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Ontogenetic changes in the root system of grapevines

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Investigations of the root system and above-ground parts of vines of the 'Cabernet Sauvignon' cultivar on the rootstock 'Kober 5BB' showed that the ontogenetic changes corresponded to eight biological periods of the vine: I. growth; II. growth and fruit-bearing; III. fruit-bearing and growth; IV. fruit-bearing; V. fruit-bearing and withering; VI. withering, fruit-bearing and weak growth; VII. withering and growth; VIII. growth. During the different periods of development in the root system as well as in the above-ground parts, generally one of the characteristics was predominant while the others were less pronounced or absent at all. The state of the roots in each biological period might be characterised with the same precision as that of the above-ground parts assuming provisionally the degree of root biological activity (their percentage distribution into feeding and conducting roots along the horizons), their interaction with mother rock, the extent of their bulk expansion, the nature and the ratio of newly-formed roots and of dying ones.
Key words: root system, biological periods of growth and development, vine age, root fibrilla

Ontogenetische Veränderungen im Wurzelsystem bei der Weinrebe. *Untersuchungen des Wurzelsystems und der oberirdischen Teile von Reben der Sorte 'Cabernet Sauvignon' auf der Unterlage 'Kober 5BB' zeigten, dass die ontogenetischen Veränderungen acht biologischen Phasen unterliegen: I. Wachstum; II. Wachstum und Fruchten; III. Fruchten und Wachstum; IV. Fruchten; V. Fruchten und Welken; VI. Welken, Fruchten und schwaches Wachstum; VII. Welken und Wachstum; VIII. Wachstum. Während der unterschiedlichen Stadien war sowohl im Wurzelsystem als auch in den oberiridischen Teilen eine der oben angeführten Stadien vorherrschend, während die anderen schwächer ausgeprägt oder gar nicht vorhanden waren. Der Zustand der Wurzeln in jedem der biologischen Stadien kann mit derselben Präzision charakterisiert werden wie der der oberiridschen Teile, wenn man den Grad der Wurzelaktivität (prozentuelle Verteilung von Wurzeln verschiedenen Durchmessers in den Bodenschichten), ihre Wechselwirkung mit dem Muttergestein, die Menge der Wurzelmasse und das jeweilige Verhältnis von neu gebildeten und absterbenden Wurzeln betrachtet.*
Schlagwörter: Rebe, Wurzelsystem, Wachstums- und Entwicklungsperioden, Alter, Faserwurzeln

Changements ontogénétiques du système racinaire de la vigne. *Les examens du système racinaire et des parties aériennes des vignes du cépage 'Cabernet Sauvignon' sur des porte-greffes 'Kober 5BB' ont eu pour résultat que les changements ontogénétiques de la vigne se déroulent en 8 étapes biologiques : I. croissance ; II. croissance et fructification ; III. fructification et croissance ; IV. fructification; V. fructification et flétrissement ; VI. flétrissement, fructification et croissance faible ; VII. flétrissement et croissance ; VIII. croissance. Au cours des différentes étapes, un des stades susmentionnés a prédominé tant dans le système racinaire que dans la partie aérienne, tandis que les autres étaient moins manifestes ou bien absents. L'état des racines au cours de chaque stade biologique peut être caractérisé avec la même précision que celui des parties aériennes, lorsqu'on considère le degré de l'activité biologique des racines (distribution en pourcentage des racines de différents diamètres dans les couches du sol), leur interaction avec les roches mères, la quantité de la masse de racines et le rapport entre les racines nouvellement formées et dépérissantes.*
Mots clés : vigne, système racinaire, périodes de croissance et de développement, âge, racines fibreuses

Diversity and number of scientific publications on vine root structure and development correspond to numerous trends connected with the vine root. More than 15.000 papers have been written since the end of the 19th century. Only a few publications, however, refer to the ontogenetic changes of the vine root system (Bouzin, 1932; Potapenko and Kostina, 1950; Breviglieri, 1955; Melkonian, 1960; Riabtchoun, 1960 and 1969; Constantinescu, 1971; Richards, 1983). Thus in practice root management with respect to vegetative periods is much more difficult than adequate cultivation of the above-ground parts.

Burić and Nikolić (1973) studied the root system of vines grafted onto different rootstocks and used the stage of „full fruit-bearing“ as a reference. Draganov et al. (1975) studied the vine root system of five to nine year old vines. Piţic (1966) found that the root system of four year old plantations was uniformly distributed along the whole feeding area. Seguin (1966) as well as Nikiforova and Vologin (1975) pointed out that vines reach a sufficient root mass at the age of eight to nine years, determined by an intensive use of soil nutrients. It is reported that the total quantity of vine coronal roots depends on the intensity of root-formation and the extent of aging and dying of active roots. The relation between these processes is mainly determined by soil and climatic conditions (Katarian and Potarov, 1964; Constantinescu, 1977; Litvinov, 1977). Litvinov and Shtapkin (1970) pointed out that root quantity increased insignificantly in vines at the age of one to three years and their thickness and length did not increase. Champagnol (1978) found out that under the conditions of the Mediterranean sandy soils five years after plantation the above-ground part (measured as shoot and yield weight) grew considerably, but there was no mentionable change in root distribution and total weight. Operan et al. (1963) reported that vines started fruit-bearing only after seven to eight years on sandy soils in the viticultural region Jiului in Rumania, because the root system poorly developed during the first years.

It is known that different rootstocks and grapevine cultivars show specific characteristics of root system growth and development. This influence also affected root architecture (Oşlobeanu, 1968). Varying soil conditions limit or enhance the possibilities for the expression of trait heredity during root system development.

Regarding the development of fruit-trees Shitt (1958) proposed a theory that their life cycle shows nine biological periods. He characterised the state of the underground parts of fruit trees in detail. The present study was carried out on the basis of this theory. Its objective was to study the ontogenetic changes of the vine root system and to describe their biological nature. Thus the agritechnical measures for the vine root system could be differentiated depending on its biological age.

Material and Methods

The objects of this study were vines of the 'Cabernet Sauvignon' cultivar on the rootstock 'Kober 5BB' at different biological and calendar age. The vines were grown under the same agrotechnical conditions on leached chernozem. They had Ombrella training (stem height: 1.60 m, vine distance: 3.40/1.20 m). The terrain has a slope of 5 to 7°, facing toward south-east-east and has an altitude of 140 to 150 m.

The vines were chosen very precisely by above-ground part appearance as well as by a number of other characteristics - stem thickness, shoot length, yield per vine (Pourtchev, 2001).

Soil-root cubes was used to study the root system (1/4 of the soil was dug in layers of 20 cm to the needed depth). The roots were collected according to different horizons, washed and dried to air-dry state and then divided into seven fractions: up to 1 mm, 1 to 2 mm, 2 to 3 mm, 3 to 5 mm, 5 to 10 mm, 10 to 20 mm and more than 20 mm. The tables of results (Table 1 to 8 and Table 10) present the mean values of five-fold replicative measurements.

The ontogenetic changes in the above-ground part were determined by growth intensity, fruit-bearing and withering. Just on the contrary, the ontogenetic changes of the root system, depending on their functional specialisation, were determined by the ratio of root growth, biological activity and dying off.

Results and Discussion

The ontogenetic changes of the vine root system were determined in correspondence to the development of the vine's above-ground habitus, like growth intensity, fruit-bearing and withering, that means by individual characteristics and not by the calendar age of the vine. According to the data obtained, only the following eight biological periods of vine development were determined: I. growth; II. growth and fruit-bearing; III. fruit-bearing and growth; IV. fruit-bearing; V. fruit-bearing and withering; VI. withering, fruit-bearing and weak growth; VII. withering and growth; VIII. growth.

Tab. 1: Period I - Root growth distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)					Σ (g)	%
	<1	1-2	2-3	3-5	5-10		
0-20	9,16	8,68				17,84	2,23
20-40	73,48	75,84	34,20	79,44	160,52	423,48	53,00
40-60	51,76	57,00	28,32	57,24	66,92	261,24	32,69
60-80	11,48	12,88	19,52	13,28		57,16	7,15
80-100	4,62	8,32	12,60	4,28		29,82	3,73
100-120	1,02	4,08	4,52			9,62	1,20
Σ 0-120	151,52	166,80	99,16	154,24	227,44	799,16	100,00

Tab. 2: Period II - Growth and fruit-bearing. Root distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)					Σ (g)	%
	<1	1-2	2-3	3-5	5-10		
0-20	33,08	28,40	29,72			91,64	7,54
20-40	79,04	78,00	35,88	86,76	225,64	505,32	41,82
40-60	55,84	57,28	33,88	76,92	109,72	333,64	27,61
60-80	23,48	36,84	35,76	49,60		145,68	12,06
80-100	13,36	19,36	20,77	30,04		83,53	6,91
100-120	6,60	9,40	8,84	7,92		32,76	2,71
120-140	3,00	4,60	6,60	2,12		16,32	1,35
Σ 0-140	214,40	233,88	171,45	253,36	335,36	1208,45	100,00

mm) was observed in the soil zone between 0 and 100 cm during the period of growth (I; from 1 to 3 years) (Table 1), while during the period of fruit-bearing (IV) distribution of root system was observed between 0 to 280 cm which corresponded to changes of the water-air balance in the soil (Table 4). Bouzin (1932) reported similar phenomena under the conditions of Crimea, Ukraine, pointing out that during the first year the vine roots penetrated to 122 cm depth for strong vines and to 75 cm for weak ones; during the second year down to 125 cm depth for strong ones and to 110 cm for weak ones with a radius of root side spreadth of 110 cm. Oungourian (1964) mentioned that in the region of Moldova with chernozem soils the roots of three year old vines of cultivar 'Cabernet Sauvignon' reached 260 to 340 cm of depth. Pourtchev (2003) reported that the root system of 90-years old grapevines from old Bulgarian cultivars ('Gâmza' on Chasselas *x* Berlandieri '41B' rootstock, 'Gâmza' own-rooted and 'Pamid' on 'Kober 5BB') planted on loess and alluvial loess in the Danubian region of Northern Bulgaria developed and penetrated to a great depth down to 27 to 32 m. The deep root penetration was observed not only for grafted grapevines, but also for own-rooted grapevines and that was explained by the favourable physico-chemical properties of the soil

Tab. 3: Period III - Fruit-bearing and growth. Root distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)						Σ (g)	%
	<1	1-2	2-3	3-5	5-10	10-20		
0-20	41,04	50,64	62,92	85,00	23,88		263,48	14,32
20-40	90,52	38,72	63,28	94,92	257,60	91,88	676,92	36,95
40-60	72,88	68,08	55,60	87,60	143,12		427,28	23,32
60-80	24,96	43,36	40,92	50,60	24,52		184,36	10,06
80-100	20,72	25,92	32,20	34,04			112,88	6,16
100-120	16,98	21,40	18,68	22,32			79,38	4,33
120-140	11,40	10,92	11,68	9,00			43,00	2,35
140-160	4,68	5,08	8,92	7,08			25,76	1,41
160-180	3,92	4,36	5,76	5,00			19,04	1,04
Σ 0-180	287,10	308,48	299,96	395,56	449,12	91,88	1832,10	100,00

This is one period less than what Shitt (1958) found for fruit-tree plantations. Huglin (1986), however, divided the development of vine from the beginning to the end of its life only into three stages: I. quick growth (up to 7 to 9 years), II. aging, III. getting old.

Regardless to individual morphological differences which were determined during this study it was found, that the soil and climatic conditions determined almost all characteristics of the biological periods. For example, root development (fractions 2 to 3 mm and 3 to 5

Tab. 4: Period IV - Fruit-bearing. Root distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)							Σ (g)	%
	<1	1-2	2-3	3-5	5-10	10-20	>20		
0-20	66,84	36,64	65,60	100,60	40,48			310,16	7,15
20-40	139,04	103,60	87,00	100,28	354,80	690,40	82,88	1558,00	35,93
40-60	76,80	79,80	62,00	104,88	178,68	500,60	184,08	1186,84	27,37
60-80	60,52	49,60	41,48	58,72	92,96			303,28	6,99
80-100	32,56	29,68	30,20	48,52	62,92			203,88	4,70
100-120	26,60	25,60	20,68	43,36	32,56			148,80	3,43
120-140	28,72	29,00	25,80	41,56	22,72			147,80	3,42
140-160	24,80	23,72	17,28	33,76	16,68			116,24	2,68
160-180	22,20	21,24	16,08	26,48	11,52			97,52	2,25
180-200	18,88	16,60	15,04	23,32				73,84	1,70
200-220	17,36	15,48	12,56	19,92				65,32	1,51
220-240	14,48	13,36	9,24	14,60				51,68	1,19
240-260	13,84	14,60	8,20	13,68				50,32	1,16
260-280	3,80	4,72	5,08	8,96				22,56	0,52
Σ 0-280	546,44	463,64	416,24	638,64	813,32	1191,00	266,96	4336,24	100,00

Tab. 5: Period V - Fruit-bearing and withering. Root distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)							Σ (g)	%
	<1	1-2	2-3	3-5	5-10	10-20	>20		
0-20	62,36	51,64	65,44	56,20	34,40			270,04	10,08
20-40	59,76	52,80	83,80	96,64	486,68	272,52	82,88	1135,08	42,40
40-60	43,20	44,20	42,00	116,80	144,92			391,12	14,60
60-80	21,12	21,48	26,36	61,28	18,80			149,04	5,58
80-100	17,88	19,80	21,,52	48,56	13,00			120,76	4,52
100-120	13,52	16,84	19,36	42,88	10,52			103,12	3,80
120-140	16,88	18,16	21,00	43,20	10,80			110,04	4,12
140-160	12,80	16,40	18,28	41,04	10,20			98,72	3,69
160-180	12,60	14,92	17,04	27,76	8,80			81,12	3,03
180-200	12,12	12,96	14,16	22,20				61,44	2,29
200-220	11,48	12,80	11,52	17,84				53,64	2,00
220-240	10,60	11,48	8,92	12,52				43,52	1,63
240-260	8,48	10,52	7,48	11,36				37,84	1,42
260-280	3,76	4,96	6,12	7,73				22,57	0,84
Σ 0-280	306,56	308,96	363,00	606,01	738,12	272,52	82,88	2678,05	100,00

and by the low water-holding capacity of the soil.

It is evident from the studies carried out that the habitus of the root system becomes typical for the cultivar by the end of the second biological period. In this study we also found out that its main traits are kept almost during the whole life cycle (Table 2 to Table 8). Consequently, species and cultivar characteristics of the root system, that means its type - horizontal, vertical or mixed, penetrating depth of main conducting roots, type of distribution of the horizontal roots by soil horizons - and the characteristics connected with the soil conditions are formed during the first three biological periods. The ontogenetic changes during these periods are hidden by habitus formation and they could not be recorded.

Beginning from the fourth period the ontogenetic changes passed on the background of a well-formed root system. They were well noticeable and allowed to follow up the direction of the changes in the first biological periods and to determine the correlation with the ontogenetic changes in the above-ground parts.

The ontogenetic changes of the root system were determined by the following three factors: ratio of root growth, biological activity and dying off. The peculia-

Tab. 6: Period VI - Withering, fruit-bearing and weak growth. Root distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)							Σ (g)	%
	<1	1-2	2-3	3-5	5-10	10-20	>20		
0-20	39,72	45,56	28,32					113,60	6,54
20-40	47,20	54,44	72,24	60,64	134,40	162,00	52,64	583,54	33,59
40-60	42,28	30,00	36,16	36,32	89,24			234,00	13,47
60-80	19,48	20,72	19,80	35,88	51,20			147,08	8,47
80-100	12,80	19,24	18,88	33,32	18,08			102,32	5,89
100-120	12,48	15,80	17,40	31,12	10,52			87,32	5,02
120-140	14,60	17,12	19,12	35,36	12,48			98,68	5,68
140-160	11,88	15,76	18,12	35,00	9,60			90,36	5,20
160-180	11,40	14,20	16,68	29,12				71,40	4,11
180-200	10,48	13,36	13,76	20,56				58,16	3,35
200-220	9,76	11,40	11,08	17,00				49,24	2,83
220-240	9,52	10,96	10,20	12,72				43,40	2,50
240-260	7,52	10,20	7,12	9,72				34,56	1,99
260-280	2,92	5,28	6,56	9,00				23,76	1,36
Σ 0-280	252,04	284,04	295,44	365,76	325,52	162,00	52,64	1737,44	100,00

Tab. 7: Period VII - Withering and growth. Root distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)					Σ (g)	%
	<1	1-2	2-3	3-5	5-10		
0-20	25,40	26,04	20,68	30,12	19,64		121,88
20-40	58,48	50,60	94,52	49,28	69,80	268,16	590,84
40-60	45,48	28,92	35,80	32,20	56,92		199,32
60-80	12,24	13,88	14,56	23,80			64,48
80-100	11,52	12,80	13,32	14,88			52,52
100-120	8,72	9,40	12,40	11,36			41,88
120-140	11,08	10,32	12,80	12,60			46,80
140-160	9,80	9,72	12,32	10,16			42,00
160-180	9,44	9,12	11,12	9,72			39,40
180-200	8,88	8,40	9,44	9,40			36,12
200-220	7,72	7,80	8,40	8,48			32,40
220-240	5,92	6,32	8,60	9,00			29,84
240-260	6,68	5,76	7,00	8,12			27,56
260-280	3,36	5,52	6,52	7,92			23,32
Σ 0-280	224,72	204,60	267,48	237,04	146,36	268,16	1348,36

rity of the life cycle of the root system was the fact that all three factors were manifested in each period although they were expressed in specific ways. However even when one of the factors dominated the others, that could not be noticed always. Thus, the decayed roots were mineralised quickly leaving scarcely noticeable traces while the decayed above-ground parts were preserved for a long time and could be recorded.

In contrary to the root system, not always all factors characterising the biological period of the above-ground part are manifested in each biological period. For example, during the first, seventh and eighth biological period there was no fruit-bearing. Sometimes in the seventh biological period little fruit-bearing can happen, but it might be almost symbolic (Table 9). However a natural relation between the development of the above-ground part (growth - fruit-bearing - withering) and the root system (growth - biological activity - dying) determining the biological age of the vine could be observed. Numerous authors reported already such a relation between the vine above-ground and underground parts (BAULIN, 1939; NEGROUL, 1958; RANKINE et al., 1962; SZÉGEDI, 1962; JUNCU et al., 1963; OPREAN et al., 1963; KAISER, 1968 and 1970; CONRADIE, 1983; GIULIVO et al., 1988; NORTHCOTE, 1988; POURTCHEV, 1995, 2000 and 2002; EDSON et al., 1995; SLAVTCHEVA and POURTCHEV, 1999 and 2002).

The biometric data characterising the state of the above-ground part and of the root system are presented in Table 9. The growth processes were predominantly compared to the processes of withering and dying off up to the fourth to fifth biological period (Table 4 and 5). Rootstock and stem thickness, leaf area, total shoot length, yield per vine (number of clusters, weight of one cluster) and thickness of the feeding roots, as well as that of the conducting roots reached their maximum and that allowed to obtain optimum yields. The calendar age of the observed vines was about 12 to 18 years,

Tab. 8: Period VIII - Growth. Root distribution in fractions (mm) and weight (g) of 'Cabernet Sauvignon' on 'Kober 5BB'

Depth (cm)	Fractions (mm)					Σ (g)	%
	<1	1-2	2-3	3-5	5-10		
0-20	55,92	37,76	78,88	76,24	50,84	299,64	17,04
20-40	59,24	52,88	83,00	135,20	156,48	486,80	27,69
40-60	37,80	41,52	42,80	46,48	130,20	298,80	16,99
60-80	30,20	31,00	22,56	32,32		116,08	6,60
80-100	25,28	23,72	17,72	30,56		97,28	5,53
100-120	17,92	16,92	16,28	26,32		77,44	4,40
120-140	20,96	19,48	17,52	29,00		86,96	4,95
140-160	14,60	17,04	14,56	27,48		73,68	4,19
160-180	13,12	15,24	13,36	18,08		59,80	3,41
180-200	10,52	11,76	11,40	11,12		44,80	2,55
200-220	8,32	8,52	8,84	8,96		34,64	1,97
220-240	7,24	7,00	8,40	8,20		30,84	1,75
240-260	6,92	6,20	7,48	7,36		27,96	1,59
260-280	3,72	6,08	6,92	6,88		23,60	1,34
Σ 0-280	311,76	295,12	349,72	464,20	337,52	1758,32	100,00

however the fourth biological period could last up to 40 to 50 or even 60 years. To a great extent, this is a function of the climatic and soil conditions as well as agronomical practices. For example, the best wines produced in the region Medoc, France are from old vineyards at the age of about 80 years, which have root systems which penetrate into great depth (SEGUIN, 1971).

From the fifth biological period, i.e. the second half of the vine life cycle the processes of decaying became prevailing. The conducting roots, mainly belonging to the larger fractions, started to die off. Annual growth of roots dropped significantly and the diameter of the root system distribution decreased. On the other hand the acid content in the grapes increased (Table 9).

The total length of the feeding and conducting roots, which has reached its maximum of 2280 m in the fourth biological period, decreased to 1382 m in the fifth biological period and to 1350 m, respectively, in the eighth biological period (Table 10).

Not only feeding roots (up to 20 mm) but also conducting ones (above 20 mm) died when the conditions were not favourable. This process was typical for any vine age and it did not characterise the biological period. Also different elements of the above-ground part started to die in the fourth biological period accompanied by dying of a great part of roots with a diameter up to

Tab. 9: Biological periods of development and physiological state of 'Cabernet Sauvignon' on 'Kober 5BB'

Biological periods of development	Calendar age (years)	Rootstock thickness (mm)	Stem thickness (mm)	Yield per vine: Number of clusters	Yield per vine: Weight per cluster (kg)	Yield per vine: Total weight (kg)	Leaf area: Average leaf area per leaf (cm^2)	Leaf area: Number of leaves (average per vine)	Leaf area: Total leaf area (m^2)	Growth (kg): Annual	Growth (kg): Two-years	Shoots thickness (4/5 internode, mm)	Shoots total length (m)	Sugars (%)	Titratable acidity (g/l)
I. Growth	2	25	25				91,95	407	3,74	0,380		0,522	15,80		
II. Growth and fruit-bearing	5	31	31	42	0,095	3,990	94,72	690	6,53	0,710	0,080	0,615	27,70	22,4	6,80
III. Fruit-bearing and growth	10	57	57	58	0,098	5,680	98,91	1265	12,51	1,410	0,220	0,702	38,90	20,6	7,10
IV. Fruit-bearing	13	61	62	73	0,108	9,950	122,17	2038	24,90	0,840	0,315	0,655	56,70	20,2	7,20
V. Fruit-bearing and withering	18	64	65	69	0,094	6,530	118,13	1850	21,85	0,680	0,350	0,684	43,50	20,2	7,25
VI. Withering, fruit-bearing and weak growth	20	64	67	63	0,072	4,540	117,68	1440	16,95	0,630	0,210	0,682	31,60	20,5	7,55
VII. Withering and growth	22	66	27	46	0,053	1,480	112,76	1150	12,97	0,580	0,050	0,664	28,90	21,0	7,65
VIII. Growth	25	67	34				105,33	845	8,90	0,940		0,629	23,10		

Tab. 10: Feeding and conducting root length (L, m) and area (A, m^2) depending on the different periods of 'Cabernet Sauvignon' on 'Kober 5BB'

Biological period	Agrobio-logical indices	Fractions (mm)							
		< 1	1-2	2-3	3-5	5-10	10-20	> 20	Σ
I	L	475,50	118,66	27,17	18,15	8,06			647,54
	A	1,00	0,56	0,21	0,22	0,18			2,17
II	L	672,83	166,38	46,98	29,81	11,88			927,88
	A	1,43	0,79	0,36	0,37	0,27			3,22
III	L	900,97	219,45	82,19	46,54	15,91	1,26		1266,32
	A	1,91	1,04	0,63	0,57	0,36	0,47		4,98
IV	L	1714,84	329,83	114,05	75,14	28,81	16,32	1,54	2280,53
	A	3,64	1,56	0,88	0,93	0,65	0,62	0,94	9,22
V	L	962,05	219,79	99,46	71,30	26,14	3,73	0,48	1382,95
	A	2,04	1,04	0,76	0,88	0,59	0,14	0,29	5,74
VI	L	790,95	202,06	80,95	43,04	11,53	2,22	0,30	1131,05
	A	1,67	0,96	0,62	0,53	0,26	0,84	0,18	5,06
VII	L	705,22	145,55	73,29	27,89	5,19	3,67		960,81
	A	1,42	0,69	0,56	0,35	0,12	0,14		3,28
VIII	L	978,36	209,94	95,82	54,62	11,95			1350,69
	A	2,07	0,99	0,74	0,68	0,27			4,75

Tab. 11: Biological periods of development and root fibrilla ratio

Biological periods of development	Number of root fibrilla per mm^2	Root fibrilla length (µm)	Root fibrilla diameter (µm)
I. Growth	225 (210-240)	256 (226-286)	15 (13-17)
II. Growth and fruit-bearing	260 (240-280)	285 (254-316)	16 (15-17)
III. Fruit-bearing and growth	310 (280-320)	354 (318-390)	17 (15-19)
IV. Fruit-bearing	390 (350-400)	430 (378-482)	18 (17-19)
V. Fruit-bearing and withering	430 (380-480)	483 (440-525)	20 (17-23)
VI. Withering, fruit-bearing and weak growth	405 (390-420)	424 (424-444)	20 (17-23)
VII. Withering and growth	355 (330-380)	407 (386-428)	18 (16-20)
VIII. Growth	330 (300-360)	380 (364-396)	17 (16-18)

20 mm. Simultaneously with the degradation of above-ground parts during periods V to VIII the conducting roots were reduced (Table 5 to 8). Practically conducting roots from the larger fractions did not remain until the end of the life cycle. Thus the above-ground part began again its life cycle and developed new roots of lower order and fractions.

Simultaneously with the withering of different elements of the above-ground part a number of recoveries (e.g. formation of a great number of sprouts along the arms, the stems and in the vine base) was observed. An analogous process occurred in the root system observing higher and lower recoveries in different root fractions.

By the end of the third biological period when intensive growth was observed in the above-ground part new conducting roots sprouted from the rootstock base. This process was most intensive in the fifth and sixth biological period when different elements in the above-ground part grew intensively and finally died off by the end of the life cycle (Table 9). The earlier the conducting roots sprouted from the rootstock base, the stronger, faster and further the conducting roots ramifications and the coronal endings were directed. In the more advanced biological periods most of the new roots sprouting from the rootstock base did not have the possibility to develop into conducting roots of larger fractions and they died together with the withering of the separate elements of the above-ground part. The non-uniform formation of new conducting roots of larger fractions and the different degree of viability depending on the biological age were the main reasons for the changes of total length and area of the feeding roots in the main root layers. At the same time the climatic conditions and the agritechnical measures had an influence on the intensity of the growth processes, biological activity, fruit-bearing, withering and dying off and they might enhance or delay the occurrence of one or an-

Tab. 12: Above-ground part and root system state during different life cycle periods

Biological periods and above-ground part status	Root system state according to the obtained results
I. Growth	Growth
II. Growth and fruit-bearing	Growth and ramification
III. Fruit-bearing and growth	Ramification and growth
IV. Fruit-bearing	Ramification
V. Fruit-bearing and withering	Ramification and withering
VI. Withering, fruit-bearing and weak growth	Dying off, ramification and weak growth
VII. Withering and growth	Dying off and growth
VIII. Growth	Growth

other biological period.

Already in the first biological period newly formed roots were observed in the main soil horizons. The stem thickness was in good correlation with the length of feeding roots (r = 0.579) and the lenght of conducting roots (r = 0.546), respectively. There were also strong positive correlations between the leaf area (r = 0.883) and the total length of shoots (r = 0.929), respectively, and the total weight of the roots. Similar correlations were found by Babrikov and Braikov (1973) and Koblet and Perret (1990).

During period I to IV the development of both the above-ground part and the root system was characterised by intensive gradual growth. The main mass of feeding and conducting roots had already penetrated into the pertaining soil volume. As a result of the intensive gradual growth of the root system during these biological periods the feeding and conducting roots reached the mother rock. The soil close to the rootstock was extracted by a considerable amount of feeding roots and during the fourth biological period they were replaced by conducting roots. The growth and regeneration of the root system occurred at the expense of the vine coronal roots. The first cycle of natural rejuvenating of the root system above-ground part was completed. After a definite time a great number of the peripheral above-ground parts and the root system stopped their function and were replaced by newly formed parts. The natural rejuvenating cycles will reoccur periodically and might be regulated by agritechnical measures like pruning which should be done at latest by the beginning of the fifth biological period.

The process of suberification began to enhance after the fifth biological period, the feeding roots became darker and their diameter smaller. The amount of suberificated roots and roots forming woody mass (increased diameter and reduced bulk density) might reach even 90% of the total root surface in the subsequent biological periods (VI to VII). The greatest saturation with feeding and conducting roots around the rootstock base was observed during the sixth biological period. A great number of feeding roots in the superficial layers was formed in the seventh biological period. Most of them would not reach the end of their ontogenetic development. This process was in close relationship with the physiological state of the above-ground part. The content of titrable acidity increased considerably and reached its maximum.

An intense degradation of the above-ground part and the root system occurred during the seventh biological period. Whatever agritechnical steps (mainly pruning) would not restore vine productivity. But also an intensive development of shallow lateral roots from the underground stem of the rootstock started (Table 7). The old life cycle in vine ontogenetic development ended and the new one began simultaneously in the biological period VIII (Table 8). The physiological activity of the feeding roots was enhanced by the increased number of root fibrilla. The more fibrilla the vine had in a certain biological period the more it could utilise the nutrient substances and water from the soil. The quick increase of root system activity during the transition from the first to the fourth biological period was also demonstrated by the fact that the total length of roots changed from 647.5 m to 2280.5 m (Table 10).

It might be claimed that the quantity of root fibrilla depended not only on soil physical properties, i.e. clay content ratio (< 0,01mm) but also on ramification order. In deeper and more ramified root systems (biological period IV to VI) with an order of 8^{th} degree the number of the root fibrilla reached its maximum (Table 11).

It was evident from the mean value of rootstock and stem thickness that the rootstock thickness increased considerably until the fifth biological period, but after the seventh biological period this tendency was insignificant. It could be supposed that this was caused by the physiological state of the vine in each stage of development. However the thickening of the stem continued until the sixth biological period. For the vines studied this value reached 67 mm in the sixth, but only 27 mm in the seventh biological period. The thickness of the rootstock on the other hand increased until the eighth biological period (Table 9).

Three types of root dying off were found in this study:

1. Dying off of the endings of the first order roots as well as of the roots of other orders. In certain years when the soil and climatic conditions were not favourable and when the physiological balance between the above-ground and underground-part was disrupted the dying off might reach even roots of 8^{th} order;
2. Systematic dying off of the shorter, lateral feeding roots of first order (even 1 to 2 months after planting). After the further growth this tendency was also observed for the longer and thicker roots of the subsequent orders of ramification;
3. Dying off of conducting roots (fractions 3 to 5 and 5 to 10 mm) and their replacement by one or several groups of the same fractions.

Dying off of feeding and conducting roots at one place and reappearing in another one ensures normal conditions for vine growth and fruit-bearing. Simultaneously dying off of roots might produce tons of organic mass per ha and year and thus might participate in humus formation and soil structure improvement. Root growth and dying off in all development stages with some differences between the years was already observed by KAISER (1968). REIMERS et al. (1994) as well as POURTCHEV (2002) found out, that root dying was more pronounced during bud swelling, grape ripening and leaf fall. Root dying off and appearance of new ones during all vine biological periods represented a natural process in vine ontogenetic development. Both growth and dying off occurred strictly consecutively and regularly. As a result of the systematic root dying off and regeneration the root system during each vegetation period as well as during the whole vine life tries to reach new, unused soil layers and the mother rock. Thus the thicker roots were freed of the thinner ones or even of whole groups of smaller fractions. The conducting roots grew to all ends of the soil volume occupied by the vines. This tendency was performed during the third and fourth biological period. The development of superficial, lateral roots was enhanced in the beginning of the fourth and fifth biological period and new root systems started to develop subjected to the same regularity - root dying off in direction from the periphery of the vine area.

As a result of the study of the root system and the above-ground part it could be assumed that vine ontogenetic changes passed through eight biological periods of development (Table 12).

During the different periods of the life cycle in the vine root system as well as in the above-ground part, generally one of the characteristics was predominant determining the age state. The other characteristics were poorly expressed or absent at all. Assuming provisionally the degree of root biological activity (their percentage distribution into feeding and conducting roots along the soil horizons, their interaction with the mother rock, the extent of their bulk spread, the nature of root juvenation and dying off and their ratio), the root state in each biological period could be characterised with the same precision as that of the above-ground part.

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