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Literature Overview

Importance of Root-Shoot Ratio for Crops Production

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Introduction

The root has a fundamental role in taking nutrients, water, agricultural production and stress tolerance. The trait "root: shoot" ratio is a very complex unlike some partial problems, it is a problem of plant integrity, where each species, every crop or variety represents a specific original solution. More than 500 scientific papers concerning this "ratio trait" was step by step analysed, and the attempt was to extrapolate the basic general trend regarding the importance of this ratio in plant production. Given the abundance of crops, varieties and their growth phases, there is an effort to capture the basic general trend of importance and use of this trait.

For these reasons, quotations are not in the text even though it is unusual unconventionally, little unscientific approach to the issue in the text. Detailed analysis of one species, crop or variety is a quite different situation. Theroot: Shoot ratio is also one of the basic very important traits, which can assess the overall plant health, complex overall physiological level and health of analyzed genotypes. It is very important to analyze root: Shoot ratio changes during vegetation period in relationship with other traits of plants to obtain imagination about the influence of this ratio on metabolical processes, growth, development, etc.

Growth rates of roots and shoots during vegetation period continually adjust to environmental conditions and "genetic program" of plant growth and development. For example, fertilization and irrigation can make important changes. In case of the high value of this ratio, there is with large probability a possibility to absorb more nutrients from the soil and this will help in increasing above-ground biomass and probably also increases resistance to the stresses (drought conditions, low level of nutrients in the soil).

Importance of Root: Shoot Ratio

Importance of plant integrity in crop research, breeding, is extremely important. Plant integrity looks like a "very easy and expanded topic" but the reality is totally different. Thanks to the very high specialization of scientists, we are losing a holistic view of plants and are making mistakes in our research due to this drawback. It is necessary to sense a plant in their whole complexity-in both roots and shoot, as well as throughout their life cycles. Only such an integrated approach can allow us to reach correct interpretations of our experimental results [1-6].

Further as follows from literal quotation [7]: Especially development of root :Shoot ratio during vegetation period is important. As an advantage it seems to be such a ratio, when at the beginning of vegetation the growth of the roots predates the growth and the development of the above-ground part, ie., if the root system reaches its maximum before the above-ground part. The quality of the root is very important, but it is not only a question of the size of the root system. There is is also a question of the root system activity and the maximum development in optimal time during crop growth, type of root branching, root penetration to the soil. It is necessary to pay attention to individual species, crops cultivras and their phylogeny and ontogeny[7,8]. In general, agriculture accepts the fact that a 1% change of the root system size corresponded to a 2% change of the grain yield. It is known, that the seed traits also affect the filial generation root morphology at the beginning of the vegetation period (especially length, surface, depth of root penetration, and also root weight). In the biology of the seeds, roots, yield formation, stress tolerance, etc., attention needs to be paid to plant integrity and adaptability during variable environmental conditions.

Most scientists study only half of the organism, namely the aerial parts of plants and are neglecting the underground parts of plants. So in this case, the question is whether the published results for crops are correct and have correct and explanatory information content. Analysis of the root system is desirable-lot of methods exist [9-13] etc. Based on subjective evaluation and scientific results, crop varieties can be divided into two groups, i.e., adaptive, plastic varieties that are tolerant to variable weather and varieties designated directly for specific conditions, especially for drought conditions, organic agriculture wit etc.

There is a lot of literature evaluating these issues, but predominantly without information concerning to root system, which plays an important role in crop production. So far from a general perspective is knownthat 55% of the total root weight isusually found between 0 and 25 cm for most crops, about 18% is between 25 and 50 cm, 15% of the root mass is between 50 and 75 cm, and below 12% of the root mass, which is particularly important for drought. Influence of Rht genes, especially cereals on root shoot ratio is often discussed and analyzed.

Interestingly, the Rht genes reduce plant height i.e., have a significant effect on the above-ground part habitus, thus often also modifying the described ratio. But the direct effect on the root traits is in some cases sporadic. Rather, there are improved plant metabolic transport conditions, etc.,"Dwarf genotypes" have in some cases a higher root weight and a ratio to the above-ground mass at the beginning of the vegetation-which is positively reflected later in yield.

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It is a metabolic advantage from a physiological point of view, especially at spring crops. [14-18]. As follows from so far obtained results, it exists little evidence of varietal differences in genotypes root growth with Rht genes, but there are some indications, that at depth the roots of the semi-dwarf varieties they take more phosphate from the soilthan those of the taller varieties.

Testing During Vegetation

The root: shoot ratio includes many aspects. This basic trait is most even evaluated in terms of weight ratios at basic phases of plant development. This is a very significant anti-stress indicator, for higher plant performance in stress environment conditions, especially at drought conditions. But plenty of concurrently evaluated other features are important, depth of root penetration and their distribution into the soil, the reaction to transient drought, root initial growth, etc.

Important is analyze of root system step by step at different growth and developmental phases. In each phase of growth and development parallel change in the ratio between roots and above-ground part exists. It is difficult but important for plant production to measure the effect of biotic and abiotic factors on root growth under field conditions. The basic trait is root density, length, and weight, the response of root growth to chemical fertilization relation to the yield.

In many plant species increasing nutrient supplies in the soil may also decrease root length but increase root weight in a quadratic fashion. The bigger plant will have a different root : shoot ratio than a smaller plant. Thus differences in r : s ratios might be from the physiological view deceiving. That is to say, it is needed to use allometry and other suitable methods to analyze the data. As mentionedroot: Shoot ratio changes with ontogenesis, so allometric principles need to be used in analyses particularly if growth alter during all vegetation period [19-21].

Root metamorphoses, which do not allow to access root/ shoot ratio

The root, during phylogenesis, can adapt to various altered conditions, by changing shape and structure. These changes are the so-called root metamorphoses which do not allow to evaluate the root to above-ground ratio. For example, there are root tubers, root eyeballs, assimilation roots and air roots, etc. The roots have from the paleontological view the first predecessors in-rhizoids-unicellular.

"Fibers" during the development of classic root types, until present, many parallel changes also have taken place since the origins of the roots [22]. Root metamorphoses are known and have permanent hereditary changes which do not allow to access root : shoot ratio. However, it is mostly at botanical species and not at classical field crops. For example, there are small example of some metamorphoses: Pulpy roots (beets and carrots) in this case, hypocotyl can also be involved , root tubers which do not form eyelets,(dahlia), special case are contractile i.e., contraction roots (for example onion)-the base of the shoot is contracted to the surface or under the soil surface Other cases are stilted, columnar, tabular roots have developed for fastening functions of wet and slope plants. Interesting is strain roots (the classic example is Ivy).

Special case is airy roots which accept air humidity, in tropics and subtropics, contain chloroplasts and have also nutritional function (monstera). Pneumatophores their growth is negative gravitropic, in swamp plants (Taxodium distichum). Haustoria roots of parasites, absorbent organs penetrate the vascular bundles of the host, take nutrients in aqueous solution etc. etc.

Different possibilities to analyze root system

Quality and optimal root shoot ratio suggest not only improving the root shoot ratio but also increasing the density of roots in deep soil layers. There is a presumption that higher density and length of roots in deep soil layers can improve yield stability under adverse conditions. Roots of crops predominantly contribute usually only by 10-20% of the total plant weight in case of the well-developed root system. Under favorable conditions at most crops, a major part of the root system is usually found in the top 20 cm of soil. Rooting pattern in crop plants is under multi-or polygenic control and of course also under environmental control, and there is a possibility to improve root system properties by plant breeding selection methods. The use of crop species and cultivars tolerant to biotic and abiotic stresses can improve plant root system function under environmental conditions. Currently, in plant breeding, a lot of possibilities to improve the root system exists as is a possibility to see in a short review: Analysis of electric or field around the root system. Image analysis of scanned root structures, soil sampling and root penetration measurements per soil unit from different depths of soil.The utilization of electric roots capacitance. Evaluation of the formation of the root system behind the glass wall.

Utilization of removable roller from soil, classic pot experiments associated with washout.Methods of tomography.Mist chambers and hydroponics.Soil cameras at different depth of the soil and for this purpose utilization of rhizotrons and rhizolabs. Utilization of isotopes and toxic substances and agar techniques. Interesting is also staining of profiles in soil. Fluorescent methods, isotopic methods, etc., For most experiments, it is necessary to have a suitable device such as minirhizotrons and rhizotrons.

C4 plants and root: shoot ratio. Mycorrhiza

C4 plants have higher water use efficiency at the comparison with C3 plants Roots at this type of metabolism are also more efficient because they also use less water for metabolic processes. Thus, the same ratio for C3 and C4 is physiologically different and this importance must be evaluated separately for each physiological type [23]. Abovegground growth of C4 plants, i.e., plants without photorespiration responds more strongly to atmospheric CO_2 concentration when soil water is limiting rather than abundant.

The roots show in most cases an increased length and dry weight at drier conditions, more pronounced in the C4 than in the C3 species. The nitrogen content of the shoots is mostly higher in the shoots of the C3 plants and in the roots of the C4 plants; Species with the C4 photosynthetic pathway have evolved mechanisms that allow Rubisco to function in a high CO_2 environment. This increases both their nitrogen and water use efficiency compared to C3 species[24].

From the historical view, it is assumed, that the development of C3 was first, whereas C4 plants developed later when the CO_2 content in the air increased [25]. Interestingness is Crassulaceae family (Crassulacean Acid Metabolism).CAM are also C4 plants that fix carbon dioxide during the night. They store it as 4 carbon malate, releasing carbon dioxide during daylight when the light dependent reactions of photosynthesis can take place [26-28]. At a relatively low value root shoot ratio, mycorrhiza may increase and change its importance. Why?A mycorrhiza is the symbiotic association between roots of a plant and a fungus which improve the osmotic adjustment response, enhances defense system against pests and diseases, and alleviate oxidative damage of cell viability. From the physiological view, plant supplies for example sugar to the fungus, and the fungus supplies to the plant water and minerals (for example phosphorus) [29].

External Conditions, Which Modificate Analysed Trait in Experiments

Very important is the evaluation of the ratio of roots to above-ground biomass in optimal conditions. Especially when there is a necessity to define a given genotype. The examples below give an overview of the most common modifications given by external conditions with that we have to count on at field and laboratory experiments. From a physiological point of view, the roots are the most sensitive part of the plant. As follows from the physiological literature, the basic changes of root system thanks to environmental conditions haveimportant influence see also [30-34].

Transient short-term flooding: This effect delays in roots growth, roots are smaller, aerobic respiration stops, mitochondria damage exists, anaerobic fermentation takes place. After returning to optimal conditions, the standard metabolism is usually partly or completely restored, but the roots data are always accompanied by a number of changes with influence on the following growth.

High temperature: High temperature. There is a possible lot of changes but, the question is at what stage of growth and development the stress will be.Large changes can be at root morphology. Firstly is affected the above-ground part (for example begin development of heat shock proteins etc.,) and subsequently depends on its reactions which is projected into the root system. Important is also temperature around the root system. It is very important in scientific experiments [35].

Low nutrient levels: Low level of nutrients mostly (not always) reduce the growth of root lengths, number of branches, volume and there is a decrease of root dry matter. However, large differences among species and crops are observed. Roots with adequate nutrient supplies have more root hairs than nutrient-deficient roots[36-42].

Low pH: At present Influence of the low pH his very good known from the vast amount of literature andfrom the practical experiences, similarly as it is in the case at soil compaction. The low pH affects significantly the establishment of lateral roots in plants. At sensitive varieties slightly inhibit major root elongation. In the presence of Al ions, which are released from soil colloids, growth is braked, roots are thicker, reduced, rhizodermis is reduced and no root cap is formed.

Soil compaction and anoxia: Lack of oxygen results in the development of an extensive, superficial system of roots and adventitious roots. If the oxygen concentration in the environment drops to 1-3%, a number of atypical biochemical reactions occur as the growth of abscisic acid concentration, change of ethylene content, overgrowth, leaves fading, etc.,Atypical morphology of roots develops and even if the metabolism returns to the original state, partial change remains.

Waterlogging of the soil: The root system is shallow, forms aerenchyma, no secondary thickening exist (woody species). Pneumathophores can be formed in woody plants, the number of tissues are reduced in herbs, especially mechanical tissues. Plants are rather developed into typical shade-loving plants [43,44].

Salinity: Salinization predominantly causes cell growth to shorten and slow down. Influence of salinity depends on the salinity type. Salinity is natural-they are saline soils and is also produced by over-fertilization in drier soils.

The simplest but effective indicator of salinity is determined by its effect on vegetative growth. Growth is a key parameter in ecological and agricultural view. Seed production is in this case also a basic parameter, simple and effective. There are three parameters that could be used to assess the effect of salt on a particular species-survival, vegetative growth and seed production. All are, of course interlinked (the integrity of the plant) [45].

Drought There is a lot of types of reactions. One of the most common plant root reactions to dryness is change deep of root penetration. i.e., there is the prolongation of root length, a decrease of their volume, dry matter and branching. Especially if drought begins at juvenile phases growth stages, drought damage can be considerable. The water availability and efficiency of water utilization in time of germination is one of the basic factors influencing field emergence rate. Water uptake is the first step for enzymes activation, and shortly, for successful germination. The large variability in water use efficiency of seeds of different species and cultivars exist[46-48].

Alternate drought during vegetation

Alternating drought during vegetation is the very complicated question which depends on growth phase of species, crops, cultivars. Contrary to some literature claims, practical experiences concerning the reaction of crops to this phenomenon differ, for example at wheat the influence of "drought", at the beginning of flowering, increase penetration of roots to the depth, even if their dry weight decreases.

Alternate drought accompanied with high temperature: In general terms this phenomenon influences especially decrease of number of root branches. This stress affects the composition and content of proteins, the formation of stress proteins, the structure and activity of thylakoid membranes in protoplasts, the activity of enzymes. In sensitive plants above 35°C, it changes the chemical properties of protoplasm and can damage the plant irreversibly. Root destruction follows.

Differences in rhizosphere temperature in nature (field) and in scientific experiments

But what is interesting and very important in experiments. Generally, the development and growth of the root system are in nature is being implemented at lower temperatures when compared to above-ground plant part- especially in the summer time. (not the surface of the soil). If this difference is applied in laboratory experiments, then the similarity of the roots and the ratio of their weights to the above-ground is more similar to the appropriate natural conditions. If we have pot experiments in the greenhouse, the temperature of the root is similar to the shoots, it is not suitable for root/shoot ratio. For example see [49,35].

Combination of abiotic stresses has a large influence on the decrease of every trait, but not in every type of environmental conditions. These types of changes can have an influence on the transport of water and metabolites in plants and also on the shoot and seed growth and development. However, there are also possible mutual physiological compensations for the effects of stress due to metabolic processes. Selected additional information see at [50-55].

Plant metabolism as possible selection criteria to increase seed quality and optimum root shoot ratio

If the seed has a good quality in all respects (vitality, germination, emergence, viability, water utilization, chemical composition,) and produces vital sprouting seedlings in stress conditions, there is probability to obtain during all vegetation relatively successful growth with optimal roots and above-ground parts.

Seed quality is strongly influenced by the mother plant and by the environmental stresses, that is to say, plant breeding research is also focused not only on the selection of seed properties but also directly on plant metabolism, physiological processes, that directly affect the seed properties. The EcoSeed (Impacts of Environmental Conditions on Seed Quality CORDIS European comission; https://cordis.europa.eu/project/rcn/104504/factsheet/en) and other international projects are an example, that represents complex a solution to this issue.Selected additional information see at [56-63]. On the basis of practical view, when the growth of sprouting plants at the beginning of vegetation period has caused by the bad quality of seed, the negative consequences are often during all the vegetation period. Seed traits determine plant growth not only at the beginning of the vegetation period.

Discussion

As stated the genotypes with good germination accompanied by good field emergence level under unfavorable conditions, develop in field conditions, larger root system i.e., volume, length, deep of roots penetration after sowing and also during following vegetation period [64-68]. It is necessary to pay attention to individual crops and their cultivars. Every crop and her varieties represent an individual solution of whole plant physiology of this genotype.

If the growth of the roots predates the growth and the development of the above-ground part, i.e., if reaches its maximum before the maximum of the above-ground part growth it is a physiological advantage, especially at drought conditions Most of the contemporary varieties lack information about their important root traits “required ”from the physiological view for different environmental conditions.

Optimal quality and physiological activity of the roots is a necessary condition for optimal shoot development and also for subsequent development of the seeds with good quality. Physiological “communication” between roots and shoots is an important factor for the relationship of the green part of plants and their underground parts. It is known that communication between plants exists in case of pest or disease attack. This is aleopathic relationships. Very important for the root shoot ratio is their internal communication and plant memory.

Darwin has already addressed this relationship in the past, i.e., he supposed that “Roots are as the brain of plants” i.e., roots can be taken as a similar body like the brain.But there is something true about it. Currently, it is known that for the transmission signals (changes of potential) between the root and above-ground plant parts plasmodesma are needed and there seems to be an important role for auxin molecule (IAA). Detailed information is possible to obtain in the following works [1,69-81].

Conclusion

The importance of the external environment, agricultural technology, crop, and its variety is important for the development of roots and consequently for the performance of above-ground parts of plantsIn spite of all the external influences of the environment during the vegetation, it is clear, that the more massive root system (better root to shoot ratio) is almost always a guarantee of more stable performance at every species, crops, and their cultivars. the root : shoot ratio is also one of the basic traits, which can help assess the complex overall physiological level of analysed genotype.

It is very important to analyzeroot: Shoot ratio changes during vegetation period concurrently with changes of other important traits of plants and to obtain imagination about complex physiology of analyzed crop. However, exceptionally in optimal or very good soil conditions, is possible to obtain the negative correlation between the root strength and the performance of the above-ground part (in this case the roots are “unnecessarily”large). Seed quality characteristics have an influence on the roots and above-ground parts of the plant. A relationship exists also vice versa.

It is possible to provide selection for cultivar resistance to stress already at the seed germination stage and on the quality of the plant root system. Quality of the embryonic roots is important for the following growth and also roots development. In the juvenile phase and in later stage, there is the same genotype!. It is a biological law only selection on the basis of the seed properties is positive, but not with high effectiveness. The analyzed shoot root ratio is genetically fixed but can be modified by external conditions. The importance of thero-ot: Shoot ratio during vegetation is indisputable. This ratio is strongly associated with plant integrity during growth and development of all vegetation period. This problem is quite a bit neglected.

References

1. Bláha L, Pazderů K (2013) Influence of the Root and Seed Traits on Tolerance to Abiotic Stress. In: Stoytcheva M, Zlatev R (Eds.). Agricultiural Chemistry, INTECH, Croatia.

2. Haberle J, Středa T, Svoboda P, Henzlová B, Kurešová G (2018) Kořenový systém plodin pro 21. století – efektivní příjem vody a živin, J. Monitoring přírodního prostředí, Mendelu, Vúmop.

3. Hoad SP, Russell G, Lucas ME, Bingham IJ (2001) The management of wheat, barley, and oat root systems. Adv Agron 2001:193-246.

4. Waines GJ, Ehdaie B (2007) Domestication and Crop Physiology: Roots of Green-Revolution Wheat. Annals of Botany 5: 991-998.

5. Giles WJ, Bahman E (2007) Domestication and Crop Physiology: Roots of Green-Revolution Wheat. Annals of Botany 100: 991-998.

6. Khan MA, Gemenet DC, Villordon A (2016) Root System Architecture and Abiotic Stress Tolerance: Current Knowledge in Root and Tuber Crops Front Plant Sci 7: 1584.

7. Bláha L, Středa T (2016) Plant Integrity - The Important Factor of Adaptability to stress conditions, Abiotic and Biotic Stress. Plants.

8. Bláha L (2019) Importance of World Plant Reservations for The Preservation of Crop Germplasm (A Review). J Agron Agri Sci 2: 006.

9. Costa C, Dwyer LM, Zhou X, Dutilleul P, Hamel C, et al. (2002) Root morphology of contrasting maize genotypes. Agron J 94: 96-101.

10. Bengough AG, Mullins CE (1990) Mechanical impedance to root growth: A review of experimental techniques and root growth image analysis. J Soil Sci 41: 341-358.

11. Bohm W (1979) Methods of studying root systems. Springer-Verlag Berlin Heidelberg, Heidelberg, Germany.

12. Box JE (1996) Modern methods for root investigations. In: Waisel Y, Eshel A, Kafkafi U (eds.). Plant roots: The hidden were not significantly different.half. Marcel Dekker, New York, USA.

13. Box JE, Ramseur EL (1993) Minirhizotron wheat root data:Relationship of Root Dry Mass to Root LengthComparisons to soil core root data. Agron J85: 1058-1060.

14. Siddique KHM, Belford RK, Tennant D (1990) Root:shoot ratios of old and modern, tall and semi-dwarf wheats in a mediterranean environment ,. Plant and Soil 121: 89-98.

15. Lupton FGH, Oliver RH, Ellis FB, Barnes BT, Howse KR, et al. (1974) Root and shoot growth of semi-dwarf and taller winter wheats. Annals of Applied iology 77: 129-144.

16. Wojciechowski T, Gooding MJ, Ramsay L, Gregory PJ (2009) The effects of dwarfing genes on seedling root growth of wheat. Journal of Experimental Botany 60: 2565-2573.

17. Katashi K, Yutaka J, Kazuto I, Nobuyoshi W, Akira Y, et al. (2004) Effect of semi-dwarf genes on the root penetration ability of wheat. In 4-th International Crop Science Congress. Australia.

18. Hasmi NI (1980) Patterns of growth in contrasting tall and semidwarf spring wheat(*triticum aestivum L.*) cultivars.Pakistan Jagri res 1: 86-89.

19. Eghball B, Settimi JR, Maranville JW, Parkhurst AM (1993) Fractal analysis for morphological description of corn roots under nitrogen stress. Agron J 85: 287-289.

20. Zobel RW (2009) Sensitivity analysis of computer based diameter measurement from digital images. Crop Sci 43: 583-591.

21. Arredondo JT, Johnson DA (2011) Allometry of root branching and its relationship to root morphological and functional traits in three range grasses. J Exp Bot 62: 5581-5594.

22. Bláha L.et al. (2003) Rostlina a stres. VÚRV, Praha.

23. Sage RF (2016) A portrait of the C_4 photosynthetic family on the 50th anniversary of its discovery: species number, evolutionary lineages, and Hall of Fame. Journal of Experimental Botany 67: 4039-4056.

24. Sage RF, Monson RK (1998) C_4 Plant Biology. Elsevier, Amsterdam, Netherlands.

25. Sage RF (2003) The evolution of C_4 photosynthesis. New Phytologist 161: 341-370.

26. Öztürk M, Rehder H, Ziegler H (1981) Biomass production of C3- and C4- plant species in pure and mixed culture with different water supply. Oecologia. 50: 73-81.

27. Derner DJ, Polley HW, Johnson HB, Tischler CR (2001) Root system response of C4 grass seedlings to CO2 and soil water. Plant and Soil 231: 97-104.

28. Ghannoum O, Evans JR, von Caemmerer S (2010) Nitrogen and Water Use Efficiency of C_4 Plants. In: Raghavendra A, Sage R (eds.). C4 photosynthesis and related CO2 concentrating mechanisms. Advances in Photosynthesis and Respiration, Springer, Dordrecht.

29. van Someren L (2017) How do mycorrhizae work? Untamed Science,

30. Zobel RW (2005) Primary and secondary root systems. In: Zobel RW, Wright SF (eds.). Roots and soil management: Interactions between roots and the soil. American Society of Agronomy, Madison, USA. Pg no: 3-14.

31. Zobel RW (2005) Primary and secondary root systems. In: Zobel RW, Wright SF (eds.). Roots and soil management: Interactions between roots and the soil. American Society of Agronomy, Madison, USA. Pg no: 35-56.

32. Toppi LS (2003) Abiotic stresses in Plants. In: Skowrońska BP (eds.). Kluwer, Pune, Maharashtra.

33. Wardlaw IA (1990) Partitioning of photosynthates is influenced by several environmental factors such as low temperature, drought, and mineral nutrient deficiency.

34. Wardlaw IA (1990) The control of carbon partitioning in plants. New Phytol 116: 341-381.

35. Bláha L, Šerá B (2014) Příspěvky k problematice zemědělského pokusnictví. Praha, Czech Republic.

36. Bláha L (2015) Significanceof seed androot crop propertiesinorganic farming. Nova Sciences Publishers, New York, Pg no: 25-40.

37. Fageria NK, Moreira A (2011) Chapter Four - The role of mineral nutrition on root growth of crop plants. Advances in Agronomy 110: 251-331.

38. Fageria NK, Baligar VC, Li YC (2008) The role of nutrient efficient plants in improving crop yields in the twenty first century. J Plant Nutr 31: 1121-1157.

39. Fageria NK, Moraes OP, Vasconcelos MJ (2011) Yield and yield components of upland rice as influenced by nitrogen sources. J Plant Nutr 34: 322.

40. Fageria NK, Santos AB, Barbosa Filho MP, Guimaraes CM (2008b) Iron toxicity in lowland rice. J Plant Nutr 31: 1676-1697.

41. Sathiyavani E, Prabaharan NK, Surendar K (2011) The Role of Mineral Nutrition on Root Growth of Crop Plants - A Review. Advances in Agronomy 110: 251-331.

42. Welch RM, Allaway WH, House WA, Kubota J (1991) Geographic distribution of trace element problems. In: Mortvedt JJ, Cox FR, Shuman LM, Welch RM (eds.). Micronutrients in Agriculture, (2nd edn) Soil Science Society of America, Madison, USA. Pg no: 31-57.

43. Čížková H, Vlasáková L, Květ J (2017) Mokřady, Ekologie, Ochrana a udržitelné využívání, Natura, Episteme Edice jihočeské univerzity, Česká republika. Natura, Episteme Edition of the University of South Bohemia, Czech Republic.

44. Davidson RL (1969b) Effects of soil nutrients and moisture on root/shoot ratios in Lolium perenne L. and Trifolium repens L. Ann Bot 33: 571-577.

45. Shalhevet J, Huck MG, Schroeder BP (1995) Root and shoot growth responses to salinity in maize and soybean. Agron J 87: 512-516.

46. Bláha L, Marková V (2011) Posouzení odolnosti jetelovin vůči suchu. 8: 79-81.

47. Fathi A, Tari DB (2016) Effect of Drought Stress and its Mechanism in Plants, International Journal of Life Sciences 10: 1-6.

48. Yoshida S, Hasegawa S (1982) The rice root system: Its development and function. In: IRRI (ed.). Drought Resistance of Crops with Emphasis on Ric. Los Bano ˜ s, Philippines. Pg no: 97-114

49. Davidson RL (1969) Effect of root/leaf temperature differentials on root/shoot ratios in some pasture grasses and clover. Ann Bot 33: 561-569.

50. McNaughton SJ, Strain BR (1991) Source-sink carbon relations in two panicum coloratum Ecotypes in response to herbivory. Ecology 72: 1472-1483.

51. Eghball B, Maranville JW (1993) Root development and nitrogen influx of corngenotypes grown under combined drought and nitrogen stresses. Agron J 85: 147-152.

52. Freckman DW, Barker KR, Coleman DC, Acra MA, Dyer MI, et al. (1991) The use of the 11 C technique to measure plant response to herbivorous soil nematodes. Funct Ecol 5: 810-818.

53. Maghsoudi MAA,Yamagishi T (2006) Differences between Water Extraction Patterns of Three Wheat (*Triticum aestivum* L.) Cultivars at Different Soil Depths under Gradually Downward Soil Drying Conditions. J Agric Sci Technol 8: 271-279.

54. Rufty TW, Israel DW, Volk RJ, Qui J, Sa T (1993) Phosphate regulation of nitrate assimilation in soybean. J Exp Bot 44: 879-891.

55. McNaughton SJ, Strain BR (1991) Source-sink carbon relations in two panicum coloratum in response to herbivory. Ecology 72:1472-1483.

56. Bláha L, Janovská D, Vyvadilová D (2014) Methods of Testing Seed and Seedling Physiological Traits for the Improvement of Rapeseed Yield Stability. Journal of Life Sciences 8: 152-163.

57. Bouniols A, Texier V, Mondiès M, Piva G (1998) Soybean seed quality among genotypes and crop management: field experiment and model simulation. Eurosoya 11: 87-99.

58. Dyer AR, Brown CS, Espeland EK, McKay JK, Meimberg H, et al. (2010) The role of adaptive trans-generational plasticity in biological invasion of plants. Evol Appl 3: 79-192.

59. Gotwaldová P, Bláha L (2008) Germinability of minor fodder crops with different provenance under different stress conditions. In: Aktuální poznatky v pěstování, šlechtění, ochraně rostlin a zpracování produktů. Vědecká příloha časopisu Úroda.

60. Young LW, Wilen RW, Bonham-Smith PC (2004) High temperature stress of Brassica napus during flowering reduces micro- and megagametophyte fertility, induces fruit abortion, and disrupts seed production. J Exp Bot 55: 485-495.

61. Megazyme (2004) Total Starch Assay Procedure (Amyloglucosidase/alfa-amylase Method). Firm material Megazyme International Ireland Ltd., Bray, Ireland.

62. Piva G, Bouniols A, Mondiès M (2000) Effect of cultural conditions on yield, oil content and fatty acid composition of sunflower kernel. Proceed of 15th International Sunflower Conference 1: 62-66.

63. Schopfer P, Plachy C (1985) Control of seed germination by abscisic acid 1iii. effect on embryo Growth Potential (Minimum Turgor Pressure) and growth coefficient (Cell Wall Extensibility) in brassica napus L. Plant Physil 77: 676-686.

64. Bláha L, Klíma M, Vyvadilová M (2011) The infleuence of the seed traits on the yield of selected genotypes of winter trape pieštany, In: Nové poznatky z genetiky a šlachťenija poľnohosspodárských rastlín: 69-72.

65. Bláha L, Hnilička F, Hořejší P, Novák V (2003) Influence of abiotic stresses on the yield,seed and root traits at winter wheat (Tritium aestivum L). Scientia Agriculturae Bohemica 34: 1-7.

66. Bláha L (2009) Possibilities to use seed traits of grases for drought tolerance prediction. in: pazderu k.(ed.) proceedings of 9th scientific and technical seminar on seed and seedlings. Czech University of Life Sciences Prague, Czechia.

67. Brenner E (2000) Trends Plant Sci 11: 413-419.

68. Calvo Garzón P, Keijzer F (2009) Cognition in plants. In: Plant-Environment Interactions Signaling and Communication in Plants. Springer, Berlin, Germany.

69. Alpi A, Amrhein N, Bertl A, Blatt MR, Blumwald E, et al. (2007) Plant neurobiology: no brain, no gain? Trends Plant Sci 12: 135-142.

70. Baluska F, Ninkovic V (2010) Plant Communication from an ecological perspective. Series: Signaling and communication in plants. Springer, Berlin, Germany.

71. Baluška F, Mancuso S, Volkmann D (2006) Communication in plants: Neuronal aspects of plant life. Springer, Berlin, Germany.

72. Baluška F, Mancuso S (2009) Plant-environment interactions. Springer,Berlin, Germany.

73. Baluška F, Volkmann D, Mancuso S (2006) Communication in plants: Neuronal aspects of plant life. Springer, Berlin, Germany.

74. Baluška F, Stefano M (2009) Plant signaling. Springer, Berlin, Germany.

75. Barlow PW (2008) Reflections on ‘plant neurobiology’. Biosystems 92: 132-147.

76. Brenner ED, Stahlberg R, Mancuso S, Vivanco J, Baluska F, et al. (2006) Plant neurobiology: an integrated view of plant signaling. Trends Plant Sci 11: 413-419.

77. Kovác L (2007) Information and Knowledge in Biology Plant Signal Behav 2: 65-73.

78. Mc Clintock B (1984) The Significance of responses of the genome to challenge. Science 226: 792-801.

79. Scott P (2008) Physiology and Behaviour of Plants. John Wiley & Sons Ltd, New Jersey, United States.

80. Sun F, Zhang W, Hu H, Li B, Wang Y, et al. (2008) Salt modulates gravity signaling pathway to regulate growth direction of primary roots in Arabidopsis. Plant Physiol 146: 178-188.

81. Zhang WS (2008) Plant Signal Behav. 3: 361-353.