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Growth correlations in apple nursery trees

Korelacje wzrostowe drzewek jabłoni w szkółce

Summary. Growth characteristics of maiden trees of several apple cultivars budded on various rootstock/interstem combinations were examined during the studies conducted in the USA (1994–1995), and in Poland (2001 and 2004). The following tree quality characteristics: parent shoot* diameter (TD) and its length (TH), total number of sylleptic shoots (TNS) and cumulative shoot extension (SEG) were measured at the end of each growing season. Correlations of TD × TNS, and TH × TNS expressed by coeficient of correlations and calculated at the end of each growing season for tested cultivars were significant in 73 and 27% of the examined cases, respectively. Additional measurements of these characteristics measured every 10 days during the entire season in 'Gala' trees on M.9 rootstock showed that on most occasions the correlations of both TD×TNS, and TD × SEG were significant in 62 and 75%, respectively, whereas those of TH × TNS and TH × SEG were significant in 38 and 45% of the examined cases, respectively. A significant correlation found between TD and TNS makes TD a more reliable parameter than TH for estimating nursery apple tree quality and its ability to lateral branching.

Key words: lateral branching, feathering, interstem, maiden tree, syllepsis

INTRODUCTION

One of the requirements for early cropping is the quality of trees used for orchard establishment. A quality tree is characterised by an adequate number of well-positioned lateral shoots, which provide sites for flower bud induction [Ferree and Rhodus 1987]. Plant ability to branch depends on many biological, cultural and environmental factors [Tromp 1992]. However, the ultimate determinant of cultivar's branching ability is under genetic control [Quinlan and Tobutt 1990]. There is a strong belief that vigorous growth of maiden trees is a necessary prerequisite for sylleptic shoot induction [Van Oosten 1968, Poniedziałek *et al*. 1996].

* Leader of one-year-old nursery tree

Having assumed that the root system functions normally, the growth rate of maiden tree may be expressed by increment of either parent shoot length and its diameter or the number and length of sylleptic shoots induced. Are these characteristics quantitatively related to each other? Experiments with maiden apple [Lipecki and Janisz 1999], pear [Jacyna 2004], and sweet cherry [Jacyna *et al*. 2005] have demonstrated that significant correlations exist between some of the above-mentioned quality characteristics. In most instances, these authors found that correlations between parent shoot diameter (TD) and the number of lateral shoots (TNS) were stronger than between parent shoot length (TH) and TNS. This was especially evident with freely branching apple cultivars 'Jonagold' and 'Elstar' [Lipecki and Janisz 1999] and sweet cherry 'Hartland', 'Somerset' and 'Windsor' [Jacyna *et al*., 2005], but not so explicit in pear trees [Jacyna 2004]. In those experiments, the observed TD × TNS correlation showed the relationship between these characteristics after growth cessation. It did not describe, however, any relationship that may have existed between TD and TNS at different stages of active tree growth.

The research reported here focused on the relationships between branching behaviour and corresponding vegetative growth characteristics in maiden trees of some apple cultivars commonly grown in north-western United States (part I). The objective of the other part of this project was to investigate growth correlations in apple maidens during the entire seasons in the climate of eastern Poland (part II).

MATERIAL AND METHODS

Part I. The experiments were carried out in 1994 and 1995 in western New York State in a relatively hot and humid climate during spring and summer months. Apple trees of 'Golden Delicious' on rootstock/interstem M.111/M.9 and M.26, 'McIntosh' on M.106/M.9, and 'Royal Empire' on M.106/M.9 and M.26 in the first year after budding were used. Upon completion of each growing season the measurement of parent shoot length (TH), its diameter (TD), and the number of sylleptic shoots (TNS) were recorded.

Part II. The experiments were performed in 2001 and 2004 in a commercial nursery in the Lublin district, eastern Poland. Apple trees of cv. 'Gala' on M.9 rootstock in the year following budding were used. The following characteristics in all experimental trees were measured every 10 days: TH, TD, TNS, and SEG (shoot extension growth) until tree growth has completely ceased. First measurements started when the length of parent shoot reached either 45 (y. 2001) or 55 cm (y. 2004). All sylleptic shoots which occurred on parent shoot up to 45 cm from the soil line were removed.

In all experiments the trees were randomly selected from one or two adjacent nursery rows of the same cultivar/rootstock combination. All trees were spaced 100 × 30 cm and were chip-budded. No lateral-branch-promotion techniques were applied. A completely randomised design with 30 (in 1994 and 2004), 20 (in 2001) and 18 (in 1995) single-tree replicates was used. The data were subjected to the analysis of variance. Mutual relations between TH × TNS, and TD × TNS in all experiments, and additional TH × SEG, and TD × SEG for experiments in 2001 and 2004, were evaluated by Pearson's product moment correlation at $P< 0.05$.

RESULTS

Final correlations between tree quality characteristics at harvest time

Comparisons of all correlation coefficients for TD × TH, TD × TNS and TH × TNS combined for 1994 and 1995 (for cv.'Gala' in 2001 and 2004) indicate that TD and TNS were most related to each other among the examined tree quality characteristcs. The correlations of TD × TNS were significant in 72.7% of all examined cases, whereas those of TD × TH and TH×TNS were significant in 59.1 and 27.2% of the examined data, respectively.

Table 1. Values of correlation coefficients (r) for quality characteristics of apple nursery trees measured at harvest time

Tabela 1. Wartości współczynników korelacji (*r*) dla cech jakościowych jabłoni mierzonych po wykopaniu drzewek

Cultivar/rootstock Odmiana/podkładka	r – values in years for: wartości w latach dla:					
	TD[s] × TH[t]		TD × TNS[u]		TH × TNS	
	1994	1995	1994	1995	1994	1995
Empire/M.7	0.64 (0.0001)	0.60 (0.0090)	0.71 (0.0000)	0.39 ns (0.1114)	0.43 (0.0167)	0.09 ns (0.7302)
Empire/M.26	0.02 ns (0.9505)	0.74 (0.0000)	0.41 ns (0.0885)	0.70 (0.0000)	0.11 ns (0.6682)	0.39 (0.0346)
Gala/M.9	0.10[w] ns (0.7033)	0.11[y] ns (0.5637)	0.54[w] (0.0134)	0.42[y] (0.0200)	0.24[w] ns (0.3065)	0.16[y] ns (0.4050)
Golden Delicious/M.111–M.9[x]	0.49 (0.0064)	0.60 (0.0084)	0.53 (0.0020)	0.19 ns (0.4460)	0.35 ns (0.0569)	0.29 ns (0.2474)
Golden Delicious/M.26	0.03 ns (0.8736)	0.44 ns (0.0655)	0.40 (0.0270)	0.61 (0.0075)	0.20 ns (0.2832)	0.37 ns (0.1262)
McIntosh/M.111–M.9[x]	0.50 (0.0049)	0.00 ns (0.9917)	0.56 (0.0013)	0.45 ns (0.0602)	0.46 (0.0098)	0.15 ns (0.5643)
McIntosh/M.106–M.9[x]	0.63 (0.0020)	0.22 ns (0.3917)	0.59 (0.0006)	0.51 (0.0319)	0.33 ns (0.0760)	0.44 ns (0.0680)
McIntosh/M.7	0.73 (0.0000)	0.58 (0.0121)	0.82 (0.0000)	0.63 (0.0050)	0.68 (0.0000)	0.34 ns (0.1637)
McIntosh/M.26	0.41 (0.0251)	0.40 ns (0.1012)	0.47 (0.0081)	0.67 (0.0025)	0.04 ns (0.8471)	0.49 (0.0376)
Royal Empire/ M.111–M.9[x]	0.18 ns (0.3424)	0.71 (0.0010)	0.70 (0.0000)	0.02 ns (0.9244)	0.14 ns (0.4615)	0.33 ns (0.1950)
Royal Empire/M.26	0.71 (0.0000)	0.16 ns (0.5246)	0.52 (0.0035)	0.24 ns (0.3479)	0.54 (0.0020)	0.33 ns (0.1833)
Grand mean for P–value[z]	0.0066		0.0084		0.0216	

All r coefficients are significant at P<0.05 unless otherwise marked with 'ns' (not significant). Probability values are given in parentheses; [s] parent shoot diameter; [t] parent shoot height; [u] total number of sylleptic shoots; [w] year 2001, [y] year 2004; [z] for P values <0.05; [x] interstem

Wszystkie współczynniki r są istotne przy P<0,05, jeśli nie oznaczono ich jako 'ns' (nieistotne). Wartości prawdopodobieństwa podano w nawiasach; [s] średnica przewodnika drzewka; [t] wysokość przewodnika drzewka, [u] całkowita liczba pędów syleptycznych; [w] 2001, [y] 2004; [z] dla wartości P<0,05; [x] wstawka

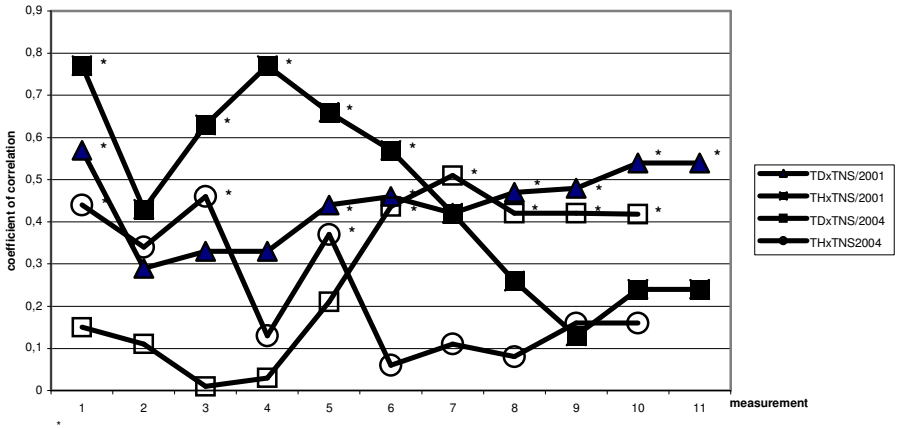
Averaged P-values (grand means) for all significant correlations of TD × TH, TD × TNS and TH × TNS amounted to 0.0066, 0.0084 and 0.0216, respectively (Tab. 1).

Mutual relationships between the examined tree characteristics were closer in 1994 than in 1995. 'Gala' trees in both years (2001 and 2004) exhibited a similar pattern of vegetative growth (Tab. 1). Irrespective of rootstock (interstem), the cultivar that showed the highest number of significant correlations for TD × TH and TD × TNS was 'McIntosh' followed by 'Empire' and 'Golden Delicious'.

In the course of these studies, the cultivars which demonstrated distinct consistency in significance for TD × TNS correlations was 'McIntosh' on either M.106/M.9, M.7 or M.26, 'Golden Delicious' on M.26, and 'Gala' on M.9 rootstocks. However, the only cultivar that showed in both years of investigation a significant correlation in TD × TH and TD × TNS was 'McIntosh' on M.7 rootstock, while 'Gala' on M.9 and 'Golden Delicious' on M.26 did not (Tab. 1).

Periodical correlations between tree quality characteristics during growing season

The results of periodical measurements of TD, TH, TNS, and corresponding shoot extension (SEG) indicated that in spite of great differences in air temperature or rainfall during the period from April to July between the years when the experiments were performed (data not shown), the trees of 'Gala' in both seasons followed a similar pattern of growth**.** This was particularly well demonstrated by the coefficients of correlation for TD × TNS (Fig. 1).



*significant at P<0.05; for measurement details see Tables 2 and 3
* istotna przy p<0,05; szczegóły pomiarów zob. tabele 2 i 3

Fig. 1. r-values for vegetative characteristics of 'Gala' apple trees in 2001 and 2004
Rys. 1. Wartości r dla cech wzrostu wegetatywnego drzewek jabłoni 'Gala' w 2001 i 2004 r.

Table 2. Values of correlation coefficients (r) for quality characteristics of `Gala` nursery trees on M.9 rootstock measured during growing season 2001
Tabela 2. Wartość współczynników korelacji (*r*) dla cech jakościowych drzewek jabłoni 'Gala' na podkładce M.9 mierzonych podczas sezonu wegetacyjnego w 2001 roku

Date of measurement Termin pomiaru	TD[w] × TH[y]		TD × SEG[z]		TH × SEG	
	r	P	r	P	r	P
08.06	0.54*	0.0252	0.79*	0.0020	0.65*	0.0046
18.06	0.41 ns	0.0751	0.62*	0.0035	0.49*	0.0293
28.06	0.52*	0.0180	0.45*	0.0444	0.70*	0.0007
08.07	0.62*	0.0036	0.49*	0.0272	0.79*	0.0000
18.07	0.56*	0.0101	0.56*	0.0105	0.69*	0.0008
28.07	0.43 ns	0.0609	0.59*	0.0057	0.58*	0.0069
07.08	0.16 ns	0.4895	0.65*	0.0020	0.37 ns	0.1038
17.08	0.07 ns	0.7561	0.75*	0.0002	0.17 ns	0.4654
27.08	0.00 ns	0.9905	0.77*	0.0001	0.06 ns	0.7956
06.09	0.05 ns	0.8374	0.81*	0.0000	0.13 ns	0.5969
25.09	0.09 ns	0.7033	0.81*	0.0000	0.13 ns	0.5969

r – coefficients marked with asterisks (*) are significant at P<0.05 whereas those with 'ns' are not; [w] parent shoot diameter; [y] parent shoot height; [z] cumulative length of sylleptic shoots.
r – współczynniki oznaczone gwiazdką (*) są istotne przy P<0,05, natomiast oznaczone jako 'ns' są nieistotne; [w] średnica przewodnika drzewka; [y] wysokość przewodnika drzewka; [z] sumaryczna długość pędów syleptycznych.

Table 3. Values of correlation coefficients (r) for quality characteristics of `Gala` nursery trees on M.9 rootstock measured during growing season 2004
Tabela 3. Wartość współczynników korelacji (*r*) dla cech jakościowych drzewek jabłoni 'Gala' na podkładce M.9 mierzonych podczas sezonu wegetacyjnego w 2004 r.

Date of measurement Termin pomiaru	TD[w] × TH[y]		TD × SEG[z]		TH × SEG	
	r	P	r	P	r	P
14.06	0.11 ns	0.5490	0.11 ns	0.5778	0.28 ns	0.1282
24.06	0.18 ns	0.3199	0.09 ns	0.6403	0.31 ns	0.1002
03.07	0.24 ns	0.1938	0.02 ns	0.9265	0.38*	0.0375
13.07	0.36 ns	0.0534	0.13 ns	0.4811	0.43*	0.0183
23.07	0.19 ns	0.3239	0.26 ns	0.1642	0.47*	0.0090
03.08	0.14 ns	0.4616	0.48*	0.0067	0.20 ns	0.2999
13.08	0.12 ns	0.6316	0.64*	0.0001	0.02 ns	0.9079
23.08	0.11 ns	0.5637	0.61*	0.0003	0.02 ns	0.8966
15.09	0.11 ns	0.5637	0.67*	0.0001	0.11 ns	0.5758

For explanations see Table 2.
Wyjaśnienie jak w tab. 2.

In both seasons, the correlation of TD × TNS and TH × TNS showed significant trends towards changing the values of correlations expressed by coefficient of correlation (r). These changes took place during almost entire period of measurements. Generally speaking, the r-values for TD × TNS exhibited an increasing trend, while those of TH × TNS showed a gradual decrease. First significant r-values for TD × TNS happened just

about the mid season (28 July 2001 and 23 July 2004) and they steadily increased (in 2001) or kept similar significant values to the very end of the season. During the initial period of the measurements, the coefficients of correlation for TH × TNS were significant, but as the time progressed they tended to be gradually decreased. From the end of July the r-values for this correlation became insignificant for the remnant of the season. It is noteworthy, however, that the beginning of a significant increase in r-values for TD × TNS was simultaneously associated with a distinct decrease in these values for TH × TNS.

The correlations of TD × SEG, and TH × SEG showed the similar trend as to a corresponding correlations of TD × TNS and TH × TNS (Tab. 2 and 3, Fig. 1).

DISCUSSION

This research has shown that the growth of sylleptic shoots, which was expressed by their number and cumulative length, was more explicitly related to the increment of parent shoot diameter (tree trunk) than to its height. These relations were demonstrated by final correlation between tree quality characteristics after completion of tree growth [Lipecki and Janisz 1999]. Most recent studies by Jacyna [2004] and Jacyna *et al*. [2005] showed that correlations between parent shoot diameter and a total number of shoots, and parent shoot height and a total number of shoots for maiden trees of four apple, fourteen sweet cherry and six pear cultivars budded on different rootstocks were significant in 71.2 vs. 14.2, 77.5 vs. 20, and 65 vs. 30% of examined cases, respectively. Comparisons of growth behaviour of the tested maiden trees indicated that irrespective of rootstock (interstem), climate, cultural practices and soil type, tree syllepsis is predominantly under genetic control. In our experiments, the observed TD × TNS correlation showed a close relationship between these two characteristics after completion of tree growth but it did not describe any relationship between these parameters, which might have existed at different stages of active tree growth.

Detailed studies in 'Gala' nursery trees demonstrated that correlations of TD × TNS and TH × TNS distinctly differed from each other during the seasons. The r-values for TD × TNS tended to increase, and those for TH × TNS tended to decrease as the season progressed. The results of many studies by Ostrowska and Chełpiński [1997a and b], Chełpiński *et al*. [1998], Lipecki and Janisz [1999], Jacyna [2004], Jacyna *et al*. [2005] indicate that TD may better determine tree ability to branch than TH. It seems particularly true for freely branching apple cultivars [Lipecki and Janisz 1999]. Physiologically, this phenomenon may be associated with synergism and/or interaction between endogenous plant hormones. Jacyna (2001) hypothesized that there are at least three main physiological processes determining mutual relations between TD, TH, TNS or SEG, namely: (1) increasing cambial activity resulting in parent shoot thickening, (2) induction of sylleptic shoots and their elongation, (3) elongation of parent shoot but at slower rate than earlier in the season. In these processes endogenous auxins (1), gibberellins (1, 2, 3) and supposedly ethylene (1) are heavily involved.

CONCLUSIONS

The number of sylleptic shoots in maiden apple trees of moderately branching cultivars is more strongly correlated with tree trunk diameter (or trunk cross-sectional area) than with tree height. In the course of the season, the correlations TD × TNS *(a)* and TH × TNS *(b)* demonstrated significant trends in the values of coefficients of correlations, namely *a* – to increase and *b* – to decrease. These studies suggest that a significant correlation found between tree trunk diameter and the number of sylleptic shoots may be helpful in using tree diameter instead of tree height to estimate the quality of apple maidens as proposed by Lipecki and Janisz [999].

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Streszczenie. Badania prowadzono w latach 1994 i 1995 w USA oraz w 2001 i 2004 w Polsce. W szkółkach badano niektóre cechy wzrostu wegetatywnego okulantów jabłoni na różnych podkładkach i wstawkach. Po zakończeniu każdego sezonu wegetacyjnego mierzono średnicę drzewek (TD) i ich wysokość (TH) oraz liczbę pędów syleptycznych (TNS) i ich sumaryczną długość

(SEG). Związki między wymienionymi cechami wyrażono współczynnikiem korelacji (r). Wartości r dla TD × TNS oraz TH × TNS były istotne (przy P<0,05) odpowiednio w 73 i 27% badanych we wszystkich latach korelacji. Dodatkowe pomiary wymienionych cech wykonywane co 10 dni wykazały, że istotność związków TD × TNS i TD × SEG wynosiła odpowiednio 62 i 75%, podczas gdy dla TH × TNS oraz TH × SEG odpowiednio 38 i 45% badanych korelacji w obu latach. Silniejsze związki między TD i TNS niż między innymi cechami wskazują, że TD może być zastosowany jako wskaźnik jakości okulantów jabłoni i ich zdolności do naturalnego rozgałęziania się.

Słowa kluczowe: rozgałęzienia boczne, wstawka, pędy syleptyczne, jednoroczne okulanty