ROOTS ATTRIBUTES OF MEXICAN *Crataegus* spp. TREES

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"The root is a neglected part of a tree although sustains the crown's productivity".

"The "Krataigos" is a tree… which has only one root sinking deeply in the earth".

Teofrasto (372-287 A. C.; 1988).

ABSTRACT

A review of knowledge generated in Mexico upon roots attributes of *Crataegus* is presented. These attributes refer to the variation in roots distribution in the soil, the variation roots size of plants subjected to water stress and the generation of number and growth of new roots during the dry season, variation in the foliation of trees. Other roots attributes investigated were the generation of buds and new roots by roots cuttings. The necessity of rootstocks selections with the desired deep-rooting ability was stressed. Such rootstocks are very desired in construction of trees of high productivity per unit of water transpired or used in irrigation. The text is complemented with schemes of water movement between the tree, its environment and, the components of trees of escape mechanism from drought.

ADDITIONAL KEY WORDS: rootstock, distribution, water relations, regeneration, foliation.

ATRIBUTOS DE RAÍCES DE LOS ÁRBOLES DEL *Crataegus* spp. MEXICANO

RESUMEN

Se presenta el conocimiento generado en México sobre los atributos de las raíces del género *Crataegus*. Éste se refiere a la variación en la distribución de raíces en los suelos o plantas sujetas al estrés hídrico, la variación en la generación de raíces nuevas, la foliación de los árboles. Otros atributos investigados fueron: generación de yemas y raíces por estacas radicales. Se ha subrayado la necesidad de seleccionar portainjertos de enraizamiento profundo. Estos portainjertos son deseados en la construcción de árboles de alta productividad por unidad de agua transpirada o aplicada en riego. Los resultados se complementan con esquemas del movimiento de agua entre el árbol, su ambiente y los componentes del mecanismo de escape de la sequía.

PALABRAS CLAVE ADICIONALES: portainjerto, distribución, regeneración, foliación.

INTRODUCTION

The roots of wild native Mexican species form the unexplored potential in Mexican horticulture. It could be used to rise the efficiency of use of soil natural resources, especially of water, to improve the crowns photosynthetic yield and the allocation of organic matter in fruits to reduce losses in fruits due to variation of available water in shallow soils.

Nothing is known about the photosynthesis in Mexican hawthorns. The European hawthorns have high photosynthetic efficiency (Suba and Légrády, 1985). Mexican hawthorns are characterized by high yields and high percentage of flowers transformed into fruits (Bustamante-Orañegui and Borys, 1984, 1991; Sánchez-Chávez *et al*., 1991). This, indicates indirectly upon the high and efficient photosynthetic net output of Mexican hawthorns. Responsible for such activity may be the deep rooting end continnous roots generation. (Borys, 1996b; García Cárdenas *et al*., 1997). Both characters seems to be the common feature of *Crataegus* trees. In other plant species the cytocinins content was highest in root apices (Jeske *et al*., 1977) and CO_2 asimilation was linearly related to root formation (Humphries and Thorne, 1964)

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The hawthorn fruit tree (local names “tejocote” or “manzanilla”) belong to species of minor importance, evoluted in Mexican territory with an opinion of being well adapted to the territorial climate and soil conditions. It is one of many Mexican fruit specialties of seasonal cultural importance (Borys, 1999, Borys and Leszczyñska-Borys, 2001).

There is a lack of knowledge upon the growth of hawthorn roots. Few data were published upon the roots size in seedlings. Data from Byelorussia indicate that the total root length of one year old seedlings was from five to eight times larger than the length of twigs (Boboreko, 1974). The total length of roots of plants seven months old, generated from root cuttings, was from two to six times larger that the length of twigs. The higher length of roots seems to indicate the soils water searching capacity of this species. The maximum length of roots per seedling was 866 cm (Borys *et al.*, 1997).

Crataegus seedlings were recommended as rootstocks for fruit trees of *Crataegus, Cydonia, Malus, Mespilus, Pyrus* (Gajon-Sánchez, 1925), although their use generated nutritional problems (Borys and Bustamante-Orañegui, 1990). The knowledge generated in Mexico upon the vegetative compatibility of hawthorn with other fruit species was summarized in the paper by Nieto-Ángel and Borys (1999).

Some species of *Crataegus,* selected as rootstocks for ornamental *Crataegus*, having vertical roots showed transplant problems, a weak anchorage and a low take of grafts (60 % in *C. arnoldiana*). The promising rootstocks species for ornamental *Crataegus* were *C. arnoldiana, C. mollis and C. sanguinea* (Cumming, 1964). A weak anchorage of *Crataegus* is a problem in Canada and this attribute is related to the poorly ramified deep root system (Cumming, 1964). No losses of hawthorn trees were observed in Mexican hawthorns commercial plantations. In Mexico, the attribute desired in hawthorns is the formation of a deeply rooted stock to avoid water deficiency during the dry season (Borys, 1996a, b). The main objective of this report is to summarize the generated knowledge upon roots various attributes of Mexican hawthorn, mainly the *Crataegus pubescens* (H.B.K.) Steud., although some may be of unknown taxonomic classification.

ROOTS DISTRIBUTION

The hawthorn trees are giving a vertical, deep growing taproots (Figure 1). Such roots were formed in trees planted in deep soils of adobe type. The fine, densely distributed root mass was found below the crown (Figure 2, 3). The reason of a densely, highly ramified roots in the crown area may be related to: higher humidity due to shading by the crown; recycling of nutrients and organic compounds washed from the crown and due to leaf fall; the

FIGURE 1. A pivotal root system of a hawthorn tree excavated during adobe mining operation. Commercial orchard, Huejotzingo, State of Puebla, México.

FIGURE 2. A very dense, ramified root system, restricted to the crown’s area of a 15 year-old hawthorns commercial plantation. One of its roots running horizontally of ±6 m from the trunk basis. Commercial plantation, Huejotzingo, State of Puebla, México.

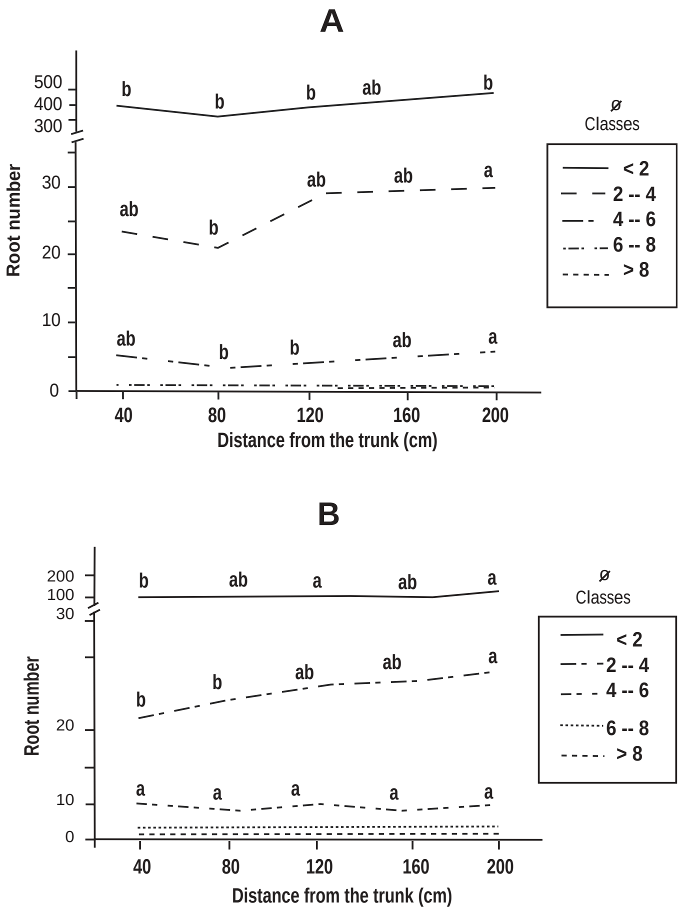

FIGURE 3. Horizontal distribution of hawthorn roots (roots number/ tree/diameter class) of five trees in two commercial orchards A and B. Data are means of two samplings of opposite directions. Roots diameter classes in mm. Values with the same letter do not differ in according to the Tukey's test with a *P*≤0.05.

FIGURE 4. A shallow root system, running horizontally, poorly ramified. Commercial plantation upon adobe, type of soil in Huejotzingo, State of Puebla, México.

soil's mechanical management with resulting root cutting and generation of new roots; planting corn or other crops in between row area.

Some trees formed horizontal, shallow root systems (Figure 4). The remains of pivotal roots left in the bottom of an adobe mine generated shoots, which finally developed into trees (Figure 5). These data indicate that Mexican hawthorns have similar attributes of deep rooting to the European species (Hempel and Wilhelm, 1983; Hinckley *et al.,* 1983, Oberdorfer, 1979) and Canadian species (Cumming, 1964). Roots horizontal maximum length noted was 6 m (Figure 2). It was not possible to state, if this root entered the root area of neighboring trees. No data was found upon the roots overlapping in *Crataegus*.

In the Mexican climate, the deep rooting forms part of an escape mechanism from the dry season effects. Emphasis should be paid to trees left at a distance of one meter from a wall formed due to the adobe extraction (Figure 5). These trees and those upon the adobe block were growing for some years without any negative signs in growth. Such wall increases the evaporation of water. Water needed by those trees should be furnished by a vertical, deep root, reaching the mine's bottom.

The results of studies upon the root distribution (Table 1, 2) show that roots main mass is restricted to 60 cm depth. In the case presented in Figure 5, the water supply depends almost totally upon water taken up by the deep vertical root reaching the mine bottom. The case observed suggests that such root has a very high water and nutrient absorption efficiency. The efficiency has to be very high considering, that the formation of foliage, flowers, the growth of shoots and fruits (up to 60 % of their final size) is taking place during the dry season of the year. The presence of pivotal roots explains, partially, the phenomenon of escape

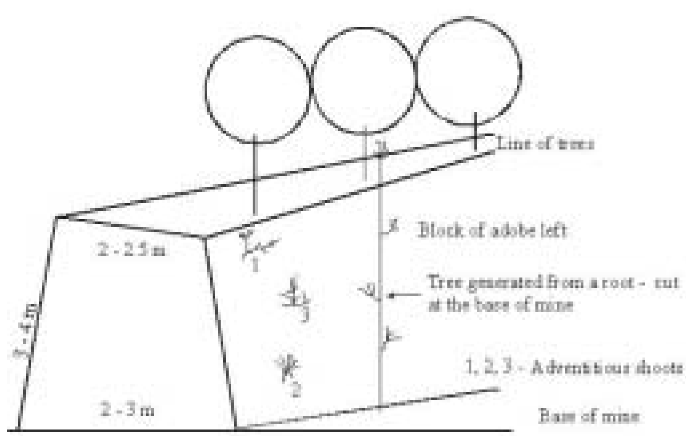

FIGURE 5. Hawthorn trees growing for 15 years upon a block of soil left in a mine of adobe. Upon its walls adventitious shoots appeared generated by exposed roots. The walls increased the evaporation and reduced water retention. Trees do not show any sign of negative reaction to the created hydric conditions.

TABLE 1. Vertical distribution of hawthorn roots number in two hawthorn commercial orchards (García Campos *et al*., inedited).

Depth (cm)	Diameter class (mm)					Total per depth	
	< 2	2-4	4-6	6-8	>8	(núm.)	(%)
			Orchard 1				
0-20	49.39 a	2.63 a	0.31 a	0.09 a	0.08 ab	1001.9	52.50
21-40	19.86 b	1.79 b	0.29 a	0.08 a	0.10 a	422.6	22.15
41-60	15.62 b	1.17 c	0.14 b	0.04 b	0.07 b	325.1	17.03
61-80	7.69 c	0.54 b	0.01 b	0.0 c	0.03 c	158.2	8.29
Total (%)	92.56	6.12	0.80	0.23	0.28		
Number	1766.30	116.94	15.34	4.34	5.32	1908.2	
			Orchard 2				
0-20	26.68 a	4.97 a	0.93 a	0.13 b	0.12 c	198.2	32.83
21-40	21.39 b	4.46 a	0.71 a	0.28 a	0.26 a	163.6	27.09
41-60	17.01 c	2.92 b	0.59 ab	0.18 ab	0.15 ab	125.9	20.85
61-80	16.28 c	2.51 c	0.28 b	0.06 b	0.07 b	115.9	19.20
Total (%)	81.38	14.86	2.52	0.65	0.60		
Number	491.16	89.72	15.24	3.86	3.70	603.7	

[z]Values with the same letter ineach column do not differ significantly according to the Tukey's test a with a $P \leq 0.05$.

TABLE 2. Vertical distribution of hawthorn roots volume (cm^3) and per cent of the total per class diameter and orchard.

Depth (cm)	Diameter class (mm)					Total per depth	
	<2	2-4	4-6	6-8	>8	(cm^3)	(%)
			Orchard 1				
0-20	14.10	8.43	3.38	2.15	9.76	144.30	37.81
21-40	5.24	5.10	3.48	2.16	20.12	137.83	36.12
41-60	3.04	3.14	1.90	1.25	10.60	76.16	19.96
61-80	1.46	1.56	0.69	0.43	1.95	23.28	6.10
Total (%)	23.85	19.25	9.46	6.00	42.43		
cm^3	91.01	69.64	36.10	22.91	161.91	381.57	
			Orchard 2				
0-20	7.77	7.63	4.74	1.62	4.66	50.66	26.42
21-40	5.20	7.56	5.00	4.26	16.50	73.88	38.54
41-60	3.82	4.63	3.31	2.30	7.78	40.92	21.34
61-80	3.14	3.65	1.59	0.90	4.48	26.36	13.75
Total (%)	19.93	23.47	14.64	9.08	32.87		
cm^3	38.22	45.00	28.06	17.42	63.12	191.72	

from drought, the adaptation of *Crataegus* to the dry season, the dry and hot sites (Hinckley *et al.,* 1983).

ROOTING AND WATER RELATIONS

The presence of dense, living roots, in the superficial layers of dry soil is interesting. Such roots during the dry season give off water. The loss has to be replenished. There exists a possibility that the pivotal root supply the water to the root located near the soil surface. The circumstantial evidence suggests that this may occur.

Descriptive schemes, summarizing the events, are presented in Figure 6, 7, 8. At the beginning of a dry season leaf drop is taking place (Table 3) which reduces tree's transpiration surface and secures the maintenance of tree's internal water status. The daily, day/night, temperature variation of the soil promotes water movement in the soil, with late-night water-vapor precipitation near the soil surface. Part of such water will be available to surface roots. What is transpired may be recycled.

Roots drying is accentuated in roots localized in the upper soil layers. The root transpiration will be higher un-

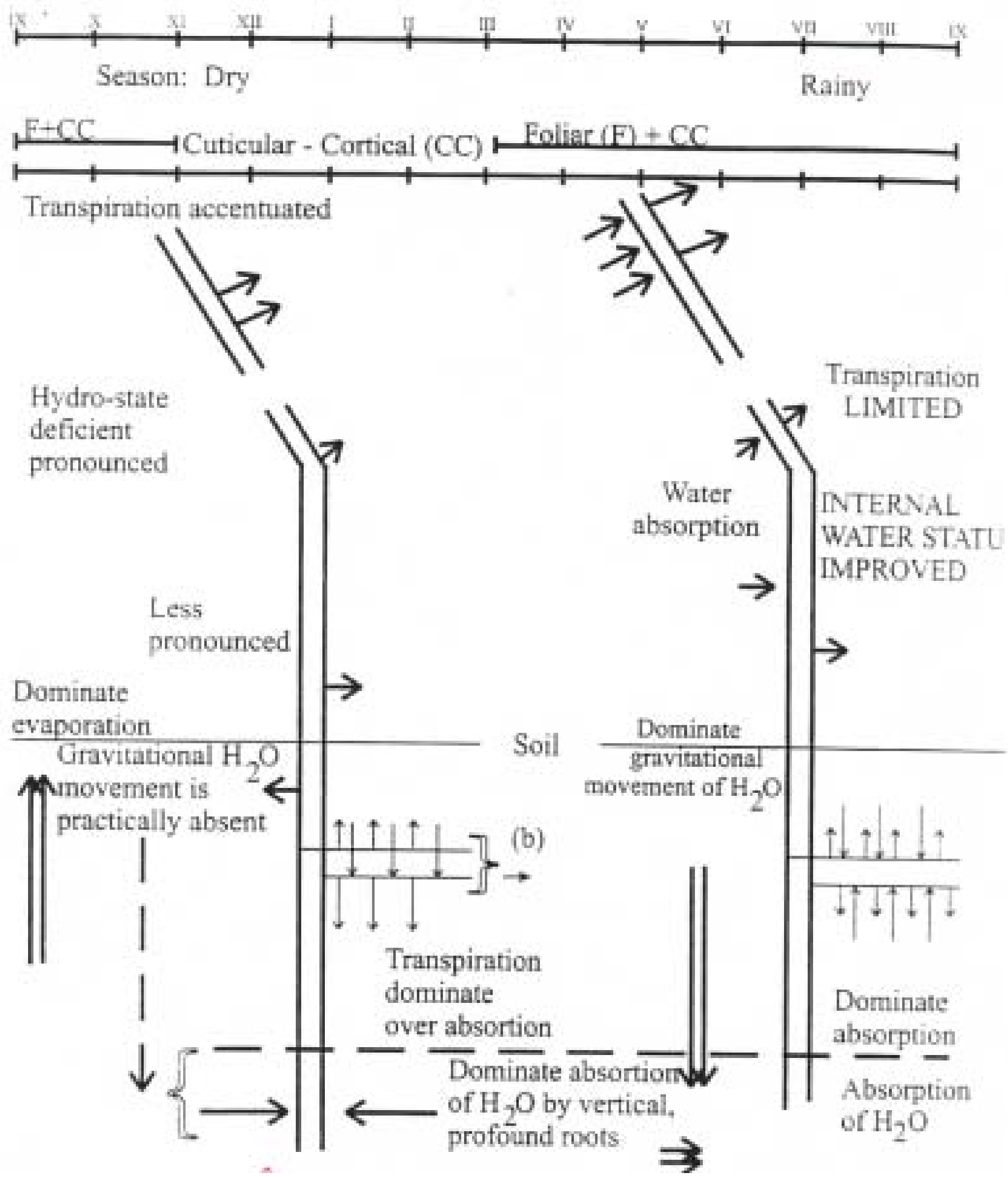

FIGURE 6. Water movement in the system "hawthorn tree enviroment" season. Water enters through one part of root system, more profound during the dry and wet, humid one and is transpired by the part located near the dry.soil surface. This water condensates, precipitates, humidifying the rhizosphere or evaporates to the soil surface.

TABLE 3. Average number of new roots generated by mature hawthorn trees during the dry a season.

Perfil depth (cm)	Number of generated roots January	February	March	May	Total	Average
0-30	2.67	5.25	4.11	7.30	19.33	4.83
30-40	1.66	3.37	4.50	7.73	17.26	4.32
40-50	4.03	4.52	4.43	7.27	20.25	5.06
50-60	2.75	4.65	4.23	6.68	18.31	4.58
60-80	2.99	3.37	3.46	5.80	15.62	3.51

der leafless trees. During the leafless period only the crown cortical transpiration occurs. During the dry season clear sky days dominate. This accentuates the differences in the day/night soil temperature. This promotes the water movements from deeper to surface roots. The movement of water from deeper roots to above ground roots was observed in corn roots (Figure 9). Such a water movement would not appear without the formation of an internal water pressure. The root pruning in leafless grapes during dry season resulted in heavy losses of sap (Borys e*t al.*, 1994). Similar phenomenon was observed in young foliated hawthorn trees grown in heavy soils although at much lower level.

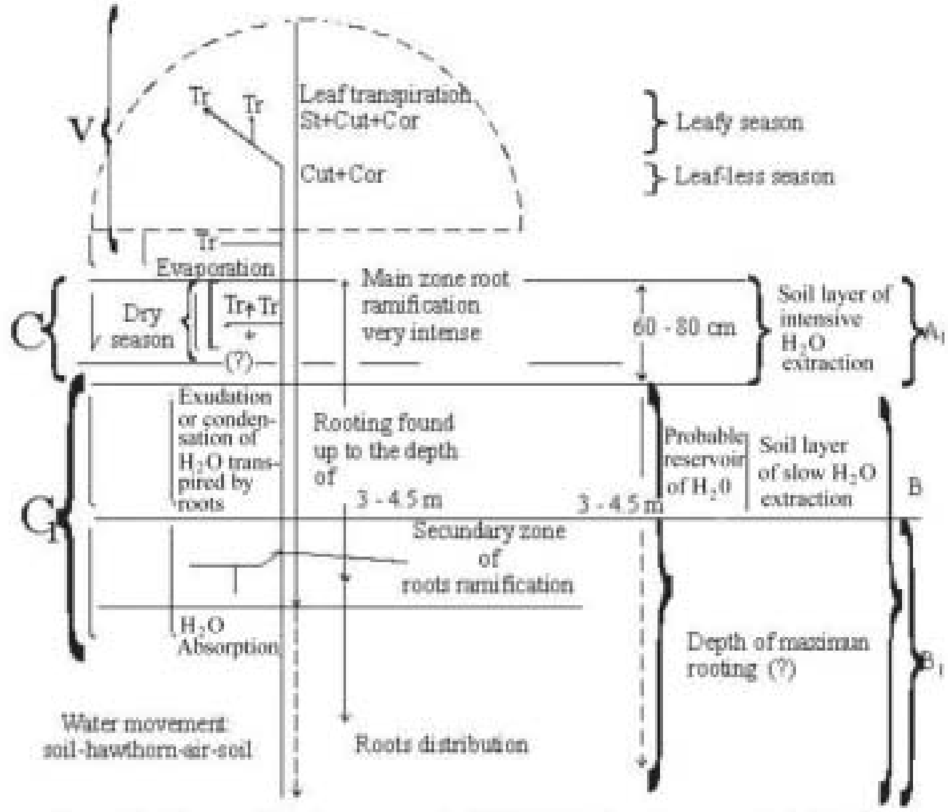

FIGURE 7. Scheme of H_2O movement relative to the hawthorn roots distribution and soils water conditions (see the text). Tr: transpiration; V: shoot; A: main source of H_2O during the leafy season; B, B_1: main source of H_2O during leafless season and the spring time: a part of leaf and fruit development occurs; C: zone of high roots density; C1: zone of diffuse rooting; St: stomatal; Cut: cuticular; Cor: cortical.

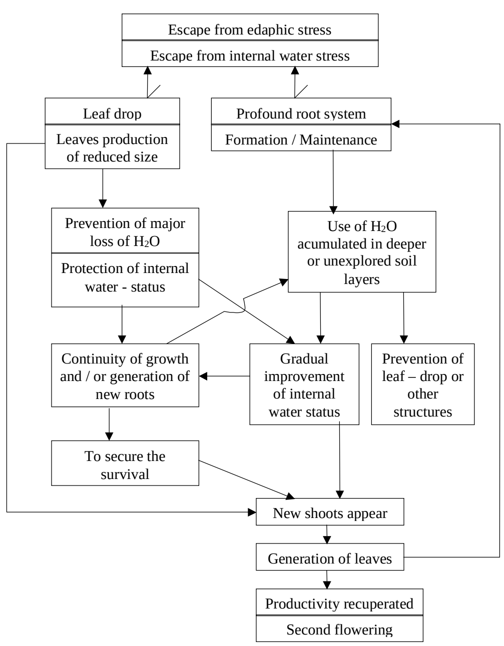

FIGURE 8. The leaf drop, a deep root system and the growth power of roots condition the major adaptation of hawthorn trees to the warm and apparent dry sites (beside of the system which control the stomata flux of H_2O and the water reserve of H_2O in fruits). The hawthorn may utilize these means to moderate its internal water status.

The formation of adventitious roots upon the exposed root-cuts, on the walls of the adobe block (Figure 5) obligates the deeply located roots to supply these roots and shoots with water and nutrients.

Mining operation resulted in some trees having their roots left hanging in the air (Figure 2). These roots being exposed to the thermic action of the sun radiation should dry. These roots were still attached to the tree with the other part of the root system located in the soil. The air exposed roots formed adventitious shoots (Borys, 1997). Their formation and later their extensive growth depended upon the water supplied by the part of the tree’s root system remaining in the soil (Figure 9).

ROOTS REGENERATING POWER

Using the profile method to study the root distribution of hawthorns, the formed wall was covered with a sheet of polyethylene which enabled to measure root generation by root stump and longitudinal growth (Figure 10). It was shown that the roots of hawthorn trees maintained the ability to generate new roots and their growth during the dry season by leafless trees (Figure 10, Table 4). Roots without difficulty generate shoots (Borys, 1991). Root cuttings easily generated new roots

FIGURE 9. Intense excretion by corn roots situated above the soil the day following a heavy rain fall. The plant was foliated normally and these roots were exposed to the open sky sun radiation (Photo taken 11.00 A.M.). Under such conditions these roots excreted a dense liquid. This phenomenon supports the idea that roots located in deeper layers of soil may supply water to the upper roots and may humidify the soil in contact with those roots.

continued root formation and reduced the transpiration by the restriction of the leaf surface (Table 4, 5, García *et al.*, 1997, Borys *et al.*, 1994). This reaction of hawthorns was distinct to the observations of Hinckley *et al*. (1983) and to our own observations made in former years, upon leaf drop presented in

FIGURE 10. New roots grown appearing upon a profile wall, during the dry season (17/02/1992).

TABLE 4. Time scale of autum and winter shedding of leaves in trees forming the *Crataegus* germplasm collection Universidad Autónoma Chapingo, Chapingo, México.

Days	Trees which lost their leaves			
	Plot J-41		Plot J-42	
	(Num.)	(%)	(Num.)	(%)
1- 30	26	9.63	23	8.61
31- 60	96	35.56	115	43.07
61- 90	111	41.11	112	41.95
91-120	21	7.78	10	3.75
121-150	16	5.93	7	2.62
Total	270		267	

and adventitious shoots (Borys *et al*., 1997). The growth of leafless grape roots during the dry season in shallow soils was reported (Borys *et al.*, 1994). Thus, the internal water status was sufficient to secure the formation of new roots and to sustain the extensive growth of roots. The roots have had sufficient energetic resources to support these activities. Trees of hawthorn and grapes were in leafless dormant stage and remained so during the dry season of normal duration. However, when the dry season was abnormally long, some trees started to grow. One group of hawthorn types was identified, which gave new growth at the early stages of the dry season, their leaves stopped to grow without dropping (Table 3). The permanence of leaves upon short shoots (functional shoots and short extensive growth) was the attribute of hawthorn types of early shooting group. This suggests, that these hawthorns got deficient in energetic resources and water. Possibly those trees maintained their leaves to produce energy for reaction to short lasting drought in July, in trees grown in heavy soil, when a short period of drought preceeded the second shooting. The leaf drop was noted on shoots of the spring extension growth (dry season growth).

The soil's superficial layers are drying during the dry season, although the roots remain alive. Moreover, they are growing in length hanging on the walls of a mine and were generating adventitious shoots (Borys, 1997). Such new shoots would not appear on roots located on the exposed walls without the water being transported from deep-located roots to those located in the upper layers of the soil. Thus, of importance is the state of root hydration. New roots constitute a source of cytocinins necessary for buds shooting. Its transport requires water (Greene, 1975; Jones, 1973; Mullins, 1967).

TABLE 5. Comparison of linear dimensions of *Crataegus* short shoots leaves grown during the dry and wet season (Borys *et al*., inedited b).

Shooting Date	Days from Last Rainfall (Num.)	Type/Tree	Dimensions of Leaves (mm) Grown During the Season: Dry Length	Dry Width	Wet Length	Wet Width	Leaves Dimensions (%) of Wet Season: Length	Width
20.1	61	26/14	60.3	27.4	80.2	34.6	75.18	78.19
		26/4	53.6	24.7	81.4	38.8	65.85	63.66
26.1	67	12/52	35.5	18.8	54.5	33.3	65.19	56.34
15.2	87	61/19	32.8	15.2	57.6	27.5	56.94	55.09
		15/17	36.1	19.8	68.2	35.9	52.90	55.09
15.2	87	H-4-9[z]	51.2	26.1	104.3	43.3	49.09	60.28
31.3	131	H-4-10[z]	28.0	15.9	59.6	25.2	47.00	62.98

[z]These trees were watered slightly.

ROOTING AND FOLIATION

Leaf drop is observed at the end of first yearly growth, before the second period of yearly shooting. The first drop refers to those leaves formed during the spring growth of the extension growth. The main season of leaf drop occurs in the fall. The leaf drop observed in trees forming a collection of *Crataegus* types, probably of two species, varied much (Table 4). Some types, at least, maintained their leaves until the spring new outgrowth. Leaf drop, which occurs at the end of the rainy growing season (October, November), the continuity of roots activity (Table 3, 4) and the appearance of new leaves of reduced size during the dry winter season (Table 5) constitute means to improve the state of hydration and trees energy balance, the meristems activity and survival, roots growth and buds shooting (Figure 8).

Seedling rootstocks of many fruit trees cultivated in Mexico present large variation in the form and size of their roots, nutrients absorption capacity, their influence upon productivity and quality of fruits, suggesting its selection, formation of clones and their utilization to homogenize the cultivars behavior, to solve or to prevent the appearance of some of the problems the national industry is facing (Borys and Herrera, 1990; Borys, 1999; Borys and Leszczyñska-Borys, 2001).

SELECTION OF ROOTSTOCKS

Stressing, in the present paper, certain attributes of *Crataegus* is justified by the worsening of deep-water reserves and the seasonal, yearly long lasting dry period. *Crataegus*, although survives water stress in shallow soils, rarely secures yearly fruit production in such soils. However, its trees being planted in deep sandy soils, showing sufficient water, produce regularly. Selecting properly the rootstock and the cultivar we may increase the efficiency of water use and the conversion of flowers into fruits.

In commercial orchards the roots of evaluated trees varied in their vertical and horizontal distribution (García *et al.*, 1997). Some of the variations found illustrate Figure 1, 2, 3, 11. The data of Mexican research indicate the possibility of rootstock selection suited to deep and shallow soils (Figure 12, 13). There is also an excellent possibility of selection of hawthorn rootstocks of low or high allocation of photosynthetic products (Figure 12, 13), thus with a desired power to control the size of tree and its productivity (Borys and Bustamante, 1991; Borys and Leszczyñska-Borys, 1994; Borys *et al.,* 1997; Nieto-Ángel and Borys, 1999). The inverse correlation found between the number of stomata and seedlings roots volume, which varried from 0.620 to 0.770 (Velasco *et al.*, in preparation) may be used in the selection of desired types.

An easy formation of adventitious buds was found in hanging roots (Borys, 1997). This attribute of Mexican hawthorns will be of value in propagation of selected rootstocks (Borys *et al.*, 1997b). Reproduction of types with a tendency to produce off-shoots at the trunk basis should be avoided (Borys *et al.*, 1997a).

ASPECTS TO BE STUDIED

Several problems related to the rootstock: scion interaction should be investigated, specially due to the possible use of *Crataegus* as a rootstock for various species of *Crataegus* and other genera e.g., *Cydonia, Pyrus, Mespilus, Malus.* Some were indicated in the paper of Borys and Bustamante (1990, 1991), Borys *et al*., 1997, Delgado *et al*., (1984 a, b), or Nieto-Ángel and Borys (1999). These problems are:

1) The effect of nutritional status of the tree or soil upon the trees productivity, fruits quality and the expression of alternancy,
2) The selection and formation of clonal rootstocks

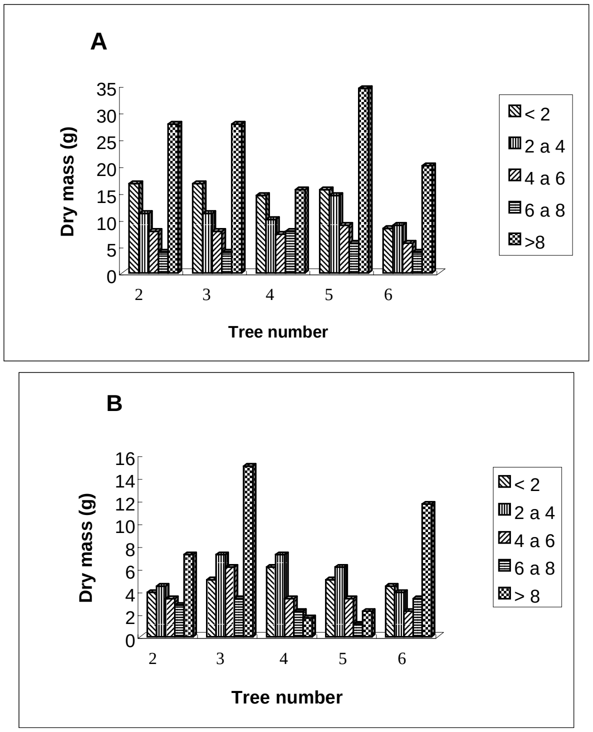

FIGURE 11. Hawthorns root dry mass of five diameter classes and five trees in two comercial orchards A and B. Date are means of two opposite directions of sampling. Onto seedling roots a local, large fruited type was grafted. Roots diameter in mm.

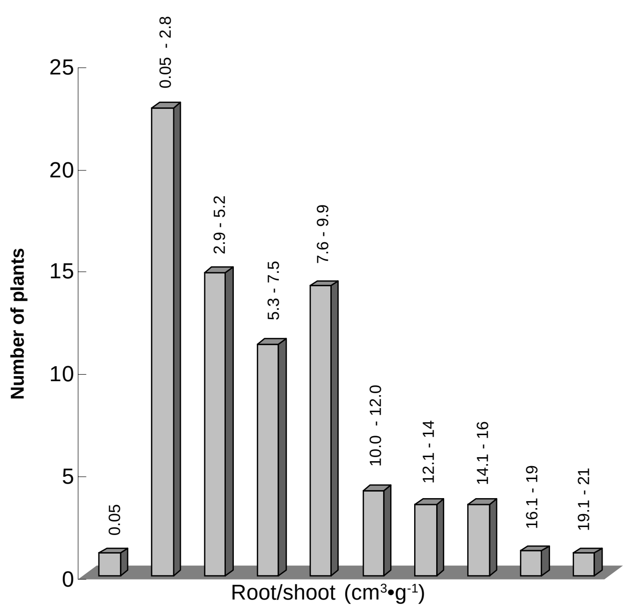

FIGURE 12. Frequency of roots volume of hawthorn seedlings in the plant population studied.

with high vegetative compatibility and fruit productivity per ha,

3) Selection of types of high productivity per cubic meter of H_2O transpired or used in irrigation,

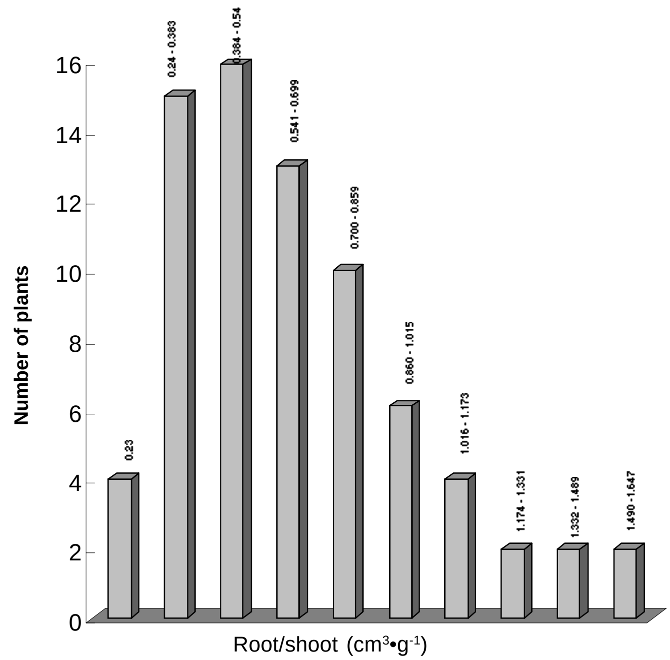

FIGURE 13. Frequency of the coefficient roots volume/shoot mass ($cm^3 \cdot g^{-1}$).

4) Selection of rootstocks of high transplant surviving efficiency,

5) Solving the question of importance in the discrepancy in appearance of nutrients deficiency symptoms in rootstock shoots and their lack in shoots of the scion (nursery and orchard level),

6) The practical implications of the hollowed trunk of rootstocks to the scion performance (nursery and orchard level),

7) The effect of asynchronous time of shooting at the rootstock and the scion,

8) The tree performance,

9) The importance of inorganic nutrients distribution-vertical and horizontal (rootstocks and scion),

10) Definition of roots efficiency (adquisition of water and inorganic nutrients).

Research of some problems, e.g. to clear the question of asynchronous shooting, should consider the distribution of growth regulators and inorganic nutrients, among the tree components, both vertical and horizontal and their functions as mentioned earlier (Borys and Bustamante, 1991; Nieto-Ángel and Borys, 1999). Such investigations could clear the way toward the better understanding of the *Crataegus*' good adaptation to the Mexican edaphic-climatic conditions and the use of *Crataegus* as a rootstock or interstock to check the trees size and density of planting fruit trees of various species. The success of using the

Crataegus rootstocks in production of dwarf trees as ornamental "bonsai" of apples, pears or hawthorns indicates some of the opportunities they offer (Borys and Leszczyñska-Borys, 1994).

Industrial use of fruits requires standardization of fruit size, pulp color, pulp composition, etc. This requires the use of rootstock, interstock and cultivars which will produce trees with the required standard of quality. To secure such standards we have to select the proper components to use them in the construction of trees. Breeding and selection may secure proper individuals tolerating the existing or the future adverse conditions as shown in *Crataegus* and other species (Arroyo and Borys, 1987; Arroyo *et al.*, 1989; Barrera-Guerra *et al*., 1982; Borys, 1982, 1989; Cruz *et al.,* 1984; Surma *et al*., 1978.

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