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ROOTS, GROWTH AND NUTRIENT UPTAKE

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While most of us are quite familiar with the growth and development of the above ground parts of crops, few of us are as familiar with how the root system grows and develops and how this effects nutrient uptake. This is understandable since looking at plant roots requires a great deal of effort. In fact, very little research is done which looks at the effects of production practices, compaction or weather on the root system.

The general objective of this paper will be to familiarize you with some of the research which has been done on how the root system develops and factors which can impact root system development. Specific objectives include:

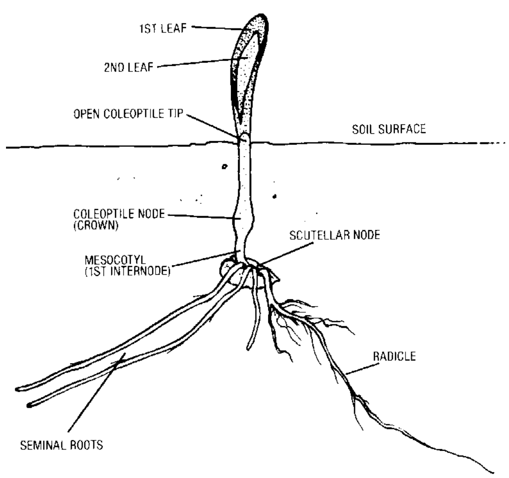
1. How the root system develops over time and the relationships between root growth, shoot growth and nutrient uptake.

2. How nutrients get to the root and the process of nutrient uptake.

3. The effects of weather and management practices on root growth and nutrient uptake.

Corn growth and development-above and below ground.

Figure 1

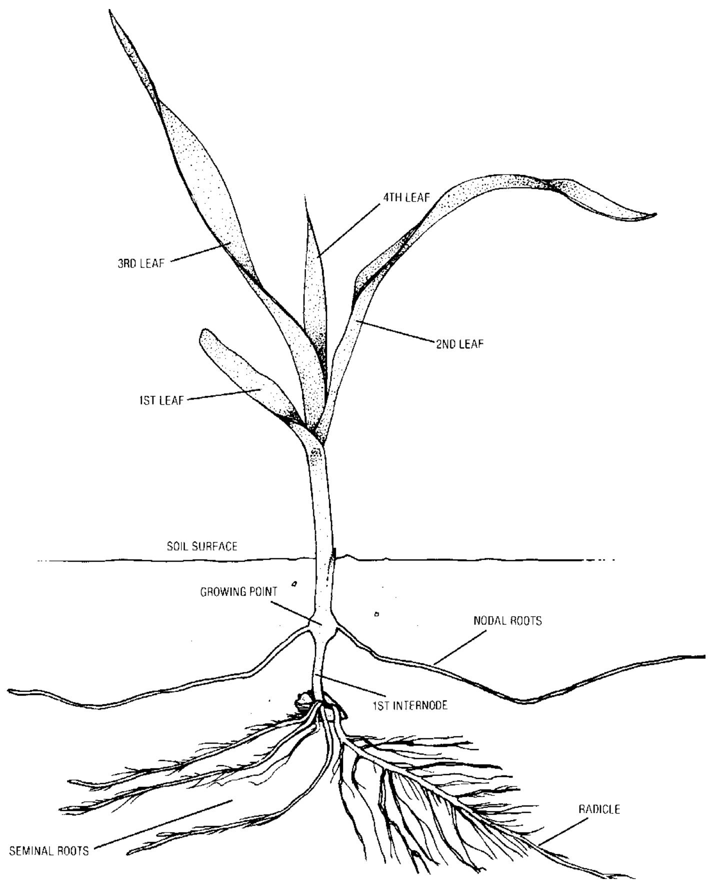


Normal growth patterns. Corn is a grass and has a fibrous type root system, as compared to soybeans or alfalfa which have tap root systems. When a corn seed germinates, the radicle, or primary root, elongates and breaks the seed coat. It is followed shortly by the coleoptile which surrounds the shoot, and then 2 to 5 seminal roots (Figure 1). This initial seminal root system anchors the young plant and absorbs water and nutrients for the first two to three weeks. Within a few days after emergence of the coleoptile and first leaves from the soil, a second root system, the nodal roots begin to develop from the crown or growing point (Figure 2).

Under most conditions the nodal root system rapidly develops and becomes the dominant root system in just a few days. Normally within a month of emergence, the seminal or seed roots begin to die. All of the remaining roots of corn develop from the nodes of the plant. As internodes elongate and the growing point moves above ground, roots are initiated at the first two or three nodes above the soil surface. These are commonly referred to as brace roots.

Some data collected at Purdue and reported in Table 1 illustrates the relationship between shoot growth, root growth and the nutrient content of the plant over the course of a growing season. The hybrid used, P3369A, was a full season hybrid requiring about 2800 heat units, growing degree days base 50, to reach maturity. At seeding (21,700 plants per acre) 14 lbs of dry matter were planted. Twenty one days later, roughly the 4 leaf stage, dry weight had only increased to 29 lb./acre. However, at that point there were 54 miles of roots per acre, located primarily in the top foot of soil. During the first three weeks after planting total nutrient uptake consisted of 0.7 lbs N, 0.12 lbs P and 0.77 lbs K.

Figure 2



Over the next 50 days, from 21 to 71 days after planting, the plant completed its vegetative growth phase. Over 9,000 lbs of stover per acre were produced and the root system increased from 54 miles per acre located in the top foot 21 days after planting, to 32,000 miles of roots per acre growing down to 3 feet where dense glacial till provided a barrier to further growth.

At 71 days after planting, July 12, the plants began to tassel and started the process of shifting from vegetative to reproductive growth. At tasseling the crop had taken up 73% of the N, 74% of the P and 85 % of the K which would be accumulated.

Over the next three weeks, from 71 to 93 days after planting, growth and increased dry matter was concentrated in the developing ear. During these early stages of ear development nutrient uptake slowed down as the plant shifted gears from producing leaves to producing grain. Dry matter production also slowed as this shift occurred. This slowing of nutrient uptake and dry matter production has been noted in a number of growth analysis studies.

Table 1. Shoot weight, root weight and nutrient content of corn at various stages during the growing season.

Growth stage	DAS (days)	Shoot dry weight (lb./acre)	Root length (miles/acre)	Nutrient content N	P (lb./acre)	K
Seeding	0	14	0	0.2	0.04	0.03
4 leaf	21	29	54	0.9	0.16	0.8
9 leaf	34	400	4,400	19	2	19
Shoulder high	49	3,300	15,700	116	12	143
Tassel	71	9,500	32,200	199	28	231
Late silk	79	11,200	38,100	218	29	222
Blister	93	14,200	38,000	221	34	217
Grain fill	113	19,800	20,700	262	39	269
Black layer	132	20,800 (whole plant) 9,650 (grain)	13,700	274	37	235

DAS = Days after seeding.

Between two and five weeks after pollination, roughly blister to full milk/dent, kernel fill proceeded rapidly and the balance of nutrient uptake occurred. At this time the root system began to senesce and die off. Actual decreases in total root length were seen after the late blister stage. By 113 days after planting root length had dropped from 38,000 miles per acre to 20,000 miles per acre. The lower leaves of the plant also began to die back as the plant got rid of "excess baggage" as it neared maturity.

During the last three weeks prior to black layer and maturity, the root system and lower leaves continued to senesce as the plant channeled photosynthate to the developing grain. Only about 5% of the total dry matter was produced during these last few weeks prior to black layer. Essentially no nutrient uptake occurred. In fact K content of the plant decreased as leaf tissue died and the K leached out with fall rains.

At maturity, 132 days after planting, over 20,000 pounds of dry matter, roots, stover and grain had been produced. In this example 46% of the dry matter was deposited in the grain, with a final yield of 204 bushels per acre.

This is just one example of how corn grows and develops. Root growth normally parallels stalk growth and will reach a maximum some time around silking. But a number of factors such as weather, compaction, fertilization practices, genetics and pests can alter the size of the root system, where it is located in the soil and the coordination of root and stalk growth.

Genetic differences. An example of differences in root growth patterns between hybrids is found in a study by Barber and MacKay (1986). They found that the time required for the maximum root growth, growth stage at which senescence began and the maximum root length per plant were quite different between a full season hybrid, Mo17xB73 and a short season hybrid P3732.

The short season hybrid produced a maximum of 2,550 feet of roots per plant with maximum root length found 75 days after planting, at silking. The full season hybrid produced 4,670 feet The short season hybrid produced a maximum of 2,550 feet of roots per plant with maximum of roots per plant and maximum root length occurred 91 days after planting.

Table 2. Effect of applied N on the growth, N uptake and yield of two corn hybrids.

Hybrid and N Treatment	Days to Maximum Root Growth	Root length per plant	N Uptake	Grain Yield
	(days)	(feet/plant)	(lb. N/acre)	(bu/acre)
B73xMo17				
0 N	91	2,880	103	79
200 N	91	4,670	177	114
P3732				
0 N	75	2,460	103	79
200 N	75	2,550	159	100

They also varied N levels and found that at O N both hybrids had similar root length, N uptake and yield. However at 200 lbs N the full season hybrid produced more roots, took up more N and had a higher yield.

This data illustrates that corn hybrids can differ in how the below ground parts respond to management, just like they differ in yield potential and other characteristics.

<u>The nutrient uptake process.</u>

Movement of nutrients to roots. For nutrient uptake to occur, the individual nutrient ion most be in position adjacent to the root. This process of positioning occurs through three basic ways. The root can "bump into" the ion as it grows through the soil. This mechanism is called root interception. Work by Barber estimates that perhaps one percent of the nutrients in a corn plant come from the root interception process.

The soluble fraction of nutrients which are present in soil solution (water) and are not held on the soil fractions flow to the root as water is taken up. This process is called mass flow. Nutrients such as nitrate-N, calcium, and sulfur are normally supplied by mass flow.

Nutrients such as phosphorus and potassium which are adsorbed strongly by soils and only present in small quantities in the soil solution move to the root by diffusion. As uptake of these nutrients occurs, the concentration in the soil solution in close proximity to the root decreases. This creates a gradient for the nutrient to diffuse through the soil solution from a zone of high concentration into the depleted solution adjacent to the root. Diffusion is responsible for the majority of the P, K and Zn moving to the root for uptake. Table 3 gives the relative importance of each mechanism in positioning nutrients adjacent to plant roots for uptake.

Table 3. Percent of the nutrients normally taken up by a corn crop which could be supplied through root interception, mass flow and diffusion.

	Percent of uptake possible through		
Nutrient	Root Interception	Mass Flow	Diffusion
Nitrogen	<1	80	19
Phosphorus	2	5	93
Potassium	2	18	80
Calcium	150	375	0
Magnesium	33	600	0
Sulfur	5	300	0

The nutrient uptake process. Uptake of nutrients by a plant root is an active process. As water is taken up to support transpiration, nutrients may be moved to the root surface through mass flow. But they are not taken directly into the root. The plasma membrane of the endoderm blocks the movement of ions into the root. At this point an active uptake process which requires energy is used to move the nutrients into the root and xylem for transport to the growing tissues. A specific protein carrier is used to bind with a nutrient ion and carry it across the membrane.

This active uptake process is a selective process. The root discriminates and only expends energy to take up nutrients it needs. Thus nutrient uptake is not proportional to the ratios of nutrients in the soil solution. Ions in large supply in the soil solution, such as calcium and sulfur, can accumulate near the root. In perennial plants this can actually result in visible quantities of calcium carbonate and calcium sulfate precipitating and coating old roots.

One important implication of the plants ability to pick and choose nutrients from the soil solution is the relative unimportance of the ratio of nutrients in the soil solution. As long as a given nutrient is supplied to the root surface at a concentration high enough to meet the demands of nutrient uptake, the demands of growth and development will normally be met. For example, the ratio of calcium and magnesium on the soil cation exchange sites and in soil solution has little effect on the ratio of these nutrients in the plant. The plant selects the ions it needs, allowing the others to accumulate in the soil solution at the root surface. Altering the soil to supply adequate amounts, the concept of critical concentrations, has generally proven more cost effective than altering soils to provide ratios of nutrients equivalent to the ratios at which the nutrients are found in the plants.

Normal patterns of uptake. Nutrient uptake parallels plant vegetative growth in many ways. Most crops take up the majority of the nutrients during the periods of vegetative growth and translocate stored nutrients to developing grain during reproductive growth. Nutrient uptake per acre increases rapidly from the 4 leaf stage to just prior to tasseling, and then stays at high levels until after pollination. During this period the crop is growing very rapidly and the demand for nutrients to support that growth is high. After pollination nutrient uptake slows. Nutrients are actually lost from the plant after the dent stage.

Uptake per unit of root. The rate at which a given segment of root absorbs nutrients or the demand for nutrients placed on the root system also changes drastically over the growing season. Table 4 illustrates this point by giving the rates of nutrient uptake on a per acre basis and per mile of corn root. Note that while the quantity of nutrients taken up per day on an acre basis is quite small early in the season, the rate per mile of root is quite high. This is primarily due to a small number of roots trying to support the rapid growth occurring at the 2 to 5 leaf stage. This restriction in the size or extent of the root system coupled with high nutrient demand to support growth is why small plants may express nutrient deficiencies early but grow out of the deficiency later, even if no additional nutrient is applied.

As the root system expands during the second month of vegetative growth, the number of roots capable of nutrient uptake per pound of dry matter increases by about five fold. Thus the demand on a given segment of the root system drops. This is an important concept. If root growth is restricted by some factor such as compaction, cold temperatures, wet soils or root worm feeding, increasing the availability of nutrients in the soil solution, through starter fertilizer use or broadcast applications might have some impact on over coming nutrient uptake restrictions. But at some point, the capacity of the active uptake system will become saturated and nutrient uptake will be limiting.

This concept of saturating the roots capacity to take up nutrients also explains why placement techniques such as banding of P may increase nutrient availability but not nutrient uptake. If too small a portion of the root system comes in contact with the nutrient, uptake may be limited by the rate at which nutrients can be moved into the root. Having lower availability but a greater portion of the root system in contact with the nutrient can result in greater uptake.

This is why many states, including Indiana, recommend combinations of banding and broadcasting of nutrients such as P and K at low soil tests. A starter band will provide an area of high nutrient availability when root systems are small and demand per unit of root is high. But the broadcast materials provide an opportunity for a large portion of the root system to come in contact with the nutrient as the root system expands and demand per plant continues to increase.

Table 4. Nutrient uptake rates by corn at various stages during the growing season.

		Uptake per acre per day			Uptake per length of root per day		
Growth stage	DAS	N	P	K	N	P	K
	(days)	(lb./acre/day)			(lb./mile root/day)		
4 leaf	21	0.03	0.006	0.04	$1.1x10^{-3}$	$2.2x10^{-4}$	$1.5x10^{-3}$
9 leaf	34	1.4	0.1	1.4	$6.3x10^{-4}$	$4.5x10^{-5}$	$6.3x10^{-4}$
Shoulder high	49	6.5	0.7	8.3	$6.5x10^{-4}$	$7.0x10^{-5}$	$8.2x10^{-4}$
Tassel	71	3.8	0.7	4.0	$1.6x10^{-4}$	$2.9x10^{-5}$	$1.7x10^{-4}$
Late silk	79	2.4	0.2	-1.1	$6.8x10^{-5}$	$5.6x10^{-6}$	0
Blister	93	0.2	0.4	-0.3	$5.2x10^{-6}$	$1.0x10^{-5}$	0
Dent	113	3.1	0.1	3.8	$1.1x10^{-4}$	$3.4x10^{-6}$	0
Black layer	132	-0.3	-0.02	-3.1	0	0	0

DAS = Days after seeding

Effects of weather on roots and nutrient uptake.

Root growth and weather. Weather can have a significant effect on root growth and nutrient uptake. The data in Table 5 from a drought year, illustrates this point. This data was collected at the Purdue Agronomy Farm during 1982, an excellent growing season, and 1983, a drought year with record high temperatures. The data clearly shows that the location of the corn root system changes with temperature and moisture stress.

Under the ideal situation of 1982, the density of corn roots in the surface three inches of soil was high, with little difference in root density throughout the top nine inches of soil. However as the soil temperatures went up and moisture went down, as in 1983, the location of the roots changed. The roots tended to be located deeper, where water was more readily available and temperatures were cooler and more favorable. Similar data was found with soybean roots.

Table 5. Effect of tillage and weather on corn root distribution at Lafayette, Indiana in 1982 and 1983.

Depth below the surface	No-till		Chisel		Plow	
	1982	1983	1982	1983	1982	1983
inches	---------------------------mg/cm^3---------------------------					
0-3	0.47	0.12	0.44	0.19	0.28	0.24
3-6	0.41	0.41	0.64	0.29	0.34	0.42
6-9	0.29	0.30	0.40	0.18	0.24	0.32
9-12	0.15	0.18	0.17	0.22	0.15	0.11
12-18	0.07	0.09	0.09	0.11	0.14	0.10
18-24	0.07	0.11	0.07	0.11	0.13	0.08
24-30	0.11	0.10	0.07	0.15	0.08	0.15

D. Mengel, Purdue Univ., unpublished data

In cool, wet years the situation is reversed. The growth of the root system is reduced, and the roots tend to locate in the surface of the soil. More importantly the activity of the root system is also reduced. Since roots are a respiring organ, oxygen is required for their activity and the rate of root metabolism is strongly effected by temperature. Thus nutrient uptake can be reduced by cool temperatures, and by overcast days which reduce photosynthesis.

One of the reasons for floppy corn is a combination of surface compaction, dry weather and high soil temperatures. Development of the crown roots or nodal roots can be inhibited by both surface crusting or compaction and very high soil temperatures. Without the anchoring effects of the nodal roots, the plant eventually gets tall enough that it can't be held upright by just the seminal roots and falls over. This spring this was especially common in fields that were planted early and shallow, then crusted by heavy beating rains and then dried out as the temperatures turned hot.

Nutrient uptake and weather. In addition to effecting root growth and distribution in soils, weather can also impact nutrient uptake. Generally in dry years the nutrient content of crops is reduced, as compared to normal or wet years. The data in Table 6 illustrates this point.

This reduction in the concentration of nutrients in stress years makes interpretation of plant analysis more difficult. For this reason we recommend that farmers not do routine monitoring or interpret the results very conservatively under stress conditions. Plant analysis is still a good diagnostic tool under stress years. But to use it successfully, comparison samples of problem and normal tissues is needed.

Table 6. Effect of tillage and weather on the nutrient content of corn leaves at silking.

Tillage System	Nutrient content in ear leaf					
	N		P		K	
	1980	1981	1980	1981	1980	1981
	-------------------------%-------------------------					
Plow	2.82	2.79	0.24	0.31	1.77	2.27
Chisel	2.73	3.89	0.23	0.32	1.56	2.21
No-till	2.77	2.84	0.23	0.33	1.49	2.27
	ns	ns	ns	ns	**	ns

ns = Differences among tillage system means are not statistically significant from each other.
** = Differences among tillage system means are statistically significant from each other.