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Outlook of root system architecture (RSA) in crop development: A review

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Abstract
Plant growth is directly related to growth and establishment of root system. A developed root system of any plants determines the water uptake capacity as well as the strength of roots to held and utilize the nutrients present in soil. Under different stress conditions such as drought and low nutrient availability the highly developed root system has a major role to access mobile and immobile resources which are present in soil. A proper established root system absorbs water and nutrients faster as compared to less developed root system. Highly established root system has more capability to go deeper inside the soil as compared to less developed root system. Under these different aspects of root system architecture like role of root system, function and utilization capacity of different roots types, effect of genetic and climatic factors, some constraints and their solutions with stress tolerance and opportunities in genetic improvements are reviewed after considering the proper availability of water and nutrients provided to the crop.

Keywords: Root system, genetic factors, plant growth, stress tolerance, utilization capacity, water uptake

Introduction
Root system architecture helps in study of root and plant yield relationship. The root system architecture is helpful in the explanation of root structure and of root shape (Pagès 1989) [16]. When the plant density increases in a particular area then the root growth is reduced due to competition between plants to plants. If the number of plants increases the root width decreases and due to decrease in spreading of roots the area in contact with roots also decreases accordingly. The study of root system is important, it defines the development and growth of roots and also provides directions of root growth (Hochholdinger *et al.* 2004; Waisel 2002) [17, 18]. When the competition increases between the plants the growth of plants reduces which leads to reduction in yield directly. On the other hand, the shape of root systems describes the spatial distribution of roots and relates to major functions of the root system such as resource capture, anchorage, and plant hydraulic (Gregory *et al.* 2003) [19]. Root system architecture helps in maintaining a particular plant population by which proper nutrients and water utilization increases the yield of the crop (Lynch and Beebe, 1995) [20]. In root crops such as Potato, Sugar beet, Beet root, the food stored in roots (Cannon, 1911) [21]. By considering the root system architecture and calculation better yield can be taken and any stress effect can be minimized properly. Under root system architecture different aspects such as root width, root length, number of rots per plant, nutrient use efficiency and water absorption capacity are studied by keeping fixed amount of Nitrogen, Phosphorous and Potassium. In stress condition some hormones and chemicals are used to generate tolerance against any stress.
Roots are considered as important organ among different parts of plant which are present in contact with shoot portion for providing essential nutrients and water after absorbing them from soil. The root contains a stele, comprised of the xylem, the phloem, and the peri-cycle (Smith and De Smet, 2012) [22]. There are generally two types of roots: (i) those that are formed in the embryo, such as the primary and seminal roots in maize (Hochholdinger, 2009) [23], tap or primary root in common bean; (ii) those formed post-embryonically from consecutive nodes on shoots, normally referred to as adventitious roots (ARs).

There are mainly two different types of root system present in plants. Tap roots - These are the downward moving root which are considered as primary roots. These are a type of root which are very hard in nature and longest roots in any plant. It gives the lateral roots which are considered as secondary roots. Tap root provides support and nutrition to the plant after going deeper in soil. In earlier stage of plant growth and development the tap root is the most vigorous root within the root system but its importance decreases as that of the lateral roots increase (Coutts and Nicoll 1991) [25]. These roots are present in Beet root, Carrot, Pea etc. Adventitious roots - These are having a thread like structure which are covered by the thin root hairs. As compare to tap root they grow in upper horizon of soil by providing nutrition and support to the plants. The seminal root system and the adventitious is more definitive root system (Charles-Dominique *et al.,* 2009) [26].

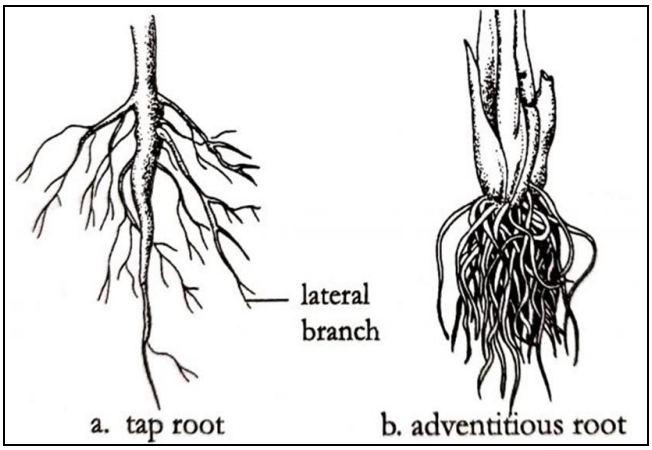

Fig 1: Types of root system

Based on plant type and structure these roots are present accordingly. In monocot plants the adventitious or fibrous roots are present where as in dicot plants the tap roots are present. The seminal root system and the adventitious, more definitive root system (Charles-Dominique *et al.,* 2009) [26]. In the plants proper functioning of roots are very important because all essential resources present in the soil are absorbed by the roots. The roots are also providing support and strength to plants (Davis and Haissig, 1994) [27]. Basal roots are important for water uptake and anchorage, whereas stolon roots are connected with nutrient acquisition (Wishart *et al.,* 2013) [28]. The roots are having different parts such as root tip, root cap, root hair etc. Different parts of roots have different functions. Root cap is present over the root tips. It provides protection to root tips and helps in receiving and transmitting information related to area near to them. Variation in root function including nutrient uptake rates are observed at increasing distance from the root tip (Clarkson 1996) [29].

Root tips absorbs nutrients and water molecules which are in touch with them. Root hairs are the thin and thread like structure present on roots. These are helping the roots by increasing area in contact by expending themselves. The resources which are away from root contact root hairs helps to absorb them. A higher number of lateral roots leads to improved possibilities of scavenging for phosphorus (Lynch, 2007) [30]. The increased lateral branching of the root is usually accompanied by a reduction of primary root development (Niu *et al.,* 2013) [31].

Root System Architecture (RSA): Root system architecture is considered as study of roots and its characteristics. Root systems are dynamic and are subject to cyclical growth and death at different stages of development (Fitter, 1996; Stokes *et al.,* 2009) [32, 33]. It is explained after taking measurements of different root characteristics such as length of primary roots, length of lateral roots or root hairs, number of roots per plant, density or area covered by plant roots and the capacity of roots to providing essential plant nutrients and water under normal as well as in stress condition. A new generation of RSA models has arisen which integrate structure, function, and environment (Godin and Sinoquet 2005) [34]. These models have already been used for the analysis of water flow (Doussan *et al*. 2006; Draye *et al.* 2010; Javaux and Vanclooster 2006) [35, 36, 37], nutrient uptake (Dunbabin *et al.,* 2004; Ge *et al.* 2000) [38, 39], carbon allocation (Bidel *et al.* 2000; Nord *et al*. 2011) [40, 41], and anchorage (Stokes *et al.* 1996) [43]. Root architectural traits, such as lateral branching and root hair density, are clearly advantageous for phosphorus-use efficiency (Rath *et al.,* 2010) [44]. The branching pattern of Lateral Roots and reported that Lateral Roots increased root surface area and compensated for the decrease in the main root length (Izumi *et al.,* 1999) [45]. The root system an important determinant of a plant's ability to exploit different resources (Lynch, 1995) [20]. Under the root system architecture, the effect of environmental, soil conditions as well as genotypic factors on roots are considered. The elongation, growth angles from the main axis, lateral branching and longevity of all root classes forms the root system which is determined by genetic, physiological, and environmental factors. Proper functioning of roots and the growth are examined in root system architecture. It is used to get information about parameters which are directly related with roots to yield parameters. Lateral Roots are responsible for root system plasticity during the critical storage root formation stage (Pardales and Yamauchi, 2003) [51]. The establishment of root system is depended on genotypes of any plants as well as the environmental factors and physical conditions of soil. Under poorly understood genetic control, RSA exhibits plasticity and responds to external environmental conditions such as soil moisture, nutrients, temperature, pH, and microbial communities (Bao *et al.,* 2014) [46].

Different Parameters of the Root System Architecture (RSA): Total length of roots calculated in m plant^{-1}, area covered by roots calculated in cm^{-1} plant^{-1}, volume occupied by plant roots calculated in cm^{-3} plant^{-1}, Number of root tips calculated in tip plant^{-1}, Angle of root, average of root diameter calculated in mm, Average of root density.

The root systems are having different roots present in plants such as primary roots, lateral roots and thin root hairs in it. These all-root types involve in providing nutrition as well as water to plants. Root types and system are different in different plants. In monocot plants different types of roots are present as the root system present in dicot plants. Root growth and function varies with different factors such as environmental factors, genetic factors, factors related to soil.

Sampling of Root System Architecture (RSA)

Crop germination: For the study of crop nutrient utilization efficiency that crop have to be grown in a particular plant geometry. In that plot proper management of resources should be there for better growth and development.

Sampling of crop plants: The samples should be taken according to growth stages of crop plants such as germination stage, vegetative stage, flowering stage and maturity stage. If we

have to attain better results, then the sampling must be done according to growth stages as well as at the time of any stress, disease or other symptoms rather than normal crop phenotypic characters shown by crops.

Calculation of different parameters: For the better results calculation methods and calculation recordings must be correct. The samples taken from field should be observed properly. There will be no mistakes in final result and notation of result

Factors Affecting the Root System Architecture (RSA)

A. Environmental

i) Topography: The land topography plays important role in root development. In plane area the roots spread evenly in the search of water and nutrients but in undulating land the roots develop more in those area where water availability and nutrients are available in required amount. Because in sloppy and undulating land availability of water and nutrients are unequal. The bilateral fan-shape architecture results from lateral roots growing mostly in the up- or down-slope direction whereas the symmetrical bell-shape architecture results from lateral roots growing symmetrically around the taproot.

ii) Temperature: High temperature leads to high rate of transpiration process. Due to high rate of transpiration plants requires more water to reduce temperature inside the plants. To absorb more water molecules roots spreads to increase water available are in contact.

iii) Water availability/precipitation: The precipitation or water availability of an area is highly influence plant root growth. If the irrigation facility is not available and plants are depended on precipitation, then crop tries to get required number of resources by increasing root area near to them. Sometimes due to unavailability or very low amount of available resources crop failure occurs because roots can be expanded up to a particular level after those plants requires energy to complete metabolic activities. Then the energy transferred towards metabolic activities. Sharp and colleagues shows water stress affects root extension (Spollen and Sharp, 1991) [47].

B. Soil Factors

i) Type of soil: In loose soil root growth is faster as compared to compact or hard soil. The space available in soil helps the roots to grow faster than the compacted soil. In holding capacity or strength of root is higher in clay loamy soil and weaker in sandy soil. Parker *et al*. (1989) [48] studied the properties of subsoil loosening and irrigation on soil physical characteristics, root distribution.

ii) Fertility and productivity: Fertility plays an important role in root functioning if soil is not having nutrients available for plants, then roots are not capable to absorb any nutrient.

iii) Soil temperature: If soil temperature is high then it means more evaporation due to sun as well as due to high soil temperature. Some metabolic activities are also reduced in roots because of high soil temperature. It reduces microbial activity in roots. The optimal soil temperature range for root growth varies depending on the species and their origin (17- 35 °C; McMichael and Burke 2002) [49].

iv) Soil condition: If soil is having any salt in high concentration or low in any nutrition then supply of that molecule towards roots is reduced. In poor textured soil the leaching effect is very high which eventually reduces the nutrients absorption capacity and water absorption capacity of roots.

C. Other Factors

i) Genetic factor: Some factors related to plant genotypes effects the root absorption capacity. Heavy feeder absorbs nutrients faster than low feeder. Those plants which are having high phosphorous use efficiency they have high root system. Some plants developed by breeding techniques which can have more rooting as compared to others.

Benefits of root system architecture

- It helps in proper study of roots and root related aspects.
- Plant nutrient use efficiency are easily examined under this.
- It helps to study the relation between root, plant growth and yield.
- Direct effect of any nutrient can be seen by study of root system architecture.
- Action of crop geometry on plant roots can be studied by root system architecture.

Constrains in root system architecture

- Scientific knowledge is required to deal with root system architecture.
- When the applied resources amount changes, results are also changed accordingly.
- Sometimes due to mistake in calculations the suitable result will not be obtained.
- During the time of sampling neighbouring plants are also got affected which alters the next sampling results.
- Diseases and stresses after the proper resources management reduces the efficiency of root system architecture.

Opportunities developed due to root system architecture

1. **Developing crop geometry:** The calculation of root density and area covered by a plant root under root system architecture helps in developing crop geometry for getting high yields. This helps in reducing competition between crop plants and better utilization of available resources. Sridhara *et al.* (2011) [50] also opined that root growth significantly influenced by planting geometry in direct seeded crop.
2. **Weed suppression:** Study of root system architecture provides information about high root growth, absorption capacity of roots and nutrients utilization capacity. By providing information about critical time weed management practices can be done accordingly.
3. **Nutrients use efficiency:** Under the root system architecture growth of plants roots are examined after the application of particular amount of any nutrient. This change in plant morphology taken care. This helps in getting high yield at particular nutrient amount applied in field. A higher number of lateral roots leads to improved possibilities of scavenging for phosphorus (Lynch, 2007) [30].
4. **Stress and disease tolerance:** During any stress or any disease attack some changes or damage occurs to plant roots. These changes leads to deficiency of some nutrients. By providing required nutrients the tolerance against those stresses may be increased.

5. **Development of genotypes:** By root system architecture root behaviour and growth can be studied and the factors which enhance the root growth are used to develop some new genotypes. In those genotypes some improvements are done by using different breeding methods to get characters related to high root growth.

Conclusion

Root system architecture provides information about the changes occurs in plant roots. On the basis of some parameters such as plant root depth, length of primary roots, nutrients use and water absorption efficiency. This different parameter defines a healthy root growth and developed root system. Roots to crop yield relationship can be examine by the study of root system architecture and enhancement in yield will be possible by proper root growth also. Root system architecture can enhance the plant growth by using different calculation and by root related parameters.

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