Root System Architecture under stress:
Implications for adaptive responses in Cotton

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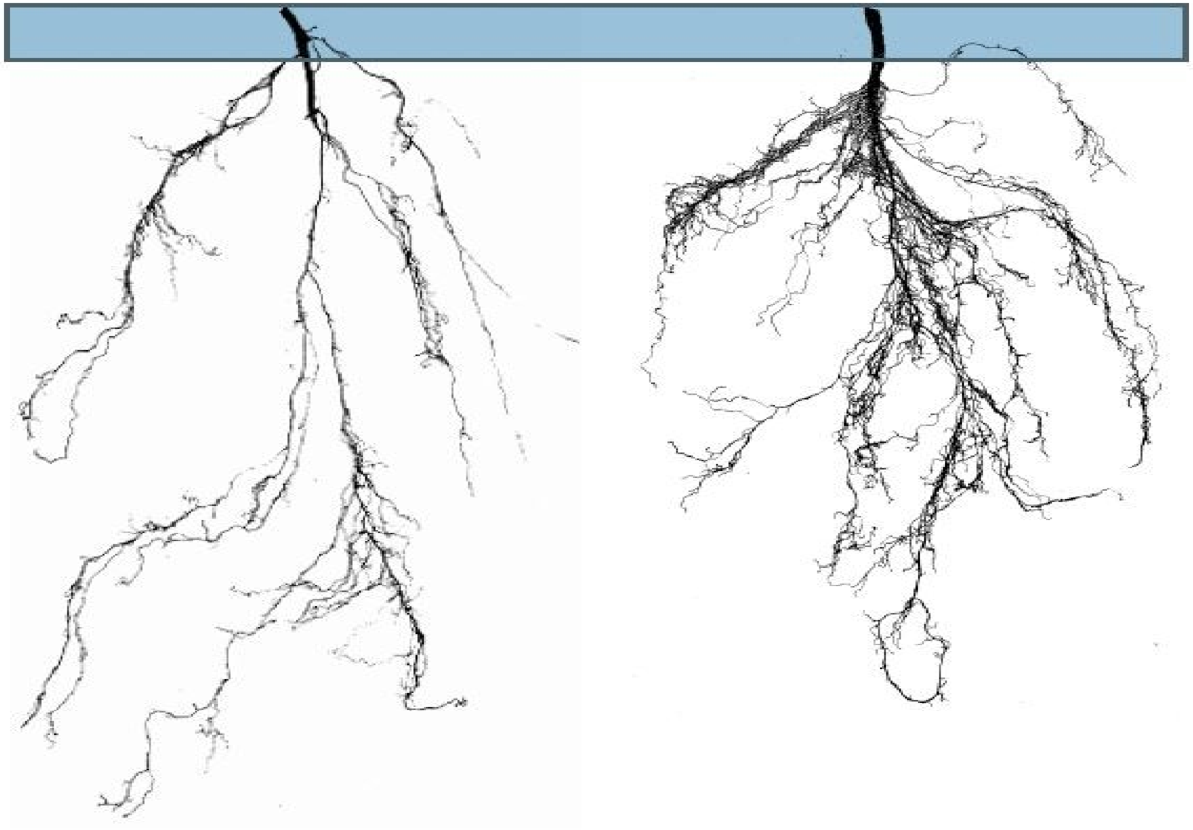
OUTLINE

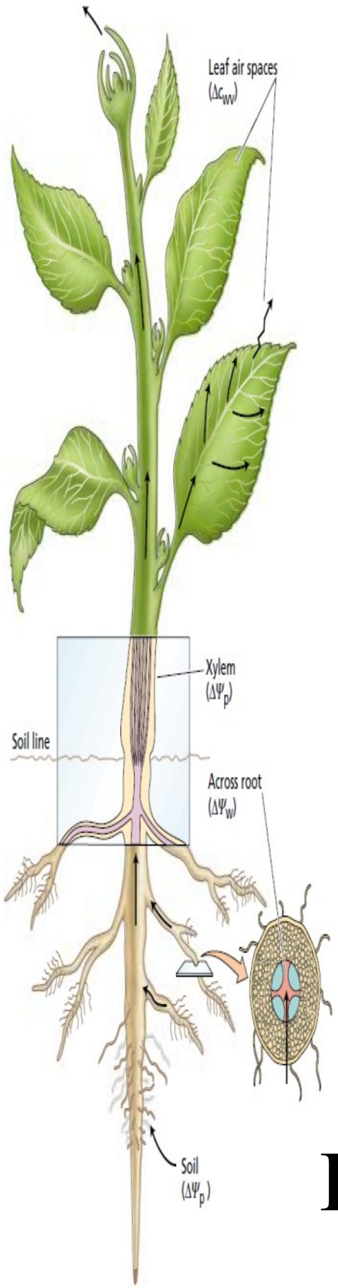
- **Introduction to Roots System Architecture (RSA)**
- **Target Environment**
- **Root traits phenotyping**
- **Adaptive responses under : Drought / Waterlogging Stress**
- **Challenges**
- **Conclusion**



“The root system acts as a plants brain "

-Charles Darwin, 1880

The "hidden" part of plant body that typically lies below the surface of the soil performs several very essential functions



Primary functions

- absorption of water and inorganic nutrients
- anchoring the plant body to the ground.

Secondary functions

- storage of Photoassimilates
- phytohormone synthesis.
- Facilitates symbiosis

Sensor of abiotic and biotic stresses

Roots act as a instrumental sensors

Knowledge / Research gaps

- ❑ limited progress has been achieved in breeding for drought avoidance through manipulation of root traits –difficult to assess in the field.

- ❑ Linking root traits and yield in rainfed cotton cultivation

- ❑ Genetic diversity in root system developmental plasticity in response to water stress

- ❑ Root growth dynamics in cracking clay soil (vertisol) in rainfed cotton

- ❑ Lack of simple, fast, precise and low-cost cotton root phenotyping method for screening large number of germplasm accessions in cotton .

Importance

- Water stress has impacts on plant height, leaf area index, fibre quality, canopy and root development (Loka et al., 2011).
- Plant maintain WP mediated through their deeper and vigorous root system and reducing transpiration in cotton (Izanloo et al.,2008 ; Agbicodo et al.,2009).
- Mild and initial-stage drought stress enhanced root length in cotton, but long-time water deficit reduced the root activity as compared to control plants (Luo et al. 2016) .
- In cotton deep rooting has been associated with higher yield under dryland condition (de Souza et al., 1983) relative root weight (Eissa et al 1983).
- Drought-stressed cotton seedlings showed increase in root length but reduced diameter (Pace et al., 1999) .
- Inadequate soil moisture reduced cotton root elongation (Ball et al., 1994 and Prior et al., 1995) .
- Reduced root length density at 42 and 70 days after emergence (Plaut et al., 1996) .
- Effect of drought stress on root distribution in cotton (Malik et al., 1979) .
- Plants grown on heavy soils are less affected by moisture stress than those of lighter soils (Sadras and Milroy,1996).
- Under high evaporative demand the cotton plant will experience short periods of moisture stress even soil at FC (Krieg 2000).

- **McMichael (1990) : Variability for root weight and root/shoot ratios in a number of exotic cotton accessions.**
- **Work by Cook and El-Zik (1992): Suggested that cotton genotypes having deep roots and increased lateral root production would be more drought resistant,**
- **Quisenberry and McMichael (1996): Indicated that genetic differences in rooting potential was related to plant productivity and that an increase in potential (primarily increases in root branching and distribution) could result in increases in yield of cotton under conditions of a drying soil profile.**
- **McMichael and Quisenberry (1993): Twenty-five cotton genotypes ranging from exotic accessions to commercial cultivars showed significant variability in the dry weights of root systems of sixty day-old plants.**
- **Quisenberry et al. (1981): Significant variability for taproot length and number of lateral roots among exotic cotton germplasm in greenhouse-grown, 35-day-old plants.**
- **Basal et al. (2003): indicated that the day-neutral converted race stocks (CRS) accessions have useful genetic variability for root growth parameters.**
- **Cook and El-Zik (1993): Incorporation of increased seedling vigor, rapid root system establishment and lower root-to-shoot ratios were recommended to improve drought tolerance in cotton.**

Root system - multitrait component

- Root number
  - Primary root number
  - Lateral root number
  - Seminal root number
  - Adventitious root number
- Root length
  - Maximum root length
  - Lateral root length
  - Seminal root length
- Root weight
- Root volume
- Root thickness
- Root density
- Root penetration ability
- Hydraulic conductance of roots

- Leaf water potential (bar)
- Soil water potential
- Plant height
- Leaf elongation rate
- Plant biomass

RSA: Root architecture is composed of a collection of root phenes which determine the temporal and spatial distribution of roots in the heterogeneous soil matrix and the ability of the plant roots to obtain mobile and immobile resources.

Root System Architecture (RSA):

Root System Architecture (RSA) is highly plastic trait (very variable)

The spatial distribution of all root traits in a particular environment is collectively referred as root system architecture (RSA).

RSA is dynamic and affected by the external environment (soil moisture, temperature, nutrients and pH).

Different root characteristics enable plants to respond, adapt and thrive in different environments.

Robbins et al (2015) J.ex.Botany
Kell,D.B (2011) Ann.Bot

Understanding roots is crucial, because healthy roots enable plants to maximize their genetic potential

- Serving as the interface between plant and soil
- Anchor the plant in the soil
- Taking up water and essential nutrients
- Direct the development of the plant
- Must respond quickly to changing environmental (water availability, salinity)
- Must interact with the surrounding environment and integrate diverse signals

Plants have several strategies to overcome stress

- **Morphological**
  (Root length
  Root diameter)
- **Anatomical**
  (Xylem diameter)
- **Functional**
  (Transporters
  Aquoporin)

Drought traits with adaptive significance

Traits associated with water relations

- Water mining → Roots
- WUE → Chloroplast
- Water Conservation → Waxes

Roots:

- Morphological and Anatomical changes
- Aquaporins
- Osmatic Adjustement (OA)
- Hormones : + ABA/ - CK, Ethylene

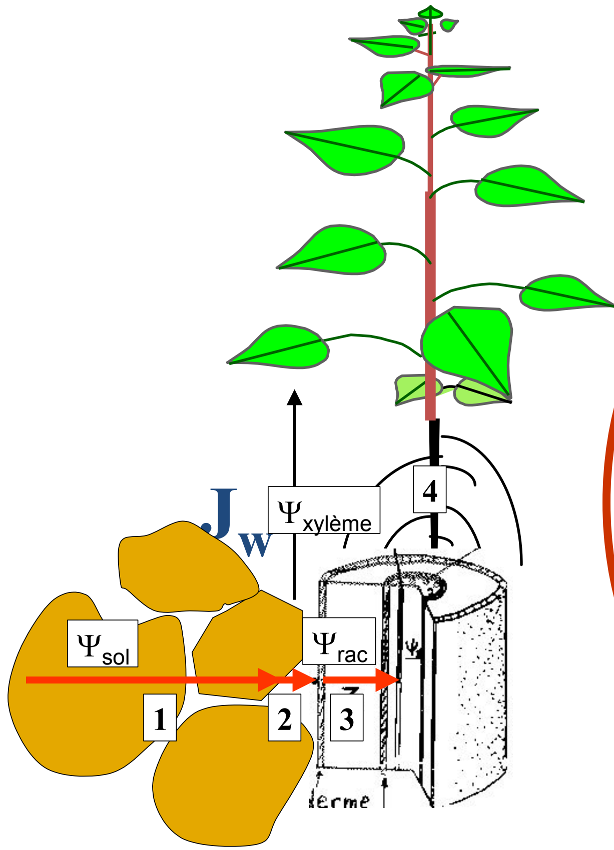
Physiology and breeding - Approach to "drought"

→ **Roots critical under water stress:**
→ **Need a dynamic assessment of water extraction**

Leaf
Water loss

↕

Root
Water uptake



Hormonal cross talk mediated by auxin, CK,GA and ABA has been implicated as a chemical signal in response to water stress to modulate RSA

Drought stress is perceived first by the root systems- the growth of lateral roots is significantly reduced (Basu et al.,2016)

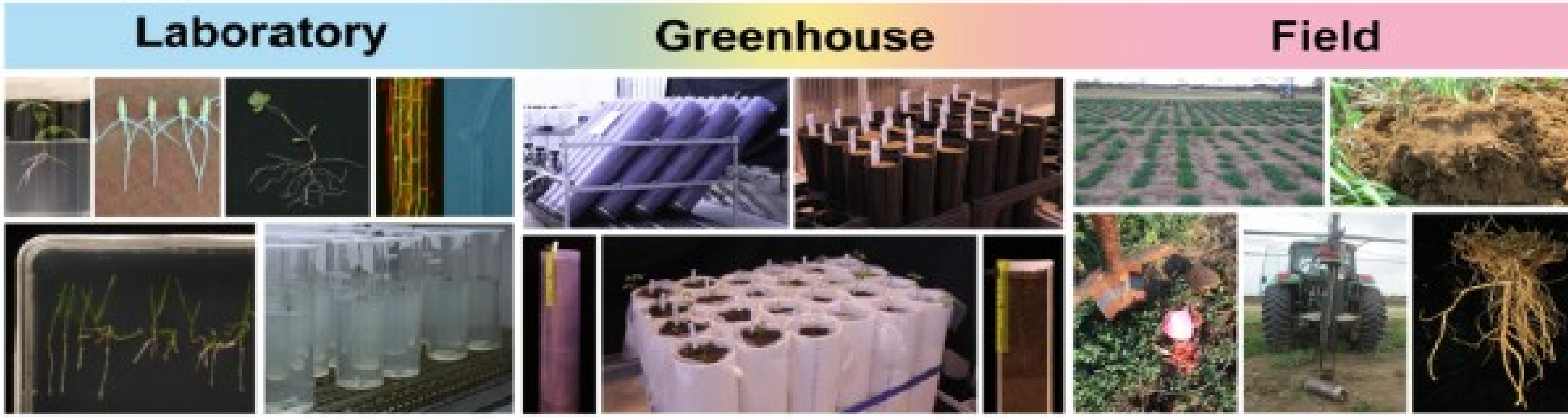
Suggested role for root traits on water uptake under drought

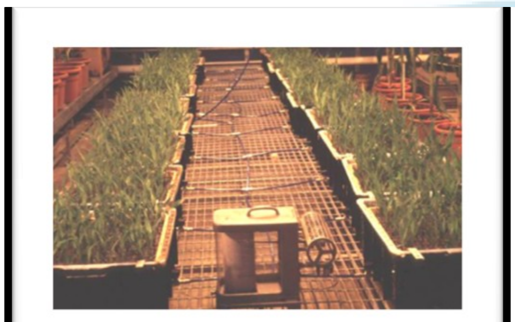
Trait	Trends observed	Suggested function for water uptake under drought
Morphological		
Lateral root formation	Increased lateral root formation with drought stress	Improved contact with shrinking water columns in the soil, differential conductivity due to differential anatomy/biochemistry compared with coarse roots
Nodal root diameter	Decreased under drought	Finer root formation to conserve resources
Anatomical		
Proportion of root cross-sectional diameter represented by stele	Increased under drought	Prioritization of retaining water in vascular tissue rather than reducing radial oxygen loss as drought occurs
Diameter/number of xylem vessels	Decreased under severe drought	Reduced risk of xylem vessel cavitation
Width of/number of cells in the outer part of the root	Decreased under drought	Reduced impedance to water uptake from the soil, and/or senescence of outer cells due to stress
Sclerenchyma cell diameter	Increased under drought	Tightly packed cells not needed for retention of oxygen as drought occurs
Suberization of sclerenchyma layer	Decreased under drought stress	Effect on water uptake not apparent: probably most important for reducing radial oxygen loss under flooded conditions
Suberization of endodermis	Increased under drought stress	Important for water transport through retention of water in vascular cells during drought, rather than for water uptake
Aerenchyma formation	Decreased under drought	Effect on water uptake not apparent: probably most important for supplying oxygen under flooded conditions
Functional		
Aquaporin expression	Mid- and late-day decrease under drought	Response to lowered transpirational demand, conservation of soil water
Diurnal fluctuations in root hydraulic conductivity and bleeding rate	All genotypes showed reduced levels at night, differential levels early and mid-day	Genotypes that time water uptake and transport to the shoots with periods of the day when transpiration is most efficient (i.e. morning) may have more efficient water use
Synchronization of diurnal changes in leaf water potential and root hydraulic conductivity	Differential trends between genotypes: Dular was better synchronized than IR64	Synchronization of root and leaf function may allow for more efficient water use

Amelia et al., 2013

PHENOTYPING: With the help of modern new screening techniques to understand cotton root system, studies on adaptive root architecture can be incorporated into most cotton research programs by taking advantage of genetic variability.

Strategies and approaches for growing plants prior to root phenotyping.





Tuberosa et al., 2002, Plant Mol Biol 48:697-712

Sumanthkumar , 2012

Root trait variation after 20 DAS

Rhizotron/soil columns/pipes systems

Techniques to quantify roots

Root pipes

Root structure

***Dro1*, a major QTL involved in deep rooting of rice under upland field conditions**

Yusaku Uga[1,*], Kazutoshi Okuno[1,†] and Masahiro Yano[1]

Crop Canopy Temperature

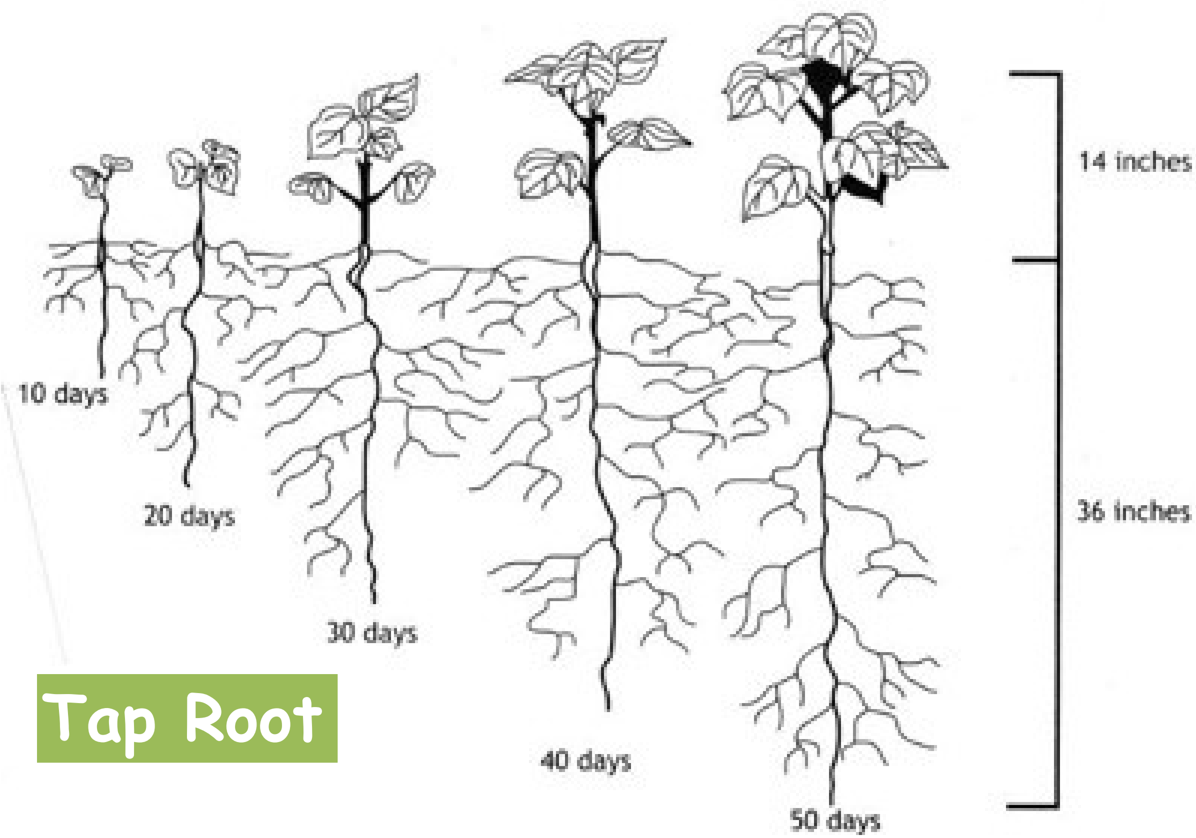
- ❖ **CT at given leaf Area is dependent on the roots to meet evaporative demand**
- ❖ **Difference between crop CT and air temp can be used as alternative approach to estimate root traits**
- ❖ **Sig. corrln. Betn Deep root biomass and a cooler crop canopy (Reynold and Tuberosa,2008)**

Root development

TAPROOT: **grows quickly and reaches to a depth of 20-25cm even before seedling emergence.**

Depth of root system usually reaches about 200-250 cm depending : soil moisture, aeration, temperature and genetic potential of variety.

Cotton plant's CHO energy is directed towards root growth prior to the reproductive growth begins



Fine root (< 2mm diameter)

Cotton has deep roots (> 1.5 m).

Early–season root development of Cotton (Oosterhuis,1990)

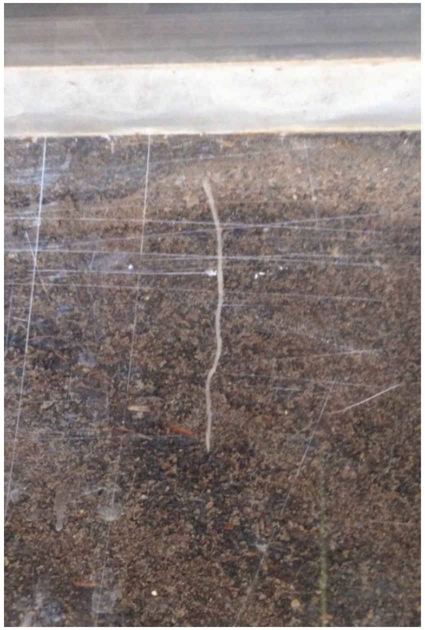
McMichael et al (1985,1987) suggested that no of vascular bundles in roots might be related to HC

Cotton root screening in PVC pipes

Fig. 1. PVC tubes filled with soil, arranged in the pit.

Fig. 2. Cotton Seedlings growing in PVC tubes.

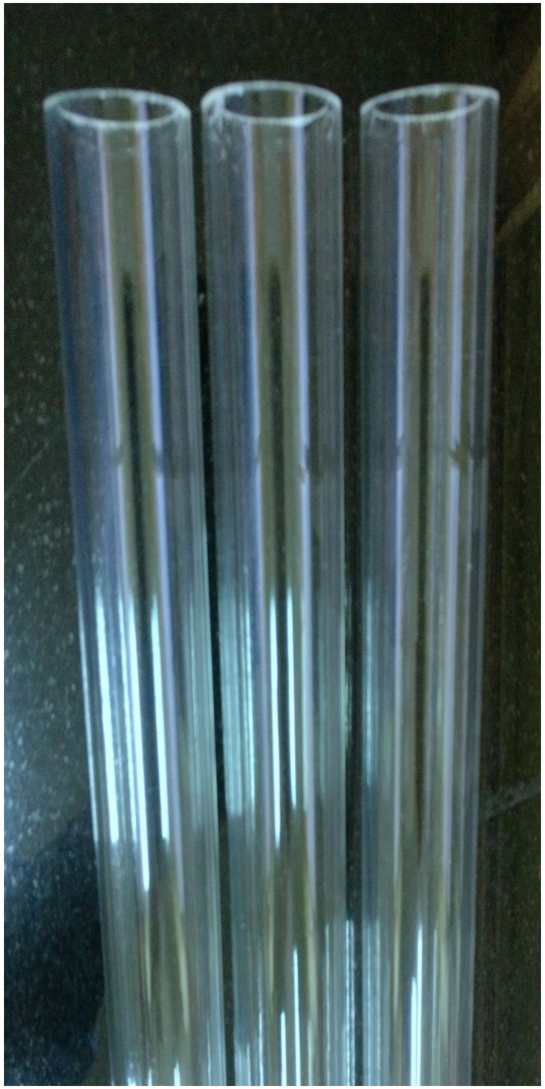
Cotton root screening in Acrylic sheet



4 day old *G.hirsutum* plant

10 day old *G. arboreum* Phule Dhanwantri

G.hirsutum germplam accession grown in acrylic tubes.

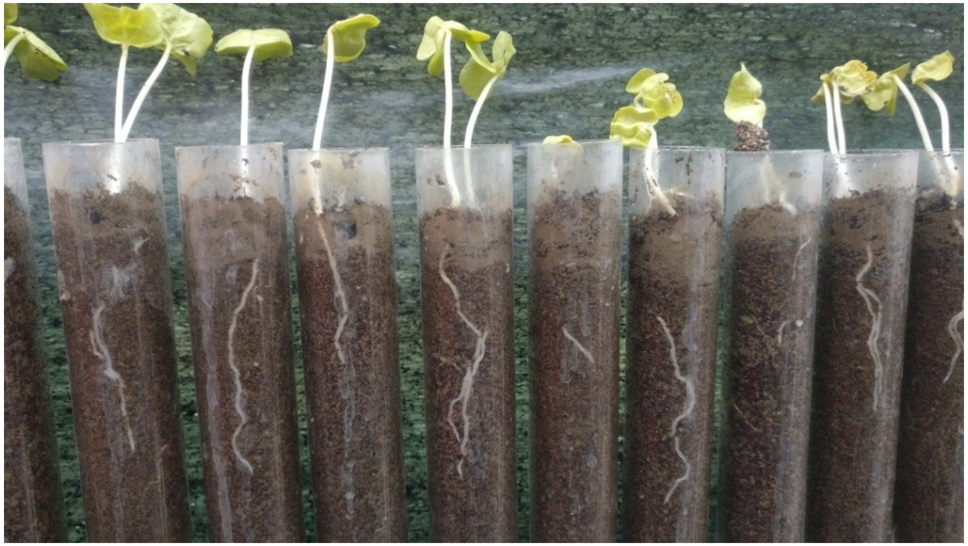


Specification: Acrylic tubes 1 m in length and 30mm outer dia & 25 mm inner diameter.

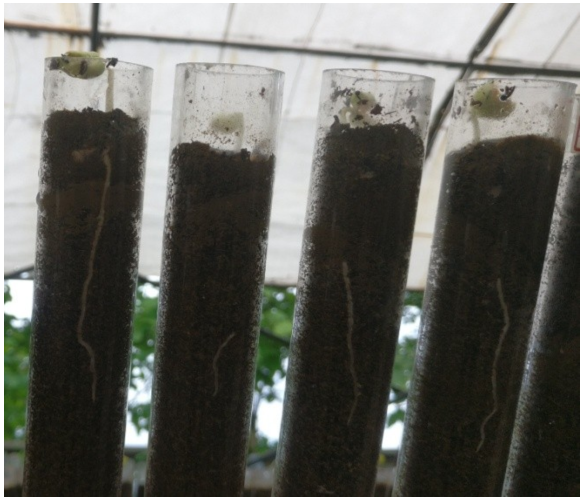
Withholding of water from 20th day	3 tubes
Withholding of water from 30th day	3 tubes
Withholding of water from 40th day	3 tubes
Normal study (daily watering)	3 tubes
Total =	12 tubes

The experiment shall be continued till 50th day or 60th day after sowing according to the growth and capacity of the acrylic tubes.

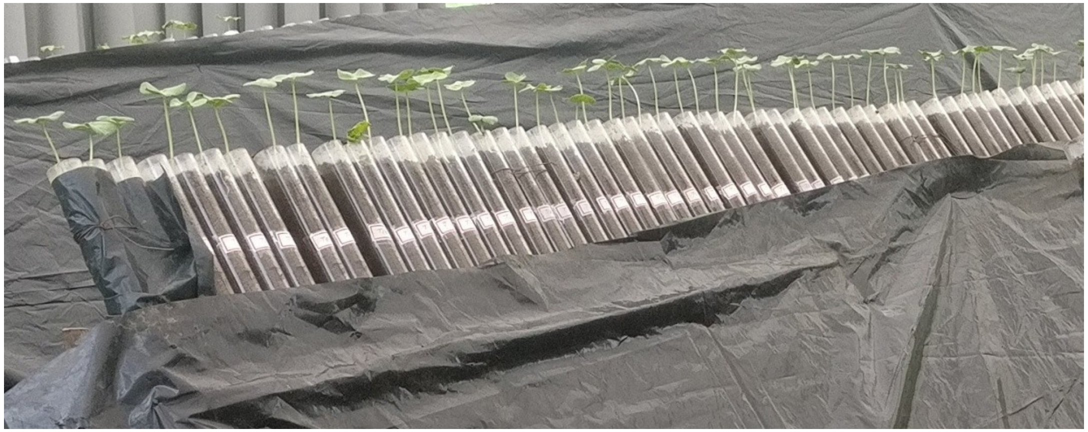
Cotton root screening in acrylic tube



4 day old G.hirsutum plant



4 day old G.hirsutum plant



5 day old G.hirsutum plant grown in transparent acrylic

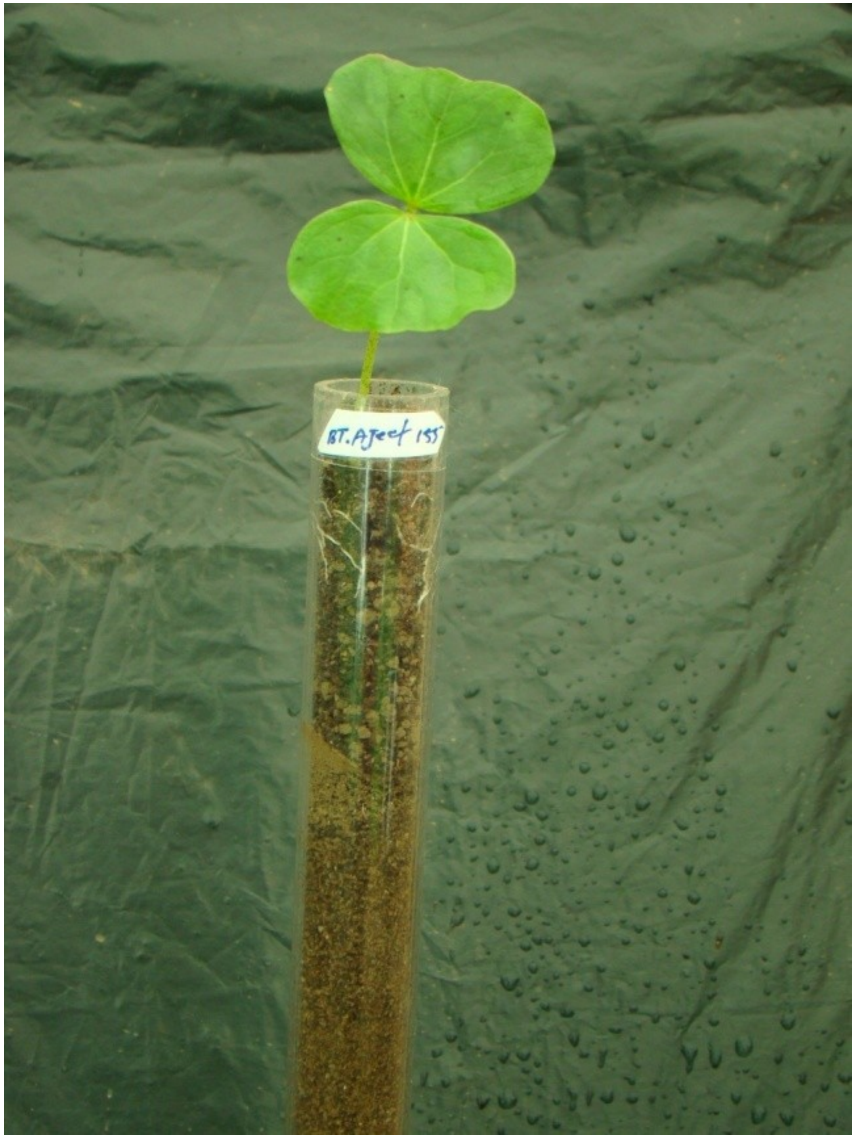
3 day old cotton plant
IC-359024

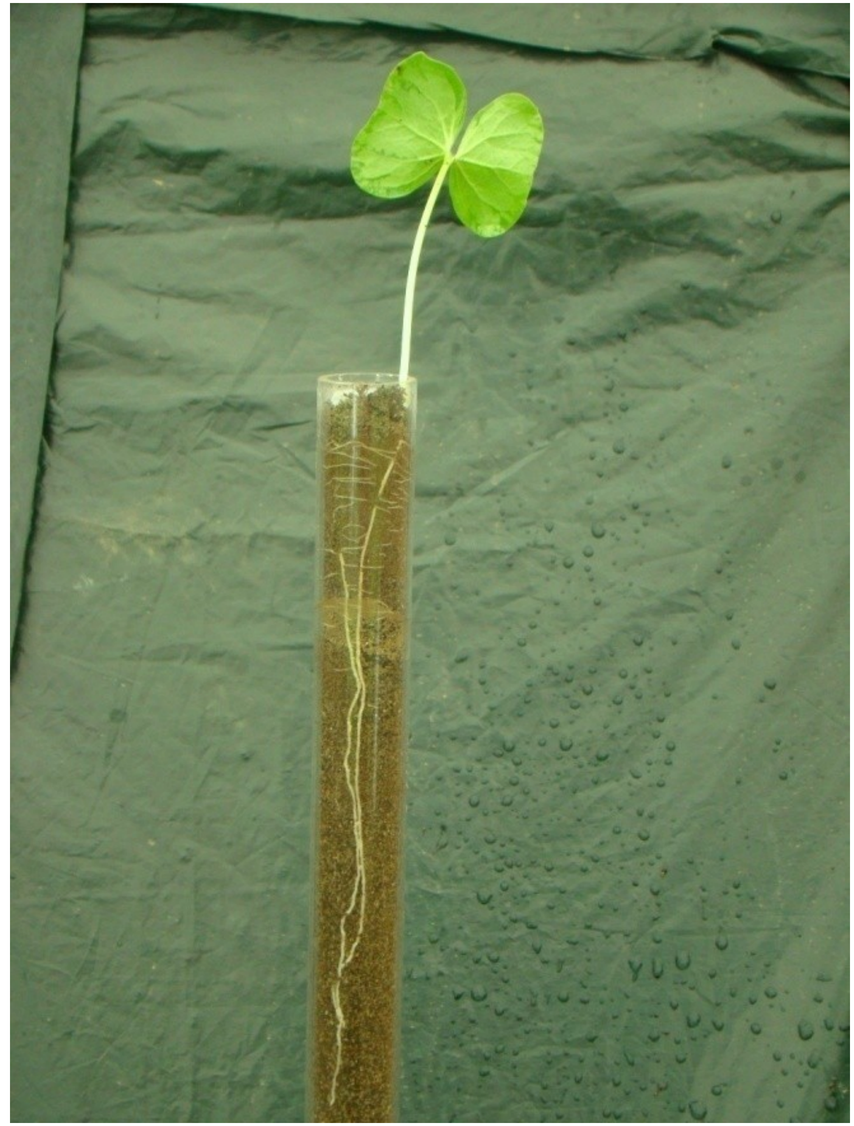
3 day old cotton plant
NH-615

15 day old cotton plant

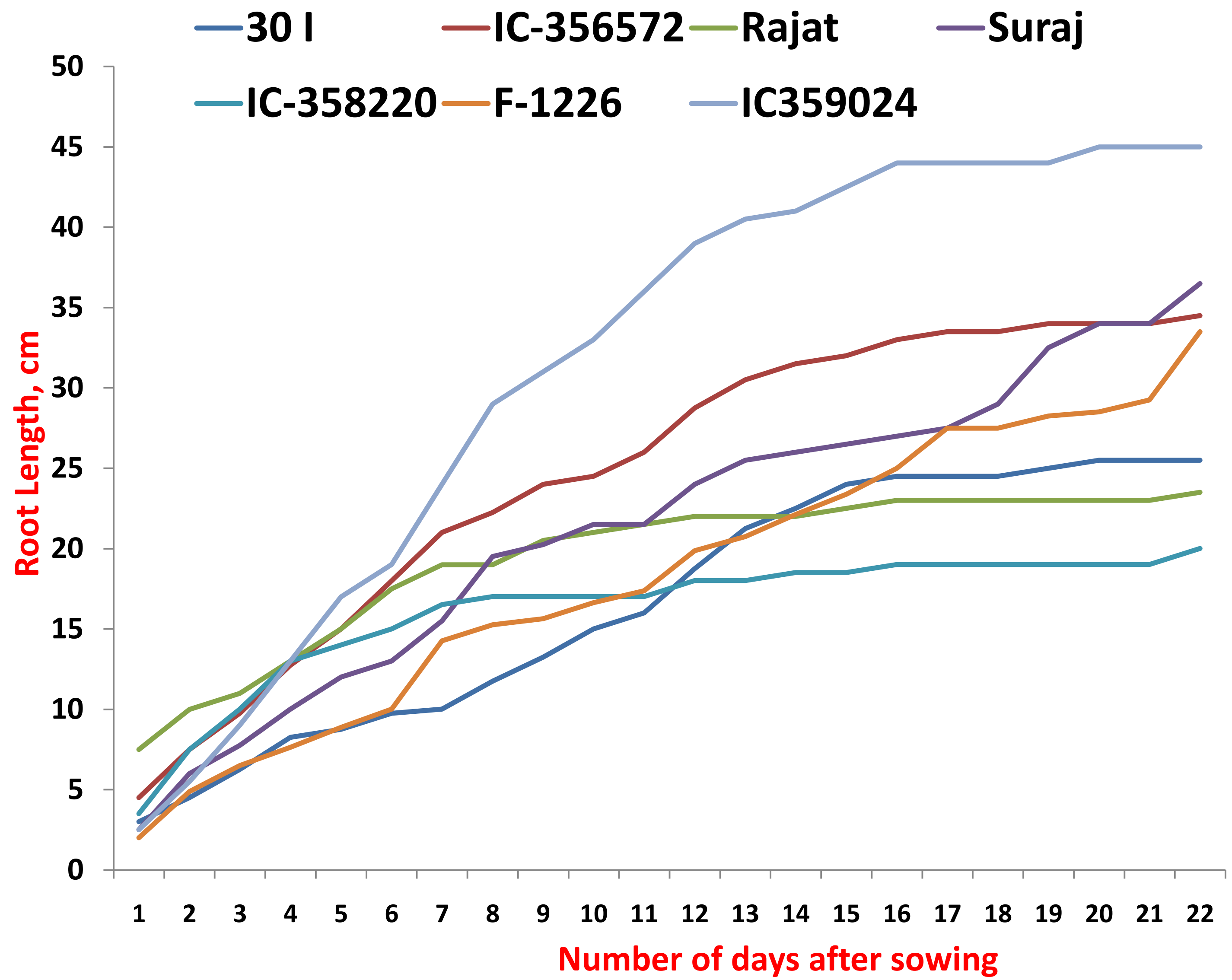
20 day old cotton plant

G.arboreum

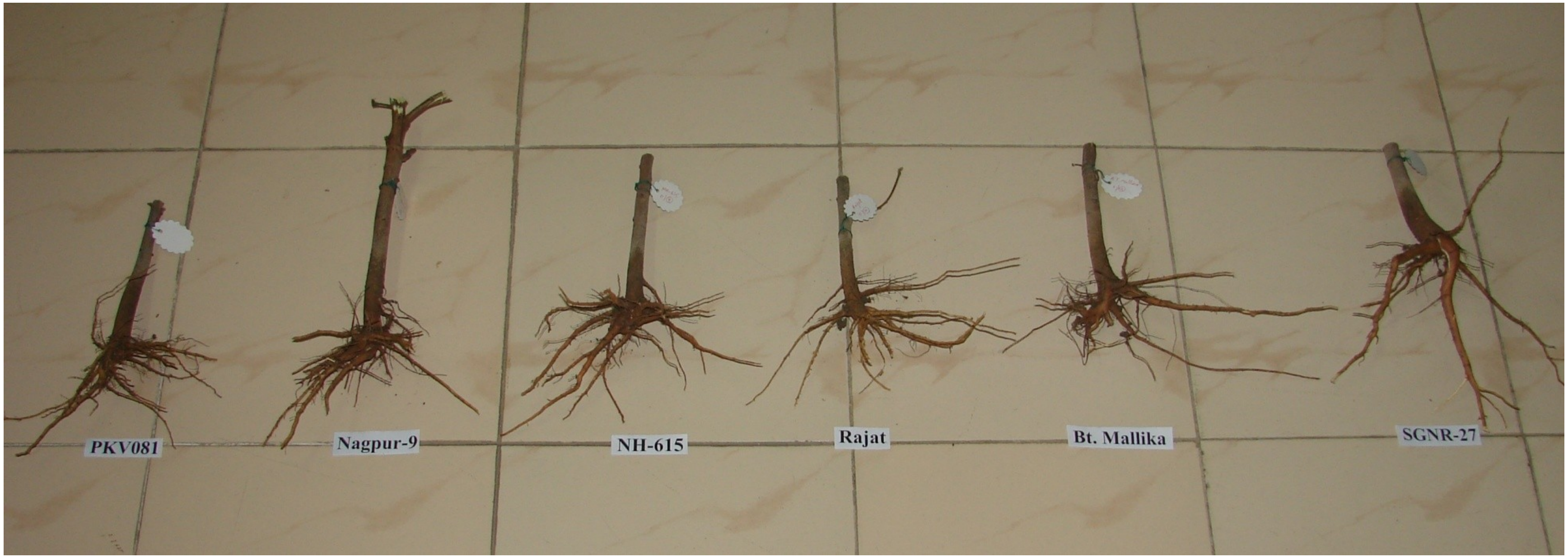


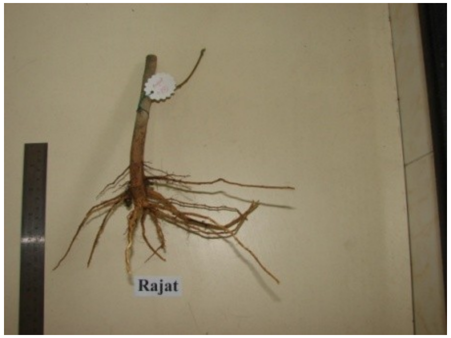


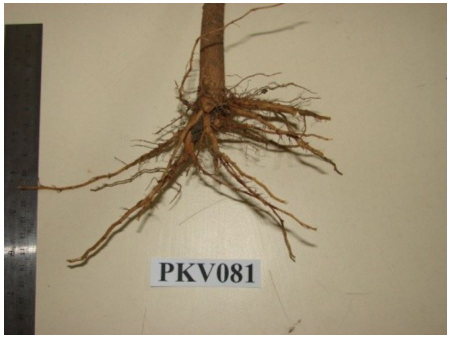
BT cotton Ajeet

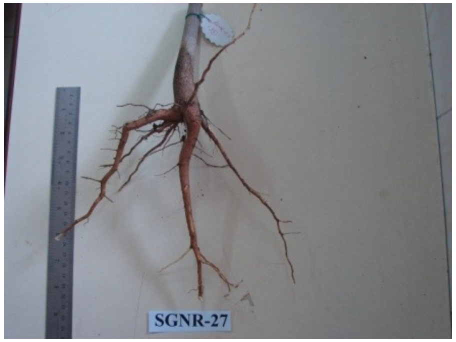

30 I
IC-356572
Rajat
Suraj
IC-358220
F-1226
IC359024
Root Length, cm
0
5
10
15
20
25
30
35
40
45
50
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Number of days after sowing

Cotton root variation in field condition









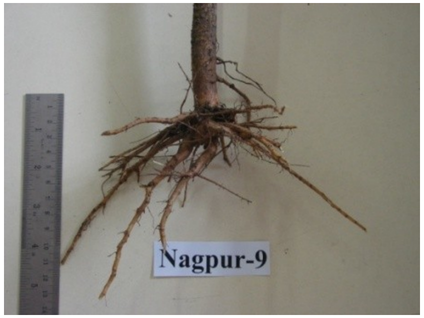


Table 1. Distribution of area (million ha) affected by various soil physical constraints in India (Painuli *et al*.,1998)

Physical constraints	Area	Main states affected
Shallow depth	26.40	Maharashtra, AP, Gujrat, Kerala , W.B
Soil hardening	21.57	Maharashtra, AP, Bihar
High permeability	13.75	Gujrat, Punjab,TN, Rajasthan, WB
Subsurface hardpan	11.31	Maharashtra, Punjab, Bihar, Rajasthan, W.B, TN
Surface crusting	10.25	Punjab, Haryana, Gujrat, WB,Odisha
Temporary Waterlogging	06.25	M.P, Maharashtra, Gujrat, Punjab, Kerala,Odisha

90 m ha of the area in the country experiences soil physical constraints

Indoria *et al*.,2017, Current science 112(12): 2405-2414

Adaptive Responses under Water logging stress

- Reorientation of Leaves and Stems
- Adventitious Root Formation and Hypertrophy
- Lenticel formation
- Fast Shoot Elongation Under Water
- Biochemical Changes Induced by Flooding: low alcohol dehydrogenase (ADH) activity

Metabolic Adaptation

- Waterlogged cotton plants had higher **ADH activity** in the roots compared to leaves and shoot. **ADH is a terminal enzyme in the ethanolic fermentation pathway converting acetaldehyde to ethanol and regenerating NAD+ in the process**

devoid of oxygen (anoxic)/
less oxygen (hypoxia)

Root growth is very much sensitive to waterlogging at early growth stages up to 45 days of sowing .

Table.1 Impact of continuous waterlogging (45 days) at different growth stages (45 and 90 DAS)

Characters	Waterlogging stress impose at			
	45 DAS		90 DAS	
	Control	Waterlogged	Control	Waterlogged
Plant Height (cm)	79	28	140	135
Leaf Area (cm^2)	1192	265	2728	25.14
Above ground biomass (g)	19.5	6.2	41.0	36.5
Root biomass (g)	**5.2**	**0.9**	**12.0**	**7.1**
Seed Cotton Yield (g/plant)	19.0	0.0	19.0	15.4

Ethylene

Plant Growth Regul
DOI 10.1007/s10725-015-0037-y

ORIGINAL PAPER

Aminoethoxyvinylglycine (AVG) ameliorates waterlogging-induced damage in cotton by inhibiting ethylene synthesis and sustaining photosynthetic capacity

Ullah Najeeb · Brian J. Atwell · Michael P. Bange ·
Daniel K. Y. Tan

Received: 1 September 2014 / Accepted: 7 February 2015

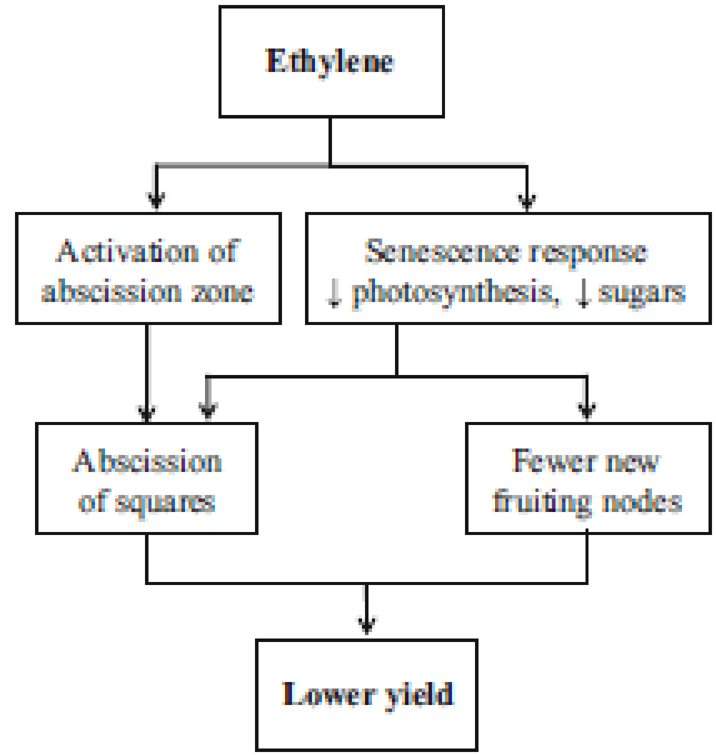
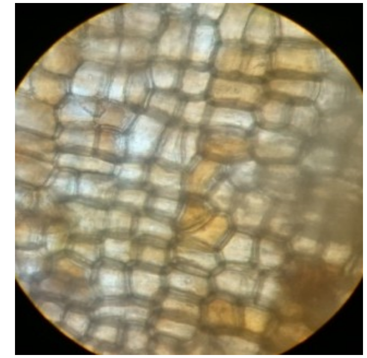


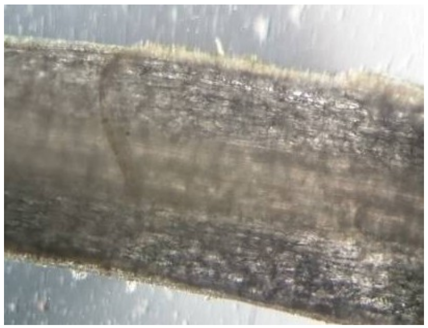
Fig. 7 Possible mechanism of ethylene-induced yield reduction in cotton under waterlogged environment

Root limitation – Oxygen supply

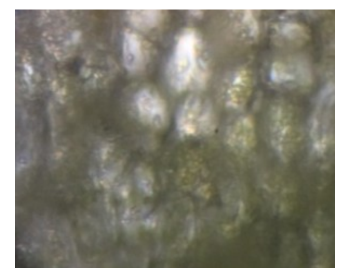
- **Due to soil water content and porosity - O_2 must diffuse to from surface through open soil pores - if closed by water logging and soil compaction – reduce root growth- plant can wilt and die**



Section of Normal area of stem



Section of Normal roots



Section of Lenticel area of stem

Adventitious roots were found to have nitrate reductase activity and hence have a role in nitrogen uptake

Adventitious root formed observed after 5-6 days of waterloging condition in the field condition of few *G.hirsutum* accessions

Lenticels formed observed after 3-5 days of waterloging condition in the field condition of few *G.hirsutum* accessions

Lenticels formed observed after 3-5 days of waterloging condition in the field condition of few *G.hirsutum* accessions

5 days after continuous water logging lenticels formed in selected *G.hirsutum* accessions

5 days after continuous water logging lenticels and adventitious roots formed in selected *G.hirsutum* accessions

2-3
dominant
Lateral root

Typical
tap root
system

Transplanted cotton crop

Direct seeded cotton crop

Zhang et al.,2017 Water 9,503;doi:10.3390/w9070503

Water logged plant / control plant

Water logged plant / control plant

Soil Compaction

ROOT PENETRATION OF A COMPACTED SUBSOIL AS A POTENTIAL COMPONENT OF COTTON GENOTYPE SELECTION FOR CULTIVAR DEVELOPMENT

O. Lloyd May, and Michael J. Kasperbauer
USDA, ARS, and Clemson University
Florence, SC

for penetration of the hardpan. Roots were scored as follows: 1) roots did not penetrate the hardpan and the entire root mass developed above the compacted layer; 2) taproot entered, but neither the taproot nor lateral roots penetrated through the compacted soil layer; 3) taproot did not penetrate, but one or more lateral roots penetrated through the hardpan; 4) taproot turned at the hardpan surface, travelled laterally until it found a weak spot, and then penetrated through the compacted soil layer; 5) the taproot entered vertically and penetrated the compacted soil layer into the subsoil, resembling root growth in mechanically disrupted subsoils or in soils lacking a hardpan. Since the data consisted of small

Figure 1. Cotton roots rated 1, 3, and 5 (L to R) on the scale used to evaluate root development over a hardpan in the field.

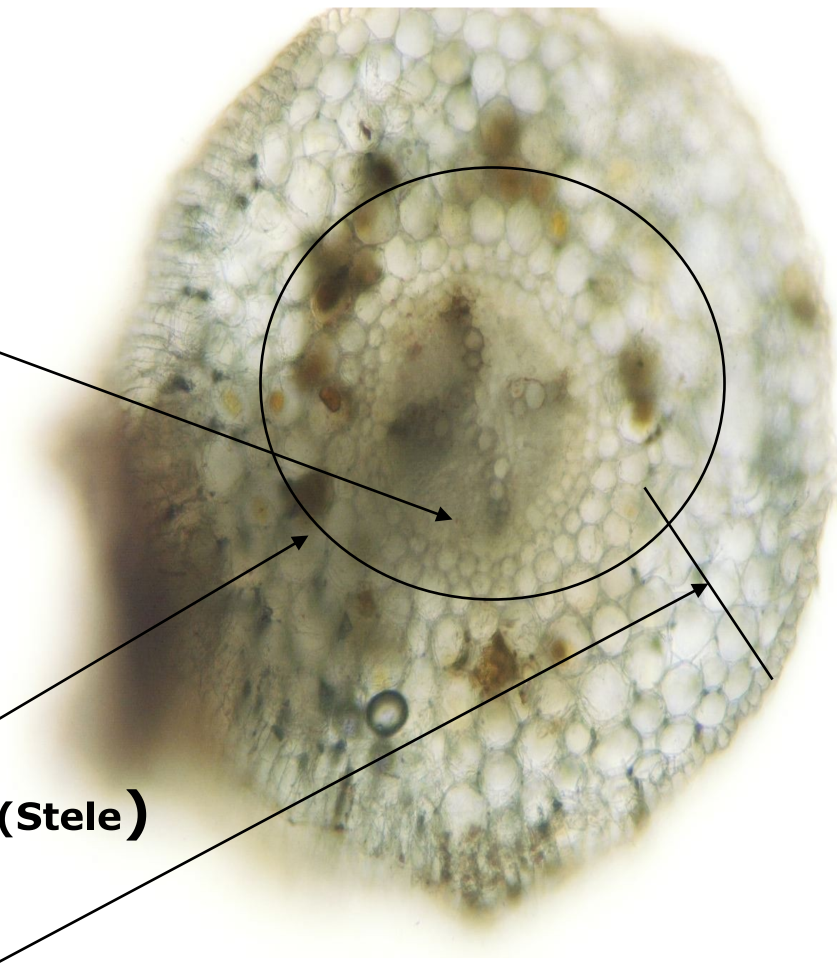
Compacted soil- increases the BD – lower root densities-inefficient in water and nutrient absorption

Cotton has a relatively low root length density when compared with other crop species. Therefore cotton plants begin to suffer water stress at higher soil water potential.

In cotton LWP at which plants become stressed is -20 bar (Hearn and Constable,1984).

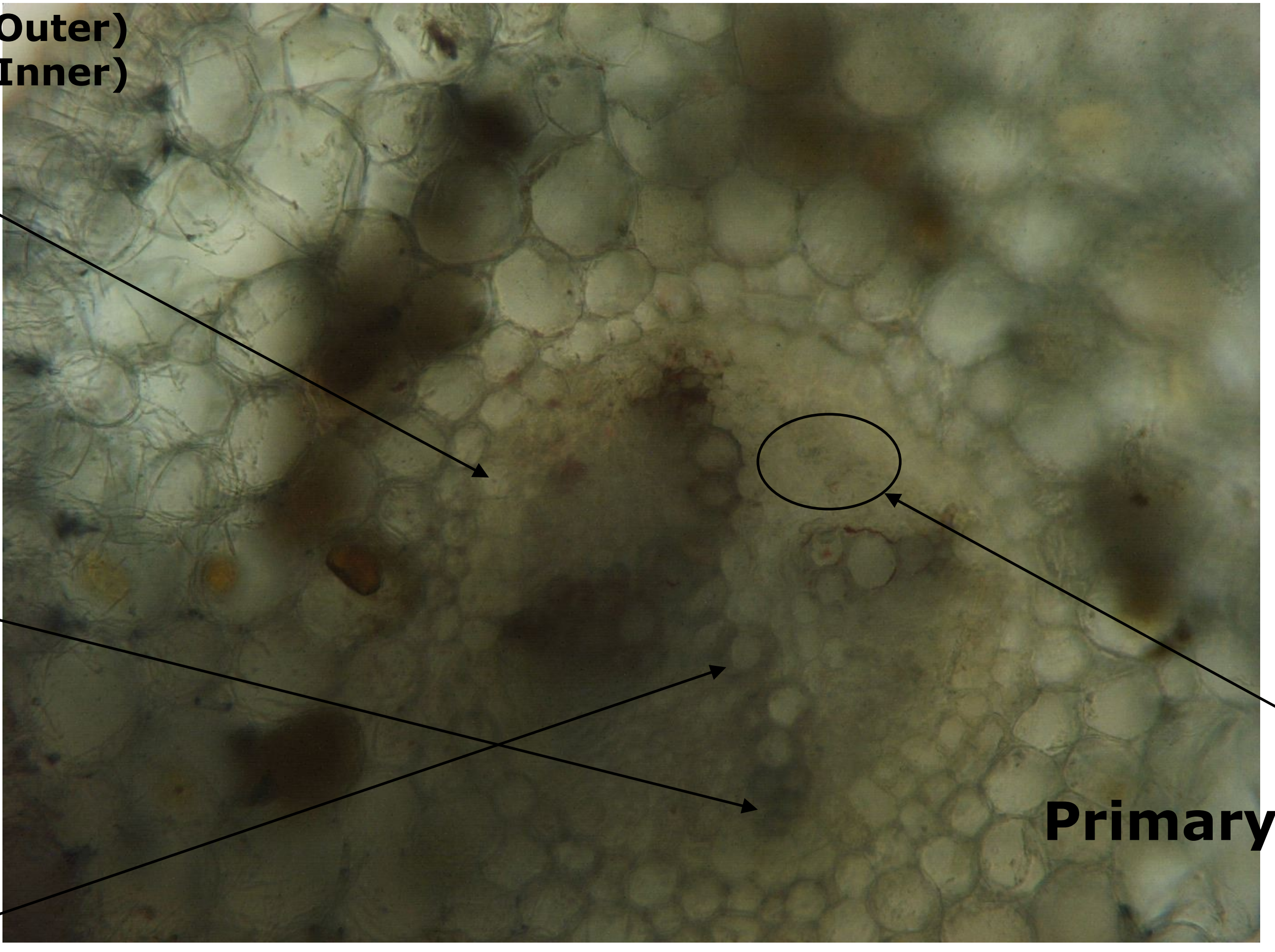
Cotton Root Anatomy

Root Cross Region of Early Differentiation (10 X)



Oosterhuis and Jemstedt(1999)

Root Cross Section
Region of Early tissue Differentiation (20X)



Oosterhuis and Jemstedt(1999)

Effect of drought stress on cotton and their responses

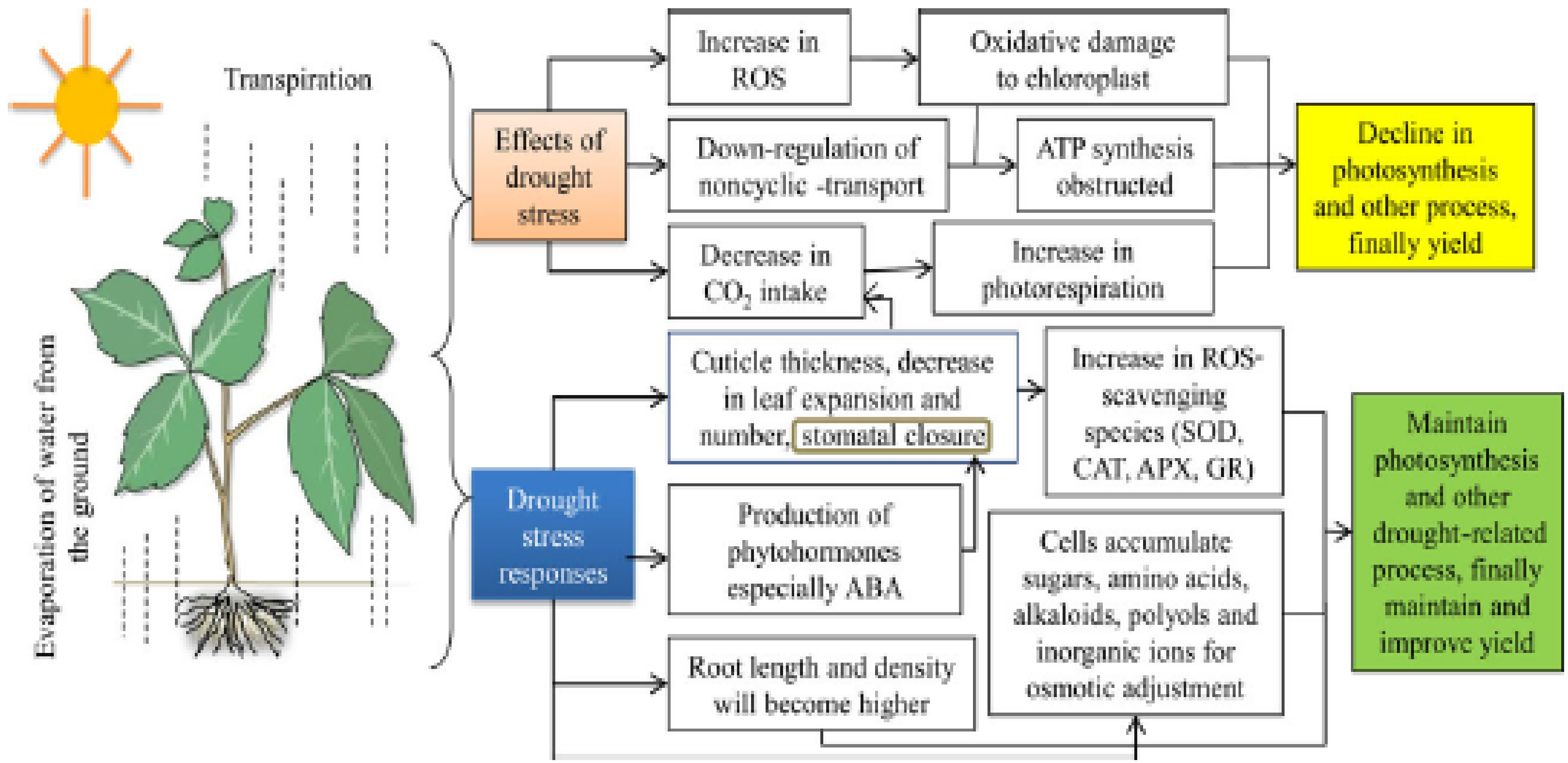


Figure 2 Numerous effects of drought stress on cotton and their responses.

Ullah et al., 2017

Adaptive Responses under drought stresses

- Deep root system
- More profuse (higher root length density)
- Higher Root – Shoot ratio
- Osmoregulation
- Increase in abscission of fruiting part
- Increase in proline content

devoid of moisture

- Presence of small roots: more surface area to increase water uptake
- Rhizodermis: suberized exodermis
- Reduction in no of corticle layers
- Hydro patterning: lateral root branching
- Hydrotropism: degradation of amyloplasts in the columella cells in response to drought stress

Source: Abiotic Stresses in Cotton: A Physiological Approach, **CICR TECHNICAL BULLETIN NO: 2 ,** ;Henry et al.,2012

Mechanism of drought tolerance and root traits

- Distance from transition zone to 1st main lateral root
- Taproot weight
- No of lateral roots
- Seedling vigor
- Rapidity of root system development
- Root to shoot ratio (Cook, 1985)
- Longer tap root length (Pace et al.,1999)
- Increase in RLD In soil layer between-70-180 cm in drying profile

Root morphology in response to drought stress (Adaptive)

TF MYB96 has been shown to regulate activation of **lateral root meristem** through an **ABA signaling cascade**, with an activation-tagged mutant showing enhanced DR with reduced lateral root formation.

The plant **microRNA miR393** has also been shown to play a role in root-mediated adaptation to drought stress response through attenuation of **auxin signaling**.

In addition to the lateral roots, the presence of **small roots** is also considered as an adaptive strategy to increase water uptake by providing more absorptive surface.

Presence of specialized tissues like **rhizodermis,** with a thickened outer cell wall or suberized exodermis, or **reduction in the number of cortical l**ayers are considered an adaptive advantage for drought stress survival.

Hydrotropism is another adaptive measure taken by plants to counter stress, where studies have shown that **degradation of amyloplasts** in the **columella cells** of plant roots on exposure to drought stress **increases hydrotropism**.

Hormonal cross-talk mediated by auxin, CK, GA, and ABA has been implicated as a potential chemical signal in response to water stress to modulate RSA.

The expression of enzymes related to root morphology (e.g. **xyloglucan endotransglucosylase**) is induced upon **mild drought stress**, while other structural proteins are down-regulated, which is strongly correlated with root growth and hence an augmentation in the surface area for water uptake.

Traits, For example, **suberization and compaction of sclerenchyma layer cells** were shown to decrease in rice under drought, which increases retention of water under drought stress.

Ref: Basu et al., (2016). Plant adaptation to drought stress [version 1; referees: 3 approved] F1000Research 2016, 5(F1000 Faculty Rev):1554 (doi: 10.12688/f1000research.7678.1)

Root system architecture:

Root system is to uptake water and nutrients from the soil through its highly responsive and plastic morphology, which allows the plant to adjust and **exploit the varying soil physical and chemical properties (**Armengaud et al., 2009).

❑ An increased depth and density of roots is considered a major mechanism for improving water uptake under drought conditions (Turner, 1986).

Alteration of root hydraulic conductance by different anatomical and biochemical traits provides the plants the ability to regulate plant water use for the critical crop stages (Vadez, 2014).

Screening for root architectural traits is one of the major bottlenecks in root research due to the difficulties associated with separation of a whole root system from the soil and the huge amount of time and labour requirements for field evaluation.

RSA assays : for root observation are

- Chambers (Singh et al., 2010)
- Soil-less media (Manavalan et al., 2010)
- Image-based phenotyping platforms (Hund et al., 2009; Iyer-Pascuzzi et al., 2010)
- Tools to analyse the images such as : RootFlow (van der Weele et al., 2003),
- EZ-RHIZO (Armengaud et al., 2009)
- RootTrace (French et al., 2009) are showing exciting opportunities to understand the root traits and apply them in crop improvement.

Table 2. Shoot:root ratios in drought-treated and control plants of Stoneville 506 and Tamcot HQ95 at the end of the drought 49 d after planting and after a recovery period (59 d after planting).† Means are followed by standard errors of the means in parentheses.

Treatment	Shoot :root ratio	
Treatment	49 d after planting	59 d after planting
Drought	5.4 (±0.4) ***	5.9 (±0.5)
Control	8.5 (±0.6)	6.3 (±0.5)

*** Means in column are significantly different at the 0.001 probability level.

† The drought treatment was imposed by withholding water for 13 d. Recovery involved supplying sufficient water and nutrients for 10 d.

Pace et al.,1999

Table 3. Taproot lengths and dry weights and secondary root lengths and dry weights in drought- treated and control plants of Stoneville 506 and Tamcot HQ95 at the end of the drought 49 d after planting.† Means are followed in parenthesis by standard errors of the mean.

	Treatment	
Plant part	**Drought**	**Control**
Taproot length (cm)	**24.5 (±1.4)***	**18.9 (±1.2)**
Taproot dry weight	**0.260 (±0.0227)**	**0.260 (±0.031)**
Secondary root length (cm)	**52.2 (±6.7)**	**42.5 (±4.9)**
Secondary root dry weight (g)	**0.221 (±0.030)**	**0.188 (±0.027)**

* Means in a row are significantly different at the 0.05 probability level.

† Recovery involved supplying sufficient water and nutrients for 10 d after withholding water for 13 d.

Pace et al.,1999

Table 4. Taproot lengths and dry weights and secondary root lengths and dry weights in drought-treated and control plants of Stoneville 506 and Tamcot HQ95 after a recovery † period at 59 d after planting. Means are followed by standard errors of the means in parentheses.

	Treatment	
Plant part	**Drought**	**Control**
Taproot length (cm)	27.1 (±1.2)*	22.5 (±1.1)
Taproot dry weight	0.381 (±0.037)*	0.493 (±0.041)
Secondary root length (cm)	67.5 (±6.7)*	96.4 (±8.9)
Secondary root dry weight (g)	0.301 (±0.035)*	0.474 (±0.049)

* Means in a row are significantly different at the 0.05 probability level.

† Recovery involved supplying sufficient water and nutrients for 10 d after withholding water for 13 d.

Pace et al.,1999

Best *G.hirsutum* germplasm accessions in term of root dry weight

Entry	Germplasm Name	IC-Number	Mean Dry wt. including seed cotton /PL (g)	Percentage of each component by weight					Estimated Biomass (t/ha)	H.I
				Root	Stem	Leaf	Seed	Lint		
1	LH372	359024	165	**20.1**	40.7	17.3	14.7	7.2	4.1	0.22
2	SA279	359666	154	**13.1**	48.4	16.3	15.0	7.2	3.8	0.22
3	Albar 57	358912	132	**11.1**	52.8	18.4	11.9	5.8	3.3	0.18
4	LRA-5166		128	**10.0**	43.8	14.1	21.5	10.6	3.2	0.32
5	EC 12400		148	**12.2**	54.5	26.3	4.8	2.2	3.7	0.07
6	CTI-310-16	357057	130	**12.5**	43.8	24.6	12.9	6.2	3.2	0.19
7	Deltapine-45	357103	187	**11.9**	51.2	19.7	11.6	5.7	4.7	0.17
8	479 SR		130	**12.5**	51.7	11.7	16.2	7.9	3.2	0.24
9	P237/68	357825	187	**11.0**	50.9	16.7	14.4	7.1	4.7	0.22
10	AC 135	356572	177	**10.8**	62.4	13.8	8.9	4.4	4.4	0.13

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Best *G.barbadance* germplasm accessions in term of root dry weight

Entry	Germplasm Name	Biomass/plant (g)	Root weight per plant (g)	H.I
1	EC-9254	248.7	**25.00**	0.24
2	ERB13758	258.7	**20.00**	0.27
3	CV-76	273.5	**22.00**	0.46
4	EC-142371	85.0	**20.00**	0.23
5	EC-104729	340.0	**23.30**	0.29
6	SIV 135-18	128.6	**20.00**	0.30
7.	C 6002-3	313.0	**24.00**	0.30

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Best *G.arboreum* germplasm accessions in term of root dry weight

Entry	Germplasm Name	Biomass/plant (g)	Root weight per plant (g)	H.I
1	30845	66.6	**20.30**	0.19
2	C-520	36.6	**19.1**	0.33
3	Malvi-11	75.5	**18.5**	0.29
4	Desi-97	42.8	**17.5**	0.33
5	AKA-28	144.7	**14.5**	0.29
6	JLH-7	58	**17.2**	0.39
7.	LD-135	35.0	**17.1**	0.44

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Best *G.herbaceum* germplasm accessions in term of root dry weight

Entry	Germplasm Name	Biomass/plant (g)	Root weight per plant (g)	H.I
1	2334-584	286.2	**30.20**	0.26
2	179-1-2P	214.3	**26.90**	0.25
3	DB-3	278.7	**29.9**	0.25
4	G.Cot-13	249.5	**27.30**	0.22
5	Type 7-2	266.1	**28.5**	0.25
6	Vijalpa	231.3	**26.2**	0.22
7.	Yerli-197-3	214.5	**25.4**	0.27

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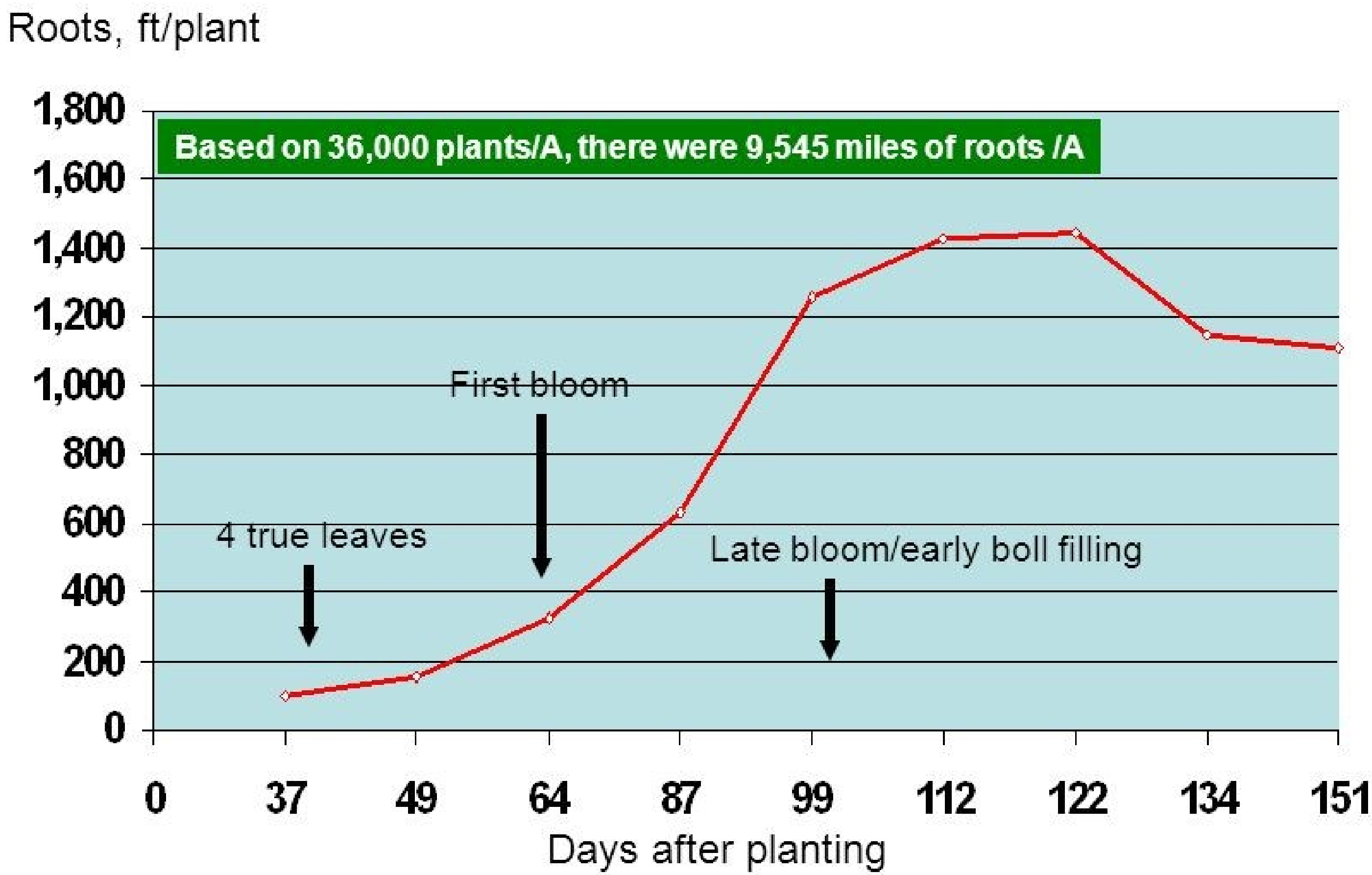
Cotton Root Length as Affected by Days After Planting (Field Study)



Source: Schwab, Mullins & Burmester, 2000

Bt- Hybrid Cotton root morphology

- In India more than 95 % area covered by Bt-Hybrids
- In some area Bt-Hybrids have been found to have **shallow roots (30 cm)** due to **early onset of reproductive phase**
- **Synchronized boll development in Bt plants altered source-sink relationship and led to early crop maturity (Hebber et al.,2007)**
- Due to **hard-pan** of the soils or surface irrigation during early seedling stage

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BMC Genomics

RESEARCH ARTICLE Open Access

The *PIN* gene family in cotton (*Gossypium hirsutum*): genome-wide identification and gene expression analyses during root development and abiotic stress responses

Peng He[1,2†], Peng Zhao[1†], Limin Wang[3†], Yuzhou Zhang[2], Xiaosi Wang[2], Hui Xiao[2], Jianing Yu[2*]

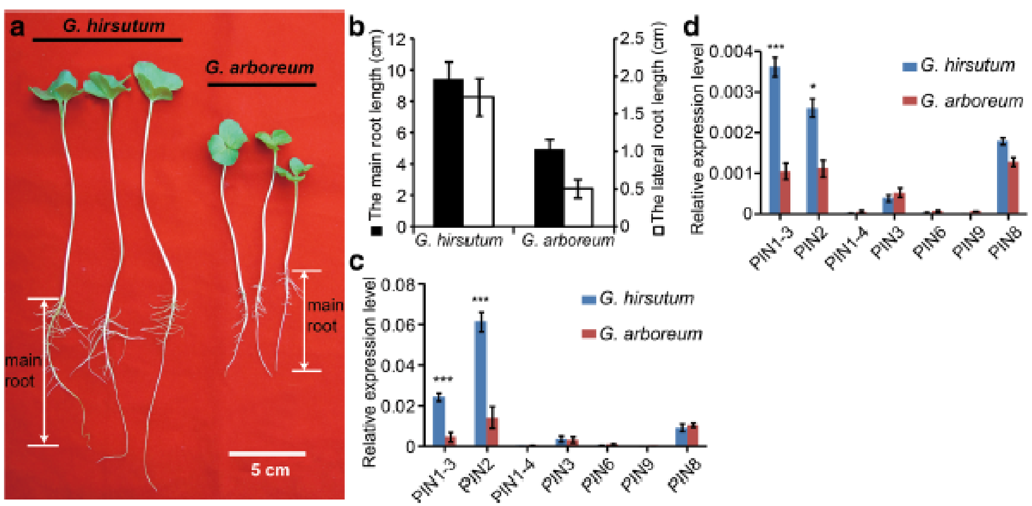


Fig. 4 The development of main and lateral roots in *G. hirsutum* and *G. arboreum*. **a** Comparisons of main and lateral root lengths of three-week-old *G. hirsutum* and *G. arboreum* seedlings. Bar = 5 cm. **b** Measurements of main and lateral root lengths of *G. hirsutum* and *G. arboreum* seedlings as shown in (**a**). Statistical analyses were carried out on three independent experiments. A total of 9 seedlings were used for each measurement. The lateral root length in this figure represents the average lengths of all investigated lateral roots. Root lengths are shown as means ± SE. Closed bars with scales to their left side and open bars with scales to their right side indicate the main root lengths and the lateral root lengths, respectively. **c**, **d** The relative expression of *PIN* genes in main (**c**) and lateral roots (**d**) from three week old plants, qRT-PCR experiments were performed on three biological replicates. Error bars represent means ± SE from three independent experiments. The relative expression level was determined using cotton *UBQ7* as a control

gene family in *G. hirsutum*. We showed that *PIN1–3* and *PIN2* are involved in cotton root development. This study will help us to elucidate the precise role of *PIN* genes in cotton root development and in adaption to abiotic stress. Our findings will also further help breeding efforts to develop and select the lodging-resistant varieties in the future.

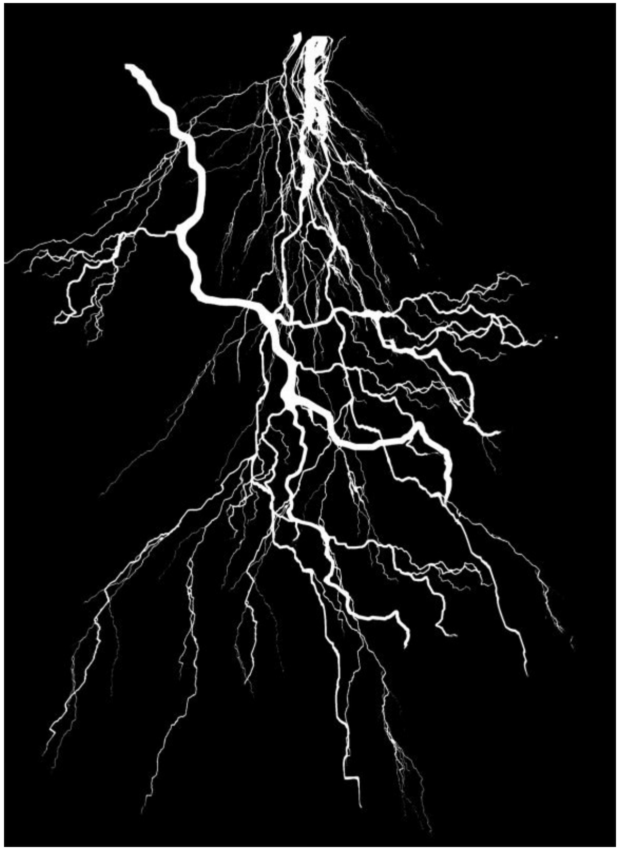
precise roles of *PIN* genes in cotton root development and in adaption to stress responses.

Challenges

- Nutrient acquisition under changing environmental conditions through roots.
- RSA is an important trait for genetic improvement of nutrient acquisition from nutrient limiting soils.
- In rice, DEEPER ROOTING 1 (DRO1) is expected to enhance grain yield under drought conditions by altering RSA.
- One major challenge will be to reconcile the optimal root architectures for, for example, N and P acquisition in one root system. Since the optimal RSA is also related to the carbon status of the plant, planting density, and air temperature .
- Use of cell- or tissue-specific promoters to control the branching density and root length will overcome this challenge . (Kong et al.,2014).

Conclusion

- Lack of proper phenotyping strategy for root traits
- Low heritability for root traits the most important constraints
- Existing genetic variability for root traits can be exploited
- Selection for and incorporation of increased seedling vigour, rapid root system establishment and lower root-shoot ratio into future cotton genotypes to improve drought tolerance .
- Sub soiling prior to planting to improve root development
- Sufficient Soil 0_2 is necessary for root development

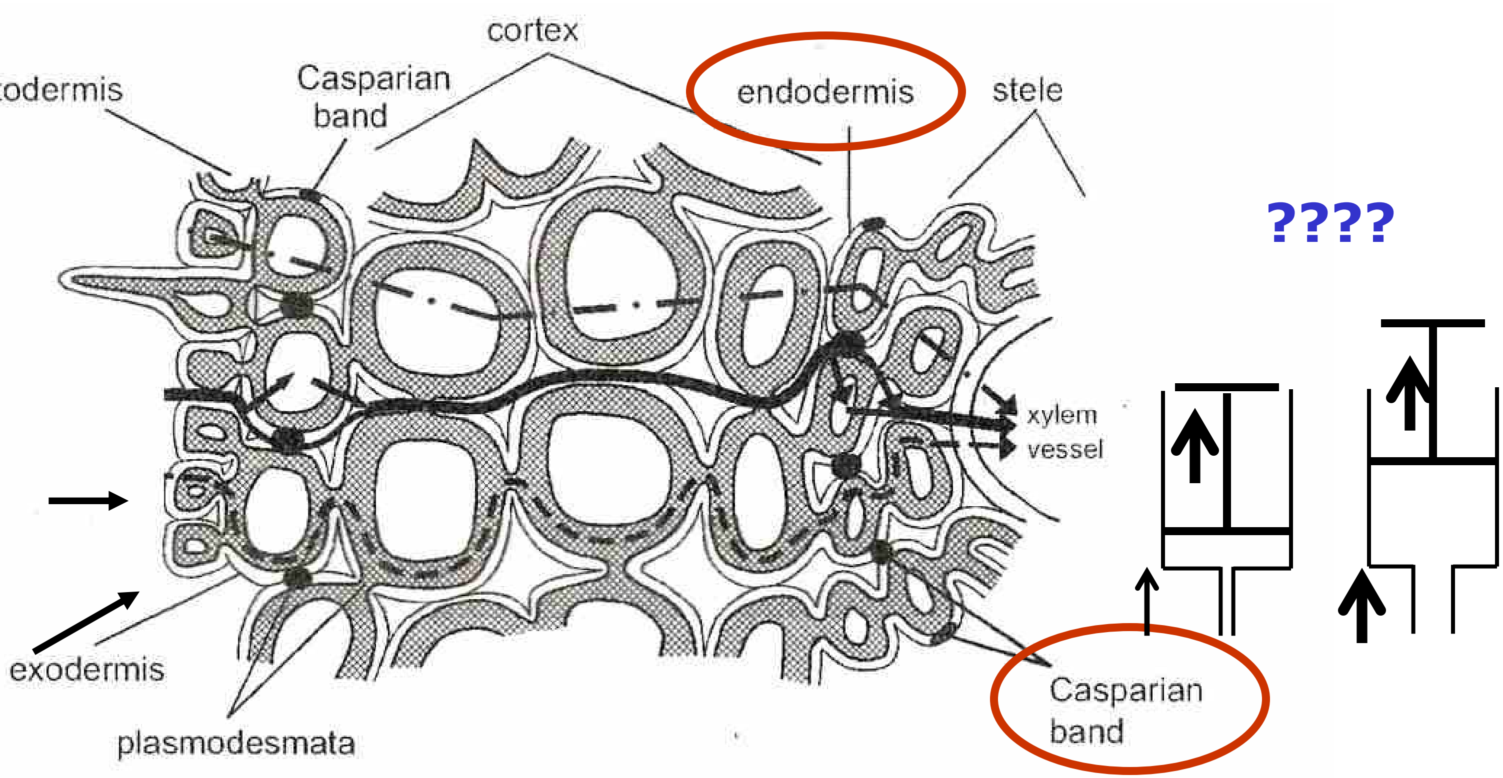


Thank you !!

Transport pathways in the root cylinder (Steudle, 2000)

Apoplastic Pathway (structural)

Symplastic Pathway (AQP)



Different pathways have different hydraulic conductance
Symplastic pathway is regulated by aquaporins

Two pathways have different hydraulic conductance

Hypothesis: Genetic and physiological regulation of aquaporing critical to control plant water loss

Hypothesis: Aquaporin control plant water loss ?