^2 mg^{-1}) in T_4 than other treatments which produced statistically the same SLA (0.38 to 0.48 cm^2 mg^{-1}). Specific leaf area showed positive relationship with increase in LAPP and negative relationship with increase in leaf dry weight per plant (data not shown). Specific leaf weight (SLW) and leaf area ratio (LAR) varied significantly ($p \leq 0.05$) among different treatments at 30, 60 and 90 DAE. At 30 DAE, SLW reached maximum (4.98 mg cm^{-2}) in T_2 being statistically the same with T_3 (3.60 mg cm^{-2}), and the lowest SLW (1.75 mg cm^{-2}) was noted in T_4 (Table 5). At 60 DAE, SLW reached maximum (2.63 mg cm^{-2}) in T_1 being statistically the same with T_2 (2.21 mg cm^{-2}) and T_3 (2.12 mg cm^{-2}), and the lowest SLW (0.91 mg cm^{-2}) was noted in T_4. At 90 DAE, oats had the higher SLW in T_2 (6.32 mg cm^{-2}), and it was statistically the same in all other three treatments (1.81 to 1.83 mg cm^{-2}). In contrast to SLA; SLW showed negative relationship with increase in LAPP and positive relationship with increase in leaf dry weight per plant. Excessive N applications decreased LAPP and therefore had the highest SLW as compared with other treatments. Combined application of N + P had favorable impacts on LAPP as compared with other treatments and therefore had the lowest SLW. Thicker leaves usually have higher densities of chlorophyll per unit area, and hence have greater photosynthetic capacities than thinner leaves (Craufurd *et al*., 1999).

Leaf area ratio: At 30 DAE, LAR reached maximum (0.24 cm^2 mg^{-1}) in T_1 being statistically the same with T_4 (0.21 cm^2 mg^{-1}), and the lowest LAR (0.09 cm^2 mg^{-1}) was noted in T_2 (Table 5). At 60 DAE, LAR reached maximum (0.70 cm^2 mg^{-1}) in T_4, followed by T_3 (0.31 cm^2 mg^{-1}), and the lowest LAR (0.17 cm^2 mg^{-1}) was noted in T_2. At 90 DAE, LAR reached maximum (0.28 cm^2 mg^{-1}) in T_3 being statistically the same with T_1 and T_4 i.e. 0.24 and 0.27, respectively, and the lowest LAR (0.07 cm^2 mg^{-1}) was noted in T_2. The LAR in oats showed positive relationship with increase in NLPP and LAPP. Excessive N applications decreased NLPP and LAPP at different growth stages and therefore resulted in the lowest LAR as compared with other treatments. Excessive P applications alone or combined application of N + P had favorable impacts on LAPP and NLPP that resulted in the higher LAR particularly at the later growth stages as compared with control which probably may be due to the increase in nutrients uptake with passage of time. In contrast, the control had more LAPP and so greater LAR at the early growth stage than other treatments. LAR in the *Aegilops* species decreased as a result of the decreasing SLA, whereas LAR in the *Triticum* species increased, due to a stronger increase in leaf mass ratio (LMR) and a smaller decrease in SLA (Bultynck *et al*., 2004). Van den Boogaard *et al*., (1996) showed, in a controlled-environment study, that a fast leaf area expansion rate in wheat was positively correlated with above-ground biomass and grain yield.

Table 5. Specific leaf area, specific leaf weight, and leaf area ratio response of oats (*Avena sativa* L.) to excessive nitrogen and phosphorus application.

Treatments	Specific leaf area($cm^2\,mg^{-1}$)			Specific leaf weight ($mg\,cm^{-2}$)			Leaf area ratio ($cm^2\,mg^{-1}$)		
	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE	30 DAE	60 DAE	90 DAE
$T_1 = N_o\,P_o$	0.53	0.38	0.58	1.91	2.63	1.82	0.24	0.22	0.24
$T_2 = N_1\,P_o$	0.23	0.48	0.17	4.98	2.21	6.32	0.09	0.17	0.07
$T_3 = N_o\,P_1$	0.28	0.48	0.62	3.60	2.12	1.81	0.15	0.31	0.28
$T_4 = N_2\,P_2$	0.58	1.24	0.64	1.75	0.91	1.83	0.21	0.70	0.27
$LSD_{0.05}$	0.14	0.47	ns	2.34	0.86	2.74	0.05	0.23	0.13

where:

N_o = N not applied, P_o = 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}, ns = not significant and DAE = days after emergence

Conclusions

Excessive N applications alone had adverse, while excessive P alone or combined N + P applications had favorable influence on shoot length, growth dynamics and leaf characteristics as compared to control (N and P not applied). The control treatment produced longer roots than all other treatments at different growth stages. Excessive P applications had negative effects on root length at the early than at the later growth stage. Excessive N applications had the most adverse effects on the root length which continued till the last sampling. Although P alone or N + P decreased root length than control; but interestingly the increase in number of roots per plant over control was remarkable particularly at the later growth stages of oats. At the early stages, control had more number of roots per plant than N alone; however, the number of roots per plant relatively increased with N alone when compared with control. There was no difference in tillers per plant among different treatments at different growth stages. With advancement in crop age, the combined N + P applications had more favorable impacts on number of tiller per plant than other treatments. Excessive P had more but excessive N had less number of tillers per plant when compared with control. Leaf length had positive association with mean single leaf area, and number of leaves and tillers per plant had positive relationship with leaf area per plant, leaf area index, and leaf area ratio. Excessive N application increased specific leaf weight because of lower leaf dry matter accumulation per plant, and decreased specific leaf area because of less leaf area per plant produced.

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