SZENT ISTVÁN UNIVERSITY

EFFECT OF THE ROOTSTOCKS AND IN-ROW SPACING ON THE GROWTH AND YIELD EFFICIENCY OF APPLE VARIETY „IDARED” AND ON THE ORCHARD PRODUCTIVITY

DOCTORAL THESIS

By

Pólyáné Hanusz Borbála

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Name of the doctoral school: Doctoral School of Multidisciplinary Agricultural Sciences

Branch of Science: Plant Growing and Horticultural Sciences

Leader: Dr Papp János
Professor
Doctor of agricultural sciences
Faculty of Horticultural Sciences
Department of Fruit Science

Tutor: Dr Hrotkó Károly
Professor
Candidate of agricultural sciences
Faculty of Horticultural Sciences
Department of Fruit Science

Approved by:

………………………………… ………………………………..
Leader of the Doctoral School the Tutor

1. Introduction, Research Background

Apple is the most important fruit in the temperate zone. Apple production includes a considerable part of research on fruit production and has the aim to elaborate methods and technologies to produce more yield of better quality using the least possible labour investment. Rootstocks offer great chances. Dwarfing rootstocks are more and more welcomed by producers as they are suitable for growing smaller trees, which can be planted in large number on the same area and higher yields can be reached per hectare. As the trees get more light the rate of improved fruit quality will be higher.

One of the most often planted variety in apple orchards in Hungary is "Idared". As it is a good and demanded variety research should consider the possibilities of more economical and site specific production. There were no trials until now, which tested the growth and yield efficiency of the variety "Idared" on different rootstocks and spacing in methodical experiments, but there are some research results reported in Hungarian and foreign literature, which support the assumption that, rootstocks and spacing will benefit the trees′ efficiency if the rootstocks and their spacing are selected according to the spacing. But the use of rootstocks in Hungary is very one-sided (HROTKÓ 1995a). The objectives of the present study include rootstocks, which were tested in Hungary, but - except for M.26, MM.106 and M.4 - were not distributed widely. Description of rootstocks rely on foreign literature (PRESTON 1970, PROBOCSKAI 1973, SEBŐKNÉ and PROBOCSKAI 1973). Later trials in Hungary involved only some of the rootstocks, mainly those combinations, which were popular in the seventies (HARMAT et al. 1982, PROBOCSKAI 1982, 1983, 1984, PETHŐ 1988, 1990, NAGY and LANTOS 1989). Therefore there are no data on rootstocks of a variety that is adaptable to a relevant spacing.

The selection of row and tree distance pre-assumes the establishment of the plantation (GYURÓ 1980), but this fact may have an influence on the growth and yield efficiency of the rootstock-scion combination of ecological and biological parameters. There is not much information about the interaction of the spacing and rootstocks in the reported research results in the literature. There were rather any methodical studies. Recommendations on row and tree distances for new rootstocks were mostly based on practical experience and vigour.

2. Literature Review

At the beginnings people had to satisfied themselves with the fruit of trees grown from the seeds they collected. Seedlings are in respect of fruit value heterogeneous and do not preserve the qualities of a variety (GYURÓ 1980). Rootstocks, where vegetative propagation was possible were first distributed in apple production more than 150 years ago (WEBSTER 1994). Later on more and more qualities were found, which benefited the production, so they became the key aspects in the course selection work. Rootstocks mainly determine the size of the tree, the training system to be applied, the quality and quantity of the produced fruit as well as its adaptability in the interaction with the scion.

Orchards planted in the 40s and 50s were featured by seedling rootstock. The most vigorous trees were planted with a spacing of 10x10m and M.4 was used as a rootstock, which was less vigorous than wild apple seedlings. In the 70s apple orchards were planted with a row and tree spacing of 5x3m but still on M.4 rootstocks, which were less vigorous, but not suitable for planting at higher density. In the second half of the 80s new rootstocks (M.9 and M.26) were used according to the western European practice. These rootstocks were suitable for planting 800-1000 trees per hectare and allowed an economical production of good quality (GONDA 1995).

Mohácsy, M. brought some Malling and Malling-Merton rootstocks into Hungary in 1936 and Probocskai, E. in 1962. Methodical studies and description of the rootstocks go back to that period, too. The established plantations of virus free M.26 an MM.106 stocks helped to distribute them more widely. By the 80s the rate of M.4 fall to 20% and the trend is still falling. The leading rootstocks are the dwarfing M.9 and the semi-dwarfing or medium vigorous MM.106 that is well adaptable and can be propagated easily. Growers for new plantations prefer dwarfing rootstocks, the high rate of M.9 confirms this tendency. Nowadays it is very urgent to adapt and register dwarfing and semi-dwarfing rootstocks and clones and to establish rootstock stoolbeds, which are still missing in Hungary (HROTKÓ 1999a). HROTKÓ (1999a) started a research programme to evaluate rootstocks deriving from foreign stocks some years ago. So the evaluation of the new rootstocks is in progress now, some of them seem to produce good results in our country too (HROTKÓ et al.1997, HROTKÓ et al.1995b, 2000). The latest results of experiments with different rootstocks have an important influence on the opinions about the recommended spacing. The trend goes towards more dense plantations. GYURÓ and PETHŐ (1969) say that hedgerow trees require a spacing of 18-24 m² (420-560 trees/ha) in correlation with the rootstocks, the breed and the soil. In shaping Haag hedge M.2 and M.4 rootstocks require 5x4 m (500 tree/ha), M.7 requires 4x3 m (850 trees/ha) of area. If Hungaria hedge is used 5x4 m (500 tree/ha) of area is suitable for M.4.

GYURÓ (1979) recommendations refer to various training system, together with a list of rootstocks as well. For varieties of slender spindle and standard vigour on M.9 and M.26 rootstocks and on spur soil and M.9, M.26 and MM.106 rootstocks he recommends 5x3 m (670 tree/ha) of area. For spindelbush he suggests 7x4 m (360 tree/ha) of area using M.4 rootstocks.

GONDA (1997) recommends an area of 3-4x0.8-1.8m (1400-4200 tree/ha) for M.9 with slender spindle. Though he thinks that the stronger rootstocks MM.106, M.4 and M.7 require 5-6x2-3m (560-1000 tree/ha) for spindle shaped crown with fruit bearing branches or free spindle shaped crown.

HROTKÓ (1999a) registered rootstocks according to vigour and listed their area requirements as well:

M.9:	2-5 m² (2000-5000 trees/ha)	MM.111:	8-12 m² (850-1250 trees/ha)
M.26:	4-8 m² (1250-2500 trees/ha)	MM.104:	12-25 m² (400-850 trees/ha),
MM.106:	5-10 m² (1000-2000 trees/ha).	A.2:	20-25 m² (400-500 trees/ha).
M.4:	12-25 m² (400-850 trees/ha)		

In the 60s trees with fruit bearing branches on M.4 rootstocks produced well on an area of 7.5x4.5m (297 tree/ha) or of 8x5m (250 tree/ha) depending on the soil type (GONDA 1995). In the 70s "Jonathan" variety on M.4 rootstocks were planted with a spacing of 5x3 m (667 tree/ha) hedge crown with oblique fruit bearing branches.

Based on Hungarian experience (GONDA 1995) the most suitable spacing for trees plate grafted on virus free M.9 rootstocks is 3.5x1.5m (1905 tree/ha). GONDA recommends spacing of larger than 4 meters row distance and 1.5-1.8 meters tree distance only in case of M.26 rootstocks.

INÁNTSY (1998) recommendations refer to spacing according to the vigour of the varieties on different rootstocks.

For “Golden” cultivar of standard vigour he recommends:

M.9	4x1 m	(2500 tree/ha)
M.26	5x2 m	(1000 tree/ha)
MM.106	6x3 m	(555 tree/ha)

For cultivars of strong vigour he recommends:

M.9	4x15 m	(1667 tree/ha)
M.26	5x2.5 m	(800 tree/ha)
MM.106	6x4 m	(417tree/ha)

3. Objectives

1. One of the aims of the experiments is to determine the vigour of the tested rootstocks and their influence on yield efficiency of the scion at site.

2. Based on data and growing experience it is to be expected that the larger the spacing is the larger the individual size of the trees will be. The experiments also aimed to study the response of the trees on the tested rootstocks at different spacing. More detailed: what is the correlation between the fruit bearing surface of the tree and that of the plantation and the correlation between the yield and the changes of the spacing. This information can contribute to a better estimation of optimal tree number and spacing within a plantation.

3. As mentioned before some data are available in literature referring to the size of the tree influenced by the distance of trees, but there are no data available referring to the influence of the spacing on the yield efficiency of a tree or on the yield efficiency. Therefore I decided to study the influence of the distance of trees on the yield efficiency per tree and further on the cumulative yield of the plantation. Understanding these interactions will help to determine the optimal distance of trees and the spacing within the plantation and to specify the knowledge about the rootstocks with respect to their relations.

4. Material and Method

4.1. Material

I mention in my work the rootstocks involved in my experiments according to the descriptions available in the Hungarian literature, where they are classified according to their vigour:
dwarf-growing: Malling 9 (M.9), semi-dwarfing: Malling 26 (M.26), medium vigorous: Malling-Merton 106 (MM.106) and Malling 7 (M.7), vigourous: Malling-Merton 111 (MM.111), Malling 4 (M.4), Malling 2 (M.2), Malling-Merton 104 (MM.104) and Alnarp (A.2).
The favourite variety “Idared” was involved as a scion cultivar in the experiments.
The experiments were established at two sites in Hungary. The climate in Szigetcsép resembles greatly the climate conditions on the Great Plane (Alföld) showing extremities in temperature distribution and generally low rainfall. Seven rootstocks were involved (M.26, MM.106, M.7, MM.111, M.2, M.4 and MM.104) in four combinations of spacing (according to the vigour of the rootstocks: 1.4-3m) in four replications and with 80 trees per combination. Trees were trained to free spindle. The experimental period covered the years between 1989-2000.
The other experiment site was Nyíradony, Tamási-puszta. It is a typical site in Nyírség, where the uncertainty of regular rainfall is the main problem in not irrigated plantations. 8 rootstocks were involved in this experiment (M.26, M.9/MM.111, MM.106, M.7, MM.111, MM.104, A.2 and M.4) according to the vigour of the trees. The experiments were carried out in 3-3 combinations of tree distances (between 1.8 and 3.5 meters) and in four replications. The applied tree architecture was free spindle. The period of experiment covered 1990-1997.

4.2.Methods

Starting with the year of the establishment of the plantation the following measurements were regularly taken: the trunk circumference taken below the lowest scaffold (at 60-70cm), the in row and perpendicular canopy area (length-width), its height and the yield per tree was estimated in Tamási-puszta or weighed in Szigetcsép. I calculated the trunk cross-sectional area (sq. m) and the

measures of the trees' canopy (canopy area and volume) upon the measurements. I calculated the canopy volume with the use of Silbereisen-Scherr formula (canopy area x height)/2 (SILBEREISEN and SCHERR 1968).
Circumstances beyond us did not allow us to weigh the yield in Tamási-puszta, so we estimated the yield per tree. We counted the fruit on a featuring branch and estimated the volume of the fruit crop by multiplying the number of fruits by the average volume. We estimated the total yield of the tree in relation with the featuring branches. I calculated the yield efficiency index per hectare from the measured data (trunk cross-sectional area m^2/ha, canopy area m^2/ha, canopy volume m^3/ha)(WESTWOOD 1978). The yield efficiency of the trees was featured by the total yield per hectare for each rootstock and each in-row distance. I used Statgraf 5.1 version of the programme package to evaluate the results. I applied the one way analysis and compared each application to the *t-test* and got a significance of 95% ($p=0.05$). As we used different in-row distance variations for every rootstock – depending on the expected vigour – the experiment could not be regarded as an experiment of two factors. Therefore I regarded each rootstock-tree-combination as a separate application in my analyses. This way the experiment could be evaluated as a single factor experiment. This way every application was to compare either it referred to the trees on different rootstocks or trees on the same rootstocks but at different in-row distances. Then I compared the results with the results reported in the literature.

5. Results and Conclusion

5.1. The influence of the rootstocks on the growth of "Idared" trees and the yield efficiency of the plantation

Based on the trunk circumference the studied rootstocks can be ordered into two well-defined groups. Obviously vigorous are MM.104, M.4 and M.2. Earlier literature reports ranked M.2 as a semi-dwarfing one (PRESTON 1970, NAGY 1979, PROBOCSKAI 1969). Initial growing results showed less vigour, but after the fifth year it did not significantly differ from the vigorous ones.
The other obviously different group consists of MM.106, M.26 and M.7 that proved to be semi-dwarfing compared to the trunk cross-sectional area, which equals most of the results reported in literature. The classification of MM.111 is still questionable. Based on the trunk cross-sectional area this rootstock is between the two groups as a medium vigorous one (HROTKÓ et al. 1997).
The canopy area allows us to build 3 groups of the rootstocks, which greatly comply with the results foreign literature reports, but contradict the Hungarian descriptions (PROBOCSKAI 1973, 1982). M.26 and MM.106 behaved as semi-dwarfing rootstocks but MM.104 and M.4 proved to be obviously vigorous. The transition group is to classify as medium vigorous including M.2, MM.111 and M.7.
Based on canopy volume the rootstocks can be ranked into 3 groups: vigorous ones MM.104 and M.4, medium vigorous M.2 and MM.111, semi-dwarfing M.7, MM.106 and M.26. This classification meets the aspects of foreign literature but contradicts PROBOCSKAI (1973, 1982) because he uses different training system.
As a summary: based on the trunk cross-sectional area, the canopy area and volume we classify the tested rootstocks as follows:

Semi-dwarfing:	M.26, MM.106 and M.7
Medium vigorous:	MM.111 and M.2
Vigorous:	M.4 and MM.104

The reason of a classification different from that of PROBOCSKAI (1973, 1982) is that trees with spindle crown brought fruits earlier, what moderated their vigour during the productive period.
Regarding the yield efficiency per trunk cross-sectional area the rootstocks responded according to the expectations and complied with the results in literature reports. The good yield efficiency of

trees on rootstocks MM.106 was proved again, although we already knew the relevant yield results of M.26 and M.7 from the literature reports (HROTKÓ 1999a, ARCHBOLD et al. 1987). It is to mention that trees on M.4 were similarly efficient as those on M.26 and MM.106. Based on yield efficiency trees on MM.111 can be classified as M.4. ARCHBOLD et al. (1987) evaluated MM.106 as the best one regarding the cumulative yield efficiency, followed by M.7 and MM.111. Rootstocks show a more diverse picture if we observe the yield efficiency of the rootstocks calculated on canopy area. MM.106 and M.2 are in the group of the best rootstocks together with M.7 and M.4. But M.26 proved to be less good in spite of its good yield efficiency as per trunk cross-sectional area. MM.104 and MM.111 produced the lowest yields. Studying the average of the last 5 growing years MM.106 is leading followed by M.4, M.2 and M.7.

5.2. Growth and yield of "Idared" trees planted at different in-row distances

The results proved that using the rootstocks (MM.111, M.2 and M.4) the trees grew better, i.e. larger average trunk cross-sectional area, larger average canopy area and volume developed owing to the greater in-row distance. In case of other rootstocks the studied in-row distances did not influenced the size of the trees, or the influence proved to be a tendency without any significant differences.

Larger tree sizes owing to larger in-row distances rootstocks can be put into two groups: there was no response to the studied range of in-row distance, or trees responded with a minimum growth to the larger spacing. This refers to M.26, MM.106 and M.7 rooted trees that are classified as semi-dwarfing ones upon the tree sizes. If the growing area was larger the trees in this group got larger as well. In the group of semi-dwarfing trees the sizes of trees did not grow compared to the smallest in-row distance, but the size of trees reached the maximum and did not even reduced if the in-row distance was the smallest. After finishing the experiment the question is still open: Using these rootstocks at what in-row distance do the size of trees start to reduce and if it happens, how far can in-row distance be reduced without having an influence on tree sizes.

The results allow us to conclude that M.26, MM.106 and M.7 rootstocks grow well on denser plantations. In-row distance of 1.4m (M.26), of 1.6m (MM.106) and of 2.0m (M.7) may be more reduced on spacing without having a negative influence on the tree size, but this contradicts the aspects of some experts and researchers.

Yields per tree clearly show the positive influence of larger in-row distance and larger spacing on the cumulative yield per tree. This is very obvious, but no positive influence or only a tendency is to be observed with semi-dwarfing rootstocks. In the scope of rootstocks the in-row distance of 3 meters showed significantly higher values with MM.111 and the in-row distance of 2.6m with M.2 compared to 2meters in-row distance. The cumulative yield efficiency per trunk cross-sectional area shows slight differences. The maximum value was reached with MM.106 planted at 2 meters in-row distance, which show only an outraging tendency compared to other in-row distances. The same tendency can be observed by M.26 at 2 meters in-row distance. But significant differences confirm the influence of the in-row distance with M.7, MM.111 and M.2, which show a maximum value at in-row distances of 3 or 2.8 meters showing a significant difference compared to smaller in-row distances. In case of M.4 and MM.104 a tendency is to be observed owing to in-row distances of 2.4 and 2.8 meters. The results obtained prove that the enlargement of the in-row distance increases the yield efficiency per tree up to a certain maximum or optimal value, but this tendency is not valid for every rootstock. M.4 and MM.104 brought the highest yield at the largest in-row distance, but their yield efficiency did not increase. M.7 and MM.106 brought higher yield efficiency on larger spacing. For dwarfing and semi-dwarfing rootstocks the smallest in-row distance applied in the experiments proved to be too large, so they did not respond to the change of the spacing. This influence was proved by the results of trees on M.2 rootstocks with cumulative yield efficiency per canopy area and volume, though this tendency is to be observed with MM.111 as well. The same cumulative yield was produced on semi-dwarfing rootstocks (M.26, MM.106, M.7) at 1.4-2 m in-row distance under not irrigated conditions as on vigorous rootstocks (M.2, M.4, MM.104) at higher

in-row distances. Regarding the last two rootstocks the improved yield efficiency per tree on larger spacing could compensate the loss of fruit bearing surface as a result of the larger in-row distance.
It is already proved or it is to be assumed that as a result of larger in-row distances followed by larger spacing would increase the yield bearing surface and the specific yield efficiency until a certain optimal value, therefore this fact should be considered when evaluating the rootstocks. It is especially true as rootstocks of different vigour respond differently to the in-row distances. Only an optimal spacing ensures a real classification of rootstocks by their yield efficiency.

5.3. The influence of in-row distance on the bearing surface of the plantation depending on the roots

The bearing surface of a plantation determines its yield efficiency. The yield bearing surface per hectare can be described by the trunk cross-sectional area and the canopy area and volume (this shows the rate of area covered by the bearing surface).
Analysing the results of trunk cross-sectional area per area unit we can conclude that a maximum or significantly not differing trunk cross-sectional area can be reached on lot of rootstocks if the in-row distance is optimal. Except for MM.106, M.7 and MM.111, where the in-row distance combinations brought less than the maximum trunk cross-sectional area. The more vigorous rootstocks did not significantly differ from the maximum trunk cross-sectional area at the tested combinations of in-row distances. This is a result of the fact that owing to larger in-row distance and same trunk cross-sectional are per tree the trunk cross-sectional area decreases following the reduced tree numbers, which can only be compensated by thicker trunks on more vigorous rootstocks as an impact of larger spacing.
The disadvantage of semi-dwarfing and medium vigorous rootstocks is in case of too large in-row distances very obvious if compared to canopy area or volume per hectare. M.26 planted at 1.4 in-row distance produced the maximum canopy area by 41.4% canopy coverage per hectare. Significantly lower values were produced by MM.106, M.7 and MM.111 if planted at too large in-row distance (2.4, 2.8, and 3 m) adjusted to the spacing and the rootstocks.
Quite similar situation developed if M.4 produced the largest canopy area at 2.4 m of in-row distance. But significantly lower canopy volume was developed by semi-dwarfing, medium vigorous rootstocks at larger in-row distances of 2.4-2.8-3 meters.
Our observations confirmed the data reported in foreign literature, which say that the reduction of spacing is followed by the reduction of bearing surface per tree and the yield per tree (kg/tree). Under some limits this can be compensated by higher tree numbers and the larger yield-bearing surface per hectare and yields do not reduce but eventually increase.

5.4. Evaluation of the response of trees on the rootstocks compared to different spacing and the reduction of the optimal in-row distance

Trees on semi-dwarfing and vigorous rootstocks respond differently to the changes if the spacing compared to yield/fruit bearing-surface and yield per tree and fruit bearing surface and yield per plantation. I present the two different responses on the example of semi-dwarfing M 26 and vigorous M.4 rootstocks.

5.4.1. M.26 (Figure 1)

Figure **1/a** shows that the trunk cross-sectional area per tree (cm^2/tree) does not increase significantly together with the increase of the spacing, but there is a rising tendency to be observed. Reducing the in-row distance the trunk cross-sectional area (trunk cross-sectional area m^2/ha) per plantation reduces greatly.
Similarly there is only a gentle rise on the curve of the canopy area per tree influenced by the increased spacing, but the canopy area of the plantation reduces if the in-row spacing reduces (**Fig. 1/b**).

The same observations are to be made about the canopy volume. The canopy volume per tree shows a slowly rising tendency but the canopy volume per plantation shows a slow falling tendency if the in-row distance increases (**Fig. 1/c**).

The spacing increases at the same time as the cumulative yield per tree (**Fig. 1/d**).

But the yield efficiency of the plantation greatly reduces if the in-row distance increases. Trees on M.26 rootstocks produced the largest cumulative yield per plantation at an in-row distance of 1600 tree/ha. Our results show that at this spacing 1587 tree per hectare or a denser spacing is suitable for M.26.

The yield efficiency per tree compared to trunk cross-sectional area per unit slowly increases as the spacing increases, but the yield per area unit decreases rapidly (**Fig. 1/e**).

The specific yield efficiency per canopy area does not change considerably though it shows a slightly falling tendency. But if the in-row distance increases the yield of the plantation decreases (**Fig. 1/f**).

The yield efficiency per tree compared to canopy volume keeps practically the same rate and hardly changes if the spacing changes (**Fig. 1/g**).

As a summary M.26 can be characterised as a typicall semi-dwarfing one. In the tested range of in-row distances the size and yield efficiency per tree do not increase owing to the increased spacing. Therefore the decreasing in-row distance become a determining factor in the development of the fruit-bearing surface and the yield of a plantation. The fruit-bearing surface of the trees increases as the spacing increases, but the fruit-bearing surface at this rate is less productive and its yield efficiency reduce.

5.4.2. M.4 (Figure 2)

No significant differences are to be observed in the development of the trunk cross-sectional area, but there is a rising tendency if the spacing was increased **(Fig. 2/a**), but the bearing surface of the plantation decreases.

The canopy area rises at a significant rate if the in-row distance reduces. The canopy area of the plantation reduces after having reached the optimal rate of 926 tree per hectare (**Fig. 2/b**).

Similarly there is a significant increase in the canopy volume per tree if the in-row distance decreases. The optimal canopy volume develops at a rate of 926 tree per hectare (**Fig. 2/c**).

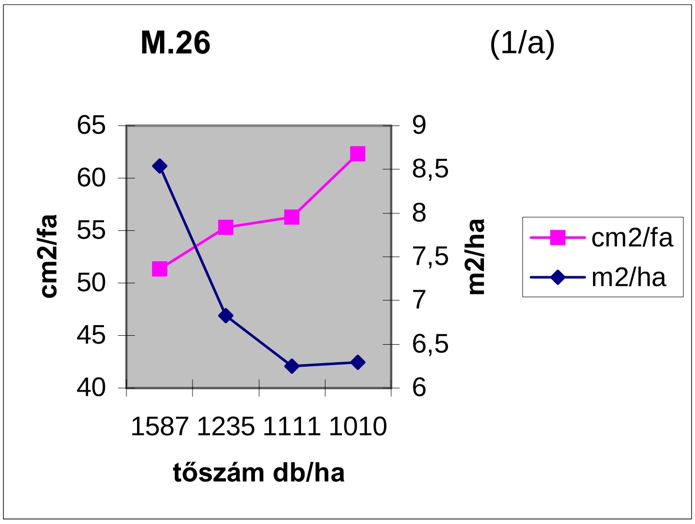
The yield efficiency per tree increases at a rapid rate till the in-row distance reaches the rate of 926 tree per hectare, but at lower rates it hardly changes. The optimal yield efficiency of the plantation developed at a rate of 926 tree per hectare and decreased if the in-row distance changed (**Fig. 2/d**).

The optimal specific yield efficiency per tree calculated on the trunk cross-sectional area is reached at a rate of 926 tree/ha, i.e. the growth of a tree is above 2.4 m in-row distance unproductive (**Fig. 2/e**). On the contrary the yield efficiency of a tree per canopy area reduces as the in-row distance reduces – even at an in-row distance of 2.0 meters (**Fig. 2/f**).

This allows us to conclude that although the canopy of the trees on M.4 rootstocks grows larger as the spacing increases, the yield does not increase at the same rate.

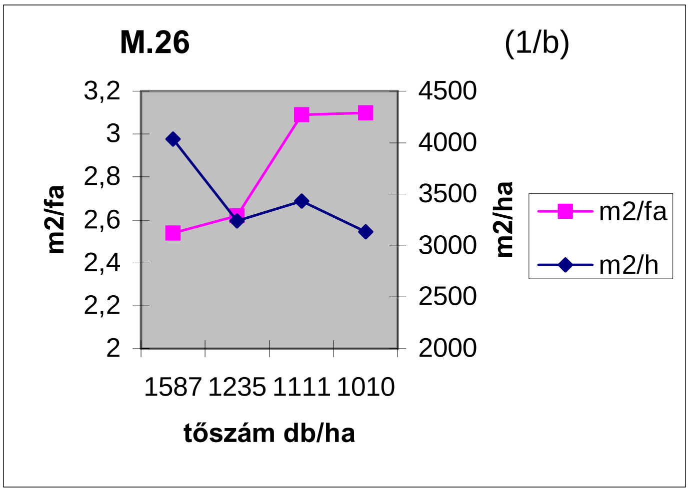
The sizes of trees on M.4 rootstocks increased as the in-row distances decreased. Therefore the optimal bearing surface in the plantation was reached at a rate of 926 tree/ha. The plantation produced the highest yield at this rate. But the yield efficiency per tree reduced as compared to the canopy size.

Comparing the research results the development of both the fruit-bearing surface and yield efficiency of the plantation confirmed the optimal rate of in-row distance of 926 tree/ha for M.4 rootstocks.



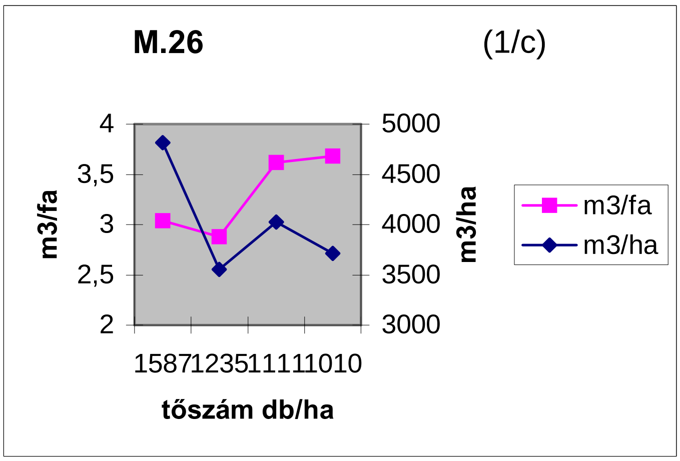
1/a figure Trunk cross-sectional area per tree(cm²/tree)

Trunk cross-sectional area per plantation (m²/ha)



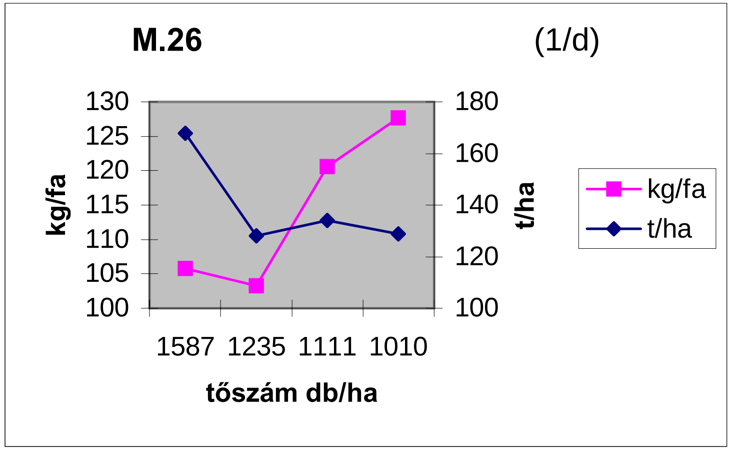
1/b figure Canopy area per tree (m²/tree)

Canopy area of plantation (m²/ha)

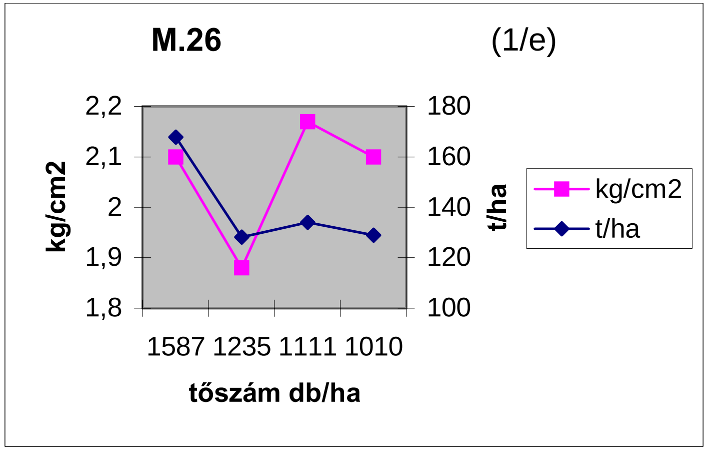


1/c figure Canopy volume per tree (m³/tree)

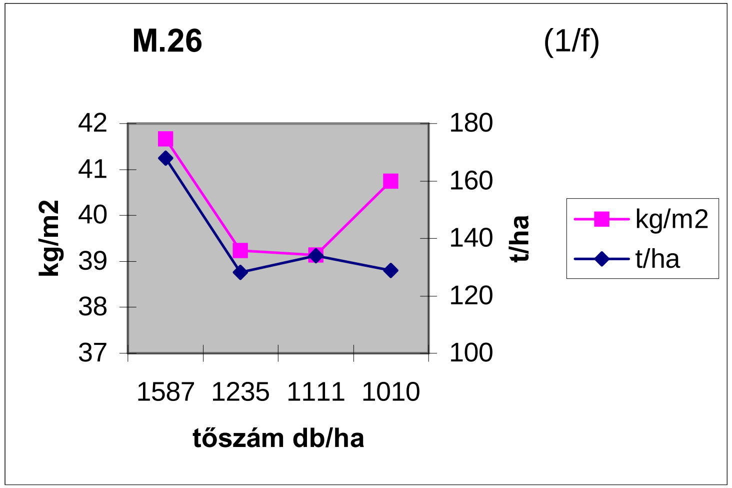
Canopy volume of plantation (m³/fa)



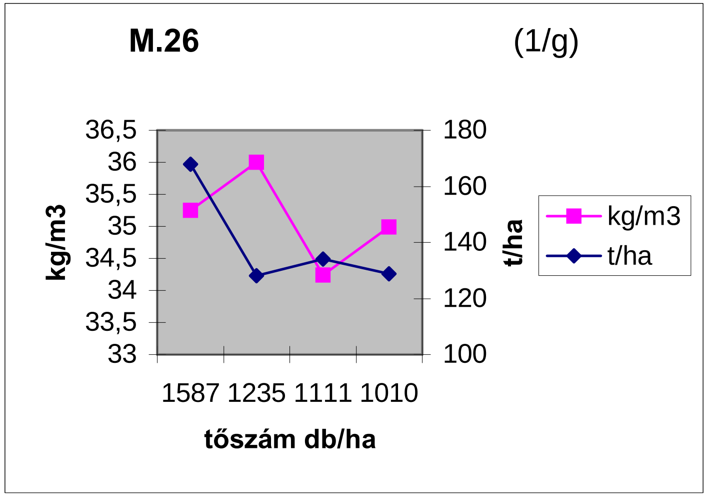
1/d figure Cumulative yield per tree (kg/tree)
Yield of the plantation (t/ha)



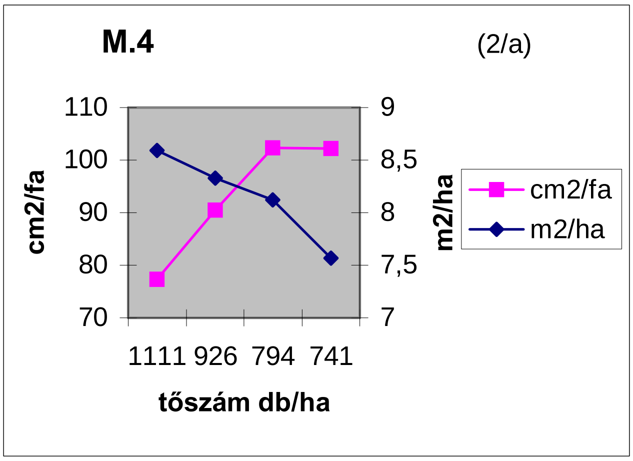
1/e figure Yield efficiency (kg/cross-sectional area cm²)
Yield of the plantation (t/ha)



1/f figure Yield efficiency (kg/canopy area m²)
Yield of the plantation (t/ha)

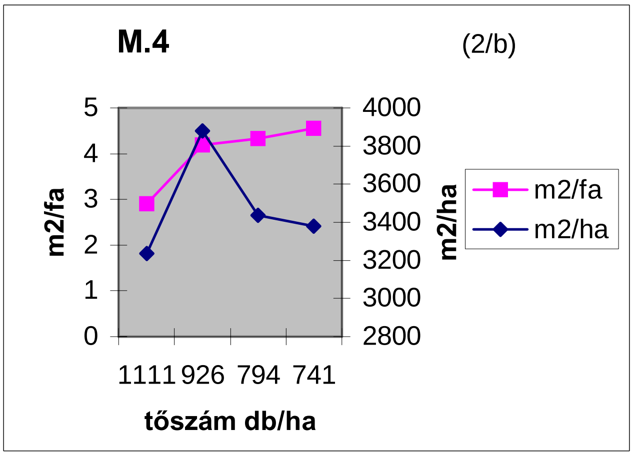


1/g figure Yield efficiency (kg/canopy volume m³)
Yield of the plantation (t/ha)



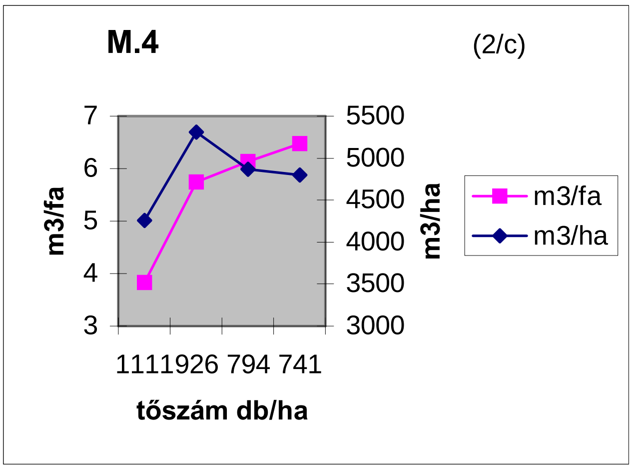
2/a figure Trunk cross-sectional area per tree(cm²/tree)

Trunk cross-sectional area per plantation (m²/ha)



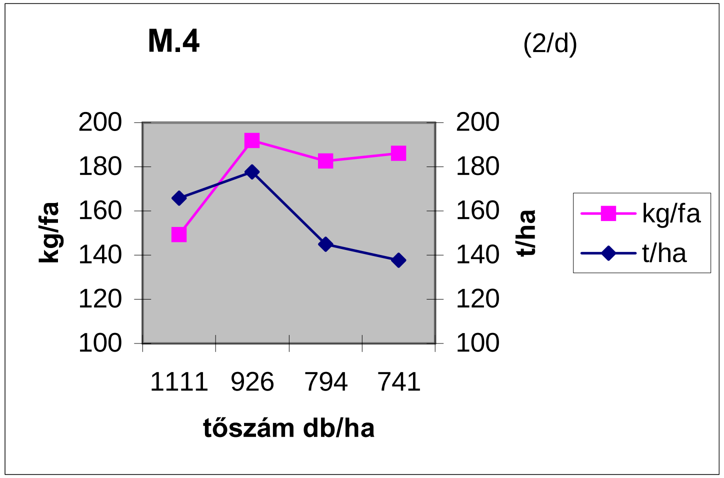
2/b figure Canopy area per tree (m²/tree)

Canopy area of plantation (m²/ha)

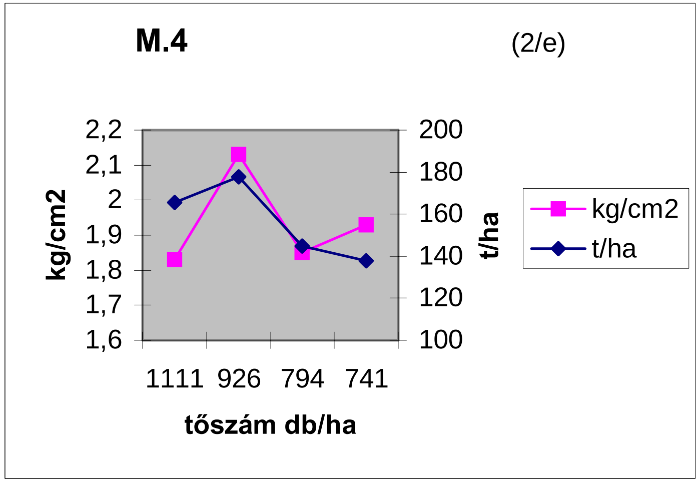


2/c figure Canopy volume per tree (m³/tree)

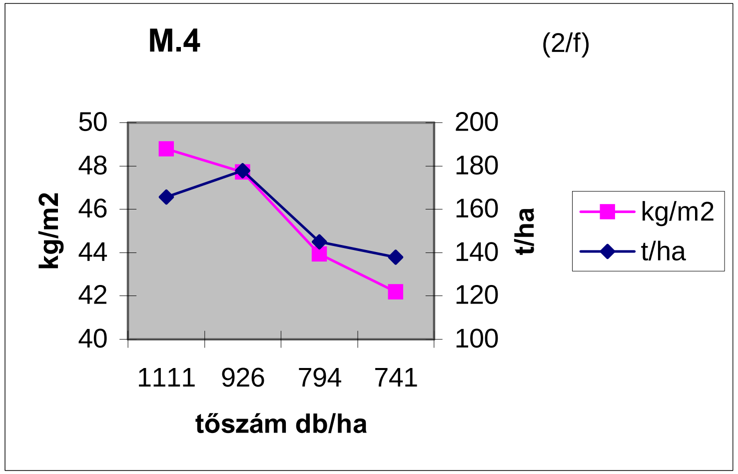
Canopy volume of plantation (m³/ha)



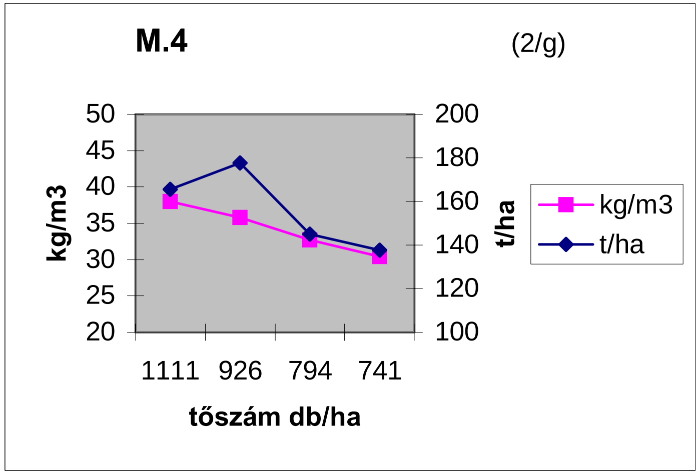
2/d figure Cumulative yield per tree (kg/tree)
Yield of the plantation (t/ha)



2/e figure Yield efficiency (kg/cross-sectional area cm²)
Yield of the plantation (t/ha)



2/f figure Yield efficiency (kg/canopy area m²)
Yield of the plantation (t/ha)



2/g figure Yield efficiency (kg/canopy volume m³)
Yield of the plantation (t/ha)

1. Relevant knowledge on the vigour of rootstocks involved into our experiments requires new approach of investigation. As a result of my research work I observed that MM.106 and M.7 develop more similar to M.26, so they are to be characterised as semi-dwarfing ones. My observations were based on the influence on sizes of trees and the responses on the enlarged spacing. Regarding the vigour of the other rootstocks the relevant data reported in literature could be confirmed.

2. I evaluated the responses of trees to the increasing spacing in the range of the tested in-row distance, which is described by the given spacing, scion and canopy shape. I observed that "Idared" cultivar on different rootstocks responded to the increasing spacing differently, which was to expect according to literature reports. The fruit-bearing surface of the trees on semi-dwarfing roots (e.g. M.26 and MM.106) increased moderately, mostly not significantly. But trees on medium vigorous or vigorous rootstocks (MM.111, M.2, M.4 and MM.104) produced a strong increase in the bearing surface.

3. I also observed that the yield efficiency of "Idared" trees influenced by spacing showed a rootstock specific difference. In the range of tested in-row distances trees on M.26, MM.106 and M.7 rootstocks did not show any changes in the yield efficiency, or they even decreased. In the range of in-row distances, where indices of yield did not increase, but even decreased, the increased bearing surface owing to the increased spacing (trunk cross-sectional area, canopy are and volume) is not productive.

4. The bearing surface and the yield of the plantation shows in relation to the change in the in-row distance a rootstock specific change but differently on each root. I also observed a reduction in the bearing surface by trees on semi-dwarfing rootstocks starting at the smallest in-row distances. Therefore the gently rising fruit-bearing surface and the yield are not able to compensate the changes caused by the changing in-row distance. In the range of the tested in-row distances an optimal in-row distance is to be determined for rootstocks.

5. I recommend the following in-row distances for rootstocks involved in the test groups of trees having spindle shaped crowns and planted on sites without irrigation:

Rootstock	Recommended in-row distance (tree/ha)
M26	1600 or more
MM106	1400 or more
M7	1100 or more
MM111	950
M2	800
M4	950
MM104	1100

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