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## Response of Seedling Root of Six Herbaceous Species to Light and Nutrient in Alpine Meadow of Qinghai-Tibetan Plateau

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**Abstract:** Six herbaceous plants native to alpine meadows of the eastern Qinghai-Tibetan Plateau were examined for their plasticity in root morphology and root biomass allocation in response to several light and nutrient levels in a field experiment. Root length, root dry weight, root length to total seedling height ratio (R/Th) and root dry weight to total seedling dry weight (R/Tw) were examined. The root morphology and biomass allocation have significant response to variation of light and nutrient availability. The seedlings root length, root weight, R/Th and R/Tw of these six species were all significantly affected by the light and nutrient. There are significant interaction effects on root length and R/Th between light and nutrient. The nutrient availability significantly increased the root length and biomass, the maximum value generally occurred in moderate nutrient availability. The shade reduced the biomass allocation to root. A higher nutrient availability improved the R/Th and R/Tw in shade conditions. But, the poor nutrient availability could increase the R/Th and R/Tw in a strong light condition. There are significant maternal effects of species on the root morphological growth and root biomass allocation. These indicated that these seedlings have different root morphology and biomass allocation strategies in different circumstance heterogeneities.

**Key words:** Root, biomass allocation, light, nutrient, alpine meadow

### INTRODUCTION

Plasticity in morphology usually is understood as phenotypic accommodation—a change in a plant's life-history strategy in response to the resources availability of environment. The success seedling recruitment also is affected by high growth rates and high allocation to vegetative spread via rhizomes (Rees *et al.*, 2001). Biomass allocation between roots and shoots is one of the most important processes regulating plant growth. The consequences of below-ground allocation for water uptake and nutrient acquisition cannot be over-emphasized (Norby *et al.*, 2001). Even after seed germination, the primary sources of light and nutrient availability are major determinant of seedling survival. Shallow root development in the first year of growth for some species can induce high seedling mortality, either directly by drought or indirectly by competition with grasses and herbs for available water (Casper and Jackson, 1997). The germination and survival of seedlings depend on light, nutrient, temperature and soil water status (Bugmann *et al.*, 1997). Nutrient effects on seedling

biology are likely to be important in some cases. Nutrients at the soil surface can potentially induce changes in seedling regeneration (Tyler, 1995).

At the seedling stage, it is difficult to make predictions of plant establishment and how root morphogenesis responds to light and nutrient availability. While roots vary widely in morphology and physiology, little is known about what selection pressures govern this variation or how this variation may be related to plant function. Ecologists have developed theories on plant growth strategies to explain variation in plant traits such as tissue morphology, biomass allocation (Grime 1977; Chapin, 1980; Falster and Westoby, 2003). The allocation of biologically expensive resources to tissue structure and function is governed by biotic and abiotic selection pressures. Broad patterns in tissue structure and function correlating with potential growth ratio have been found in leaves (Reich *et al.*, 1997), but broad studies of root traits have been limited.

Changes in the allocation of biomass to root may also be a critical component of a plant's response to the different microsites, changing the distribution of

biomass to the shoot and the root under a given environment condition (Andalo *et al.*, 1996). In natural situations, the plant may lead to greater competition between root systems by increasing the overlap of root foraging zones between individuals (Bazzaz, 1990). The overall morphology of root architecture is changed by the aerial environment (Bernston and Woodward, 1992). The morphology and allocation response of root growth are important component of the response to different irradiance and nutrition conditions. They also mediate an evolutionary response. Therefore these characteristics have been studied to assess the potential selective effect of special climate condition. Studies should be given priority to the biomass allocation above-and below-ground response to a changing habitat. In considering how light and/or nutrient availability influence seedling biology, it is important to conduct a manipulative experiments in field. At the seedling stage, how root morphogenesis response to different light and nutrition conditions. There have been few investigations into the effects of light and nutrition conditions at the stages of root growth in alpine meadow.

Given that allocation of biomass to below-ground organs is important, it is important to understand how seedling root cope with low light and nutrient availability. The present research studied the effect of different irradiance and nutrient conditions on the seedlings root growth of six herbaceous species in alpine meadow in east of the Qinghai-Tibetan Plateau with special attention to the morphology of root length and biomass. Specially, the questions we addressed were: (1) is the irradiance and nutrition variation acting directly on the six seedling root morphological variation? ; (2) is there a maternal effect of species on the root biomass allocation?; (3) what root biomass allocation strategies would take for these species in circumstance heterogeneity?

## MATERIALS AND METHODS

**Material studied:** Seeds of six alpine meadow herbaceous species (*Vicia sepium* L., *Astragalus polycladus*, *Cremanthodium lineare* Maxim., *Trollius farreri* Stapf, *Artemisia desertorum* Spreng and *Artemisia hedinii* Ostenf.) were obtained from sites in the alpine meadow grassland of the eastern Qinghai-Tibetan Plateau, China (Table 1). All six species are perennial and widespread species in the east of Qinghai-Tibetan Plateau. The six species were widely distributed species and are able to establish and persist in many habitat conditions in the alpine meadow. The six species were chosen for study for two reasons. First, they represent an important component of the seedling and/or adult herbage

Table 1: Species and mean seed weight (SW) ( $\pm$ SE) per hundred seeds studied

Ab	Species	Seed weight/ 100 seeds (mg)	Family
Vs	<i>Vicia sepium</i> L.	1954.53 $\pm$ 5.67	Leguminosae.
Ap	<i>Astragalus polycladus</i>	141.833 $\pm$ 0.40	Leguminosae.
Cl	<i>Cremanthodium lineare</i> Maxim.	77.83 $\pm$ 2.67	Compositae.
Tf	<i>Trollius farreri</i> stapf	47.77 $\pm$ 0.74	Ranunculaceae
Ad	<i>Artemisia desertorum</i> Spreng	25.30 $\pm$ 1.06	Compositae
Ah	<i>Artemisia hedinii</i> Ostenf.	9.07 $\pm$ 0.54	Compositae

community of a primary alpine meadow site. Second, the six seedling species used in this study all had a relatively extensive habitats in alpine meadow. Because of the importance of these seedling species in alpine meadow and their extensive adaptability, they were considered to be among the most important species to examine for seedling root growth responses to microenvironments.

**Study site:** The field experiment was carried out in a alpine meadow belt at Gannan, Gansu Province, China (altitude 2900 m, 102.53-E, 34.55-N), which is situated in the east of Qinghai-Tibetan Plateau. Average annual temperature is 2.0°C the lowest daily temperature averages 8.9°C concentrated in December, January and February; the highest daily temperature averages 11.5°C concentrated in June, July and August. The average precipitation of a year is 550 mm, concentrated in July, August and September. The vegetation there typifies alpine meadow (Wu, 1980).

**Methods:** Seeds of the six species were defleshed, surface-sterilized (10% sodium hypochlorite for 10 min) and germinated in plastic pots (40×40×50 cm) containing washed sand (no nutrition) in field at the alpine meadow condition, Gannan, Gansu Province, China. The 300 seeds/species from the seed collections used in this study were weighed to determine average seed mass (Table 1). The seeds of six species were sown at the same time. In each plastic pot, 3 seeds were sown uniformly, which avoided the competition among seedlings and every species in each treatment were repeated 10 plots. Each species were sown in one of twelve treatments.

The light intensity conditions were controlled with different-density black shade cloth over a frame of the same dimensions. Light treatments include four levels: L100, 100% of full sunlight; L50, 50% of full sunlight; L25, 25% of full sunlight; L12, 12% of full sunlight. The light intensity within each shade cloth of the experimental treatments was measured using a Decagon Model SF80 Sunfleck Ceptometer (Decagon Devices, Inc. Pullman, Washington, USA) on a cloudless day. Thirty light measurements (photon flux density,  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) using the single sensor setting were taken from each light regime. Three nutrient treatments were: N0, without

Table 2: Summary of micro habitats characteristics of the twelve treatments plots in the experiment

Nutrient	Light			
	L100	L50	L25	L12
N0	L100N0	L50 N0	L25 N0	L12 N0
N50	L100N50	L50 N50	L25 N50	L12N50
N100	L100N100	L50N100	L25N100	L12N100

We selected an extensive field area to carry out the experiment in alpine meadow. Shown for each variable is the mean at the initiation of the experiment in April 2004. These symbols (in Table 2) express five light regimes and two nutrient regimes: 100% full sunlight (L100), 50% full sunlight (L50), 25% full sunlight (L25) and 12% full sunlight (L12) and three nutrient regimes, no addition of nutrient solution (N0), 10% of full-strength Hoagland's nutrient solution (N10) and 100% of full-strength Hoagland's nutrient solution (N100)

nutrition; N50, 50% of full-strength Hoagland's nutrient solution; N100, 100% of full-strength Hoagland's nutrient solution. This experiment controlled principally light and nutrient treatments and divided into twelve treatment conditions (Table 2): L100N0, L100N50, L100N100, L50N0, L50N50, L50N100, L25N0, L25N50, L25N100, L12N0, L12N50, L12N100; others were in the nature field environments. Apart from the normal rain, the seedlings were well watered during the all growth seasons; all treatments were meted out the same water. The nutrient solutions were added one time a day, N0 treatments were added the same water. From sowing, these treatments were being at all times.

Seedlings were grown for a constant time period after seed reserve depletion because seed reserves can influence the stage at which plants become dependent upon external supplies of nutrients (Atkinson, 1973). The time of independence was determined by noting when seeds/cotyledons were no longer attached to the seedling. In all plant species, seedling growth continued throughout the study period and no roots emerged from the bottom of the pots indicating that seedlings had not become pot-bound. At 60 days after seedling emergences for each treatment of each species indicated that the four species were at similar developmental stages at the time of seedling harvest, suggesting that harvest at a constant time following seed reserve depletion was appropriate. Fifteen seedlings per treatment each species which were identical growing state were harvested intact and the following data collected. Root length and seedling total height were measured. Seedlings were carefully washed and measured its total height and root length, then seedlings were oven dried (70°C) for 48 h and dry biomass of root and total seedling was obtained by electronic balance (the precision is 0.0001 g). Root-to-total seedling ratios were calculated as root dry weight/total seedling dry weight (R/Th) and root length/total seedling height (R/Tw) compared among treatments.

**Statistical analyses:** The data were analyzed using Two-way ANOVA statistically with Spss 12.0 to test significance ( $p < 0.05$ ) of treatments. Correlations were performed considering the all nutrition and light intensity treatments for length and dry weight ( $p < 0.05$ ).

## RESULTS

### Effect of light, nutrient and seed mass on root growth:

The seedlings root length, root weight, root length/total seedling height (R/Th) and root weight/total seedling weight (R/Tw) of these six species were all significantly affected by the light and nutrient (Table 3). There are significant interaction effects on root length (ANOVA:  $F = 5.695$ ,  $p < 0.001$ ) and R/Th (ANOVA:  $F = 9.529$ ,  $p < 0.001$ ) between light and nutrient, but no significant interaction effect on root weight and R/Tw (Table 3). The responses of seedling root to light and nutrient availability were larger in morphology than in biomass allocation.

The different seed-mass species were significantly difference in root length (ANOVA:  $F = 439.321$ ,  $p < 0.001$ ), root weight (ANOVA:  $F = 32.880$ ,  $p < 0.001$ ), R/Th (ANOVA:  $F = 185.430$ ,  $p < 0.001$ ) and R/Tw (ANOVA:  $F = 62.673$ ,  $p < 0.001$ ) (Table 3). So, there are significant maternal effects of species on the root morphological growth and root biomass allocation.

There are significant positive relationship between root length and total seedling weight ( $p < 0.01$ ) and between root weight and total seedling weight ( $p < 0.01$ ) (Table 4). The root length and root weight are important for seedling growth. There is a significant negative relationship between R/Th and total seedling weight ( $p < 0.01$ ) and a slight negative relationship between R/Tw and total seedling weight (Table 4). These indicated that the larger seedling has shorter root length in these species.

**Root morphology and biomass allocation:** The root morphology and biomass allocation have significant response to variation of light and nutrient availability. The seedling had a shorter and lighter root in shade conditions. The nutrient availability significantly increased the root length and biomass, the maximum value generally occurred in moderate nutrient availability (Fig. 1 and 2). A higher nutrient availability improved the R/Th and R/Tw in shade conditions. But, the poor nutrient availability could increase the R/Th and R/Tw in a strong light condition (Fig. 3 and 4). The shade reduced the biomass allocation to root.

These indicated that these seedlings have different root morphology and biomass allocation strategies in different circumstance heterogeneities.

Table 3: Three-ways (light, nutrition and species) ANOVA summary of all effects on the growth of root length, root weight and R/Tw, R/Th at 40 days

Experiment	Root length		Root weight		R/Th		R/Tw	
	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value
Species	439.321	0.000	32.880	0.000	185.430	0.000	62.673	0.000
Light	20.545	0.000	8.683	0.000	125.290	0.000	29.374	0.000
Nutrition	50.553	0.000	30.881	0.000	258.352	0.000	40.826	0.000
Light×Nutrient	5.695	0.000	1.458	0.194	9.529	0.000	2.776	0.013

Table 4: Pearson's coefficients of correlation (r) for relationships (with significant p<0.05 coefficients in bold ) between all pairings of six species seedlings

Experiment	Root length	R/Th	Total height	Root weight	Total weight
R/Th	-0.120*				
Total height	0.889**	-0.492**			
Root weight	0.684**	-0.215**	0.623**		
Total weight	0.710**	-0.417**	0.809**	0.817**	
R/Tw	0.149*	0.573**	-0.134*	0.257**	-0.113

Correlations were performed considering the all nutrition and light intensity treatments,\*Correlation is significant at the 0.05 level (2-tailed).; \*\* Correlation is significant at the 0.01 level (2-tailed). R/Th is the ratio of root length to the total seedling height; R/Sw is the ratio of root dry weight to the total seedling dry weight

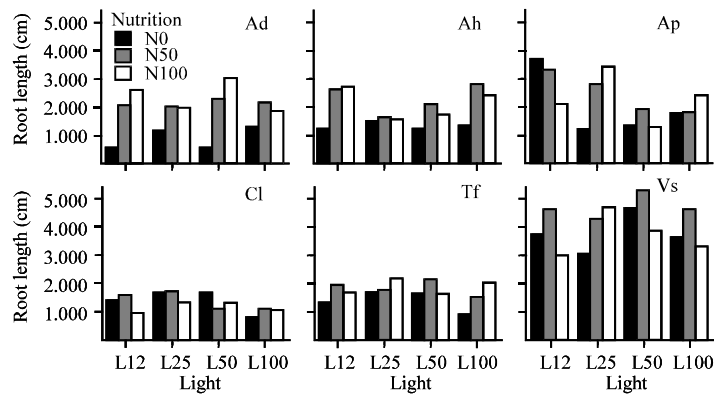


Fig. 1: The mean seedling root length of six species in different light and nutrient availability. All seedling root dry weight of seedlings differed significantly (p<0.05) between light and nutrient levels

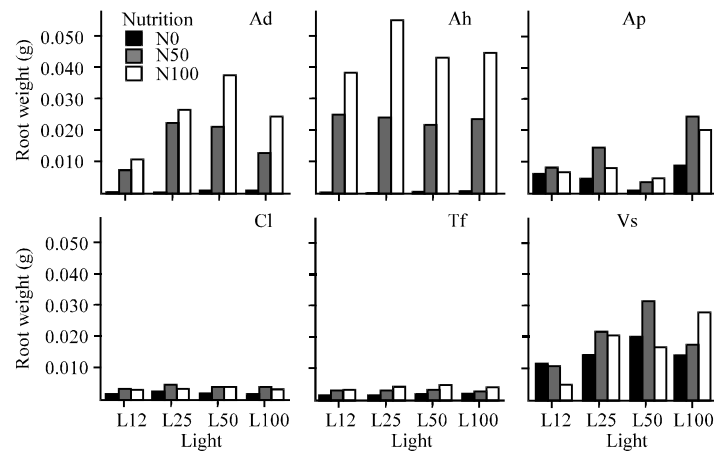


Fig. 2: The mean seedling root dry weight of six species in different light and nutrient availability. All seedling root dry weight of seedlings differed significantly (p<0.05) between light and nutrient levels

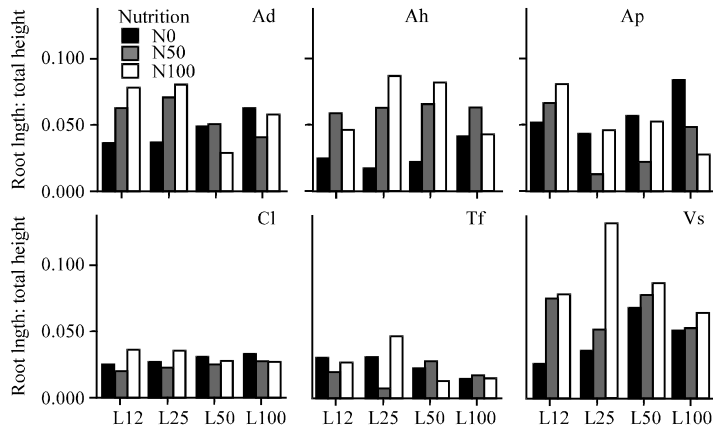


Fig. 3. The mean ratio of seedling root length to seedling total height of six species in different light and nutrient availability. All seedling root dry weight of seedlings differed significantly ( $p < 0.05$ ) between light and nutrient levels

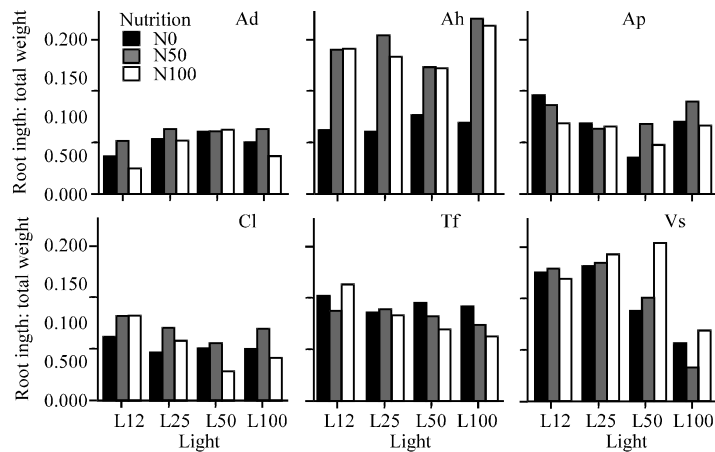


Fig. 4. The mean ratio of seedling root dry weight to seedling total dry weight of six species in different light and nutrient availability. All seedling root dry weight of seedlings differed significantly ( $p < 0.05$ ) between light and nutrient levels

### DISCUSSION

Research indicated potentially important interactions among light, nutrient and species that could influence regeneration dynamics (Walters and Reich, 2000). The seedling root growth and allocation were affected significantly by the light and nutrient availability directly and in interaction with the maternal effects of different seed-mass species. Abiotic and biotic factors may restrict seedling recruitment processes. Resource addition has a more positive effect on the seedling survival of species (Milberg *et al.*, 1999). Some finding observed that many of the same environmental constraints and organismal tradeoffs that shape the evolution of plant morphologies, life histories and physiologies also influence the dynamics of interspecific interactions and the mechanisms

of coexistence that control community and ecosystem functioning (Tilman and Pacala, 1993; Rees *et al.*, 2001).

The variation in seed size may be an important adaptive factor in the future changing environment (Westoby *et al.*, 1992). The seedling root growth response may be considered by the genetic variability in seed volume (Andalo *et al.*, 1998). Krannitz *et al* (1991) have shown that, independent of root growth, seedlings from genotypes of *Arabidopsis thaliana* with larger seeds survived longer than seedlings from genotypes with smaller seeds when nutrient supply was deficient. We considered that the root biomass variety of seedling from the smaller-seed species was influenced by the nutrient and light availability, but the seedling from the larger-seed species was influenced slightly.

Pigliucci (2005) suggests that adaptive phenotypic plasticity occurs in natural populations and average differences among environments across genotypes. The recognition that plasticity can be adaptive has stimulated a wealth of studies on how plasticity alters interactions between individual organisms and their environments (Sultan, 2000). Plasticity in morphology usually was understood as phenotypic accommodation—a change in a plant's life-history strategy in response to the resources availability of environment. It is now clear that a wide diversity of organisms express phenotypic plasticity in response to biotic and abiotic aspects of their environments (Miner *et al.*, 2005). The success seedling recruitment also was affected by high growth rates and high allocation to vegetative spread via rhizomes (Rees *et al.*, 2001).

Biomass allocation was one of the central concepts in modern ecology, providing the basis for different strategies; a plant had a given amount of resources at any point in time and it allocated these resources to different structures (Weiner, 2004). Plasticity in allocation usually was understood as a change in a plant's life-history strategy in response to the resource availability of environment. These plastic responses in our study include change in morphology, growth, life history. Comas and Eissenstat (2004) have concluded that many factors and root morphology and architecture influence root growth rates, such as carbohydrate supply and environmental conditions. Plants alter the growth and structure of roots in response to different concentrations of nutrients, which maximizes nutrient foraging in patchy soils. This response increases the capture of essential nutrients and affects competitive interactions among plant species (Hodge, 2004). Seedling biomass and root-to-total biomass ratio responded positively to increased irradiance (Robakowski *et al.*, 2003). The vertical foliage distribution also strongly influenced physiological processes such as photosynthesis and affected individual plant growth (Xiao and Ceulemans, 2004). C-S-R strategy theory (Grime, 1979) predicts that chronic shortages of soil nutrients selectively favor conservative use of resources, including low turnover rates of tissues, low reproductive effort, low relative growth rate and extreme longevity (the stress-tolerator strategy). We concluded that the seedlings will alter the root biomass allocation to improve their fitness and establish successfully in different environment heterogeneities, which is also a life-history strategy. The seedlings preferentially allocated biomass to the part obtaining the resource that is limiting growth and survival. So the root morphology and biomass allocation strategies are seemed to very important, in many circumstance where resource is limiting, especially

in the inclement climate environment of the Qinghai-Tibetan Plateau which the circumstances are not in favor of seedling establishment.

In conclusion, the seedlings will have different root morphological variation and root biomass allocation strategies and the different seed-mass species have different root growth strategies. These showed that seedling growth strategy evolved in the face of selective pressure.

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#### REFERENCES

- Andalo, C., B. Godelle, M. Lefranc, M. Mousseau and I. Till-Bottraud, 1996. Elevated CO<sub>2</sub> decreased seed germination in *Arabidopsis thaliana*. *Global Change Biol.*, 2: 129-137.
- Andalo, C., C. Raquin, N. Machon, B. Godelle and M. Mousseau, 1998. Direct and maternal effects of elevated CO<sub>2</sub> on early root growth of germinating *Arabidopsis thaliana* seedlings. *Ann. Bot.*, 81: 405-411.
- Atkinson, D., 1973. Some general effects of phosphorous efficiency on growth and development. *New Phytologist*, 72: 101-111.
- Bazzaz, F.A., 1990. Response of natural ecosystems to the rising CO<sub>2</sub> levels. *Ann. Rev. Ecol. Syst.*, 21: 167-196.
- Bernston, G.M. and I. Woodward, 1992. The root system architecture and development of *Senecio vulgaris* in elevated CO<sub>2</sub> and drought. *Functional Ecol.*, 6: 324-333.
- Bugmann, H., R. Grote, P. Lasch, M. Lindner and F. Suckow, 1997. A New Forest Gap Model to Study the Effects of Environmental Change on Forest Structure and Functioning. In: Mohren, G.M.J., K. Kramer and K. Sabaté (Eds.), *Global Change Impacts on Tree Physiology and Forest Ecosystems*, Kluwer Academic Publishers, pp: 255-261.
- Casper, B.B. and R.B. Jackson, 1997. Plant competition underground. *Ann. Rev. Ecol. Syst.*, 28: 54-5570.
- Chapin, F.S., 1980. The mineral nutrition of wild plants. *Ann. Revi. Ecol. Syst.*, 11: 233-260.
- Comas, L.H. and D.M. Eissenstat, 2004. Linking fine root traits to maximum potential growth rate among 11 mature temperate tree species. *Functional Ecol.*, 18: 388-397.

- Falster, D.S. and M. Westoby, 2003. Plant height and evolutionary games. *Trends Ecol. Evolut.*, 18: 337-343.
- Grime, J.P., 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *Am. Naturalist*, 111: 1169-1194.
- Grime, J.P., 1979. *Plant Strategies and Vegetation Processes*. John Wiley and Sons, New York.
- Hodge, A., 2004. The plastic plant: Root responses to heterogeneous supplies of nutrients. *New Phytologist*, 162: 9-24.
- Krannitz, P.G., L.W. Aarssen and J.M. Dow, 1991. The effect of genetically based differences in seed size on seedling survival in *Arabidopsis thaliana* (Brassicaceae). *Am. J. Bot.*, 78: 446-450.
- Milberg, P., B.B. Lamont and M.A. Pérez-Fernández, 1999. Survival and growth of native and exotic composites in response to a nutrient gradient. *Plant Ecol.*, 145: 125-132.
- Miner, B.G., S.E. Sultan and S.G. Morgan *et al.*, 2005. Ecological consequences of phenotypic plasticity. *Trends Ecol. Evol.*, 20: 685-692.
- Norby, R.J., K. Ogle, P.S. Curtis, F.W. Badeck, A. Huth, G.C. Hurtt T. Kohyama and J. Peñuelas, 2001. aboveground growth and competition in forest gap models: An Analysis for Studies of Climatic Change, *Climate Change*, 51: 415-447.
- Pigliucci, M., 2005. Evolution of phenotypic plasticity: Where are we going now? *Trends Ecol. Evo.*, 20: 481-486.
- Rees, M., R. Condit, M. Crawley, S. Pacala and D. Tilman, 2001. Long-term studies of vegetation dynamics. *Science*, 293: 650-655.
- Reich, P.B., D.F. Grigal, J.D. Aber and S.T. Gower, 1997. Nitrogen mineralization and productivity in 50 hardwood and conifer stands on diverse soils. *Ecology*, 78: 335-347.
- Robakowski, P., P. Montpied and E. Dreyer, 2003. Plasticity of morphological and physiological traits in response to different levels of irradiance in seedling of silver fir (*Abies alba* Mill). *Trees*, 17: 431-441.
- Sultan, S.E., 2000. Phenotypic plasticity for plant development, function and life history. *Trends Plant Sci.*, 5: 537-542.
- Tilman, D. and S. Pacala, 1993. In: *Species Diversity in Ecological Communities*. Ricklefs, R.E. and D. Schluter (Eds.) Univ. of Chicago Press, Chicago, pp: 13-25.
- Tyler, C.M., 1995. Factors Contributing to Postfire Seedling Establishment in chaparral: Direct and Indirect Effects of Fire. *J. Eco.*, 83: 1009-1020.
- Walter, M.B. and P.B. Reich, 2000. Seed size, nitrogen supply and growth rate affect tree seedling survival in deep shade. *Ecology*, 81: 1887-1901.
- Weiner, J., 2004. Allocation, plasticity and allometry in plants. *Perspectives in Plant. Ecol. Evol. Syst.*, 6: 207-215.
- Westoby, M., E. Jurado and M. Leishman, 1992. Comparative evolutionary ecology of seed size. *Tree*, 7: 368-372.
- Wu, Z.Y., 1980. *Vegetation of China*. Science Press, Beijing, pp: 642-653.
- Xiao, C.W. and R. Ceulemans, 2004. Allometric relationships for below- and aboveground biomass of young scots pines. *Forest Ecol. Manage.*, 203: 177-186.