FOLIA
HORTICULTURAE
Ann. 17/2, 2005, 37-52

Relationship between the yield and quality of green dill and the height of plants

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Key words: *Anethum graveolens*, crop, phytometric traits, chemical composition

ABSTRACT

The structure of dill yield, its phytometric traits and the level of dry matter, volatile oils, chlorophylls, beta-carotene and vitamin C in plants harvested at a height of 20, 30, 40, 50 and 60 cm were compared. Increases in the total and marketable yields and in the yield of different parts of dill plants were commensurate with the increasing size of plants, while the proportion of leaves and its parts in the yield decreased and that of the stem increased. As the size of plants increased, the site of the first leaf setting was virtually unchanged. However, the average diameter of the stem at its base, the number of leaves per plant and the altitude of the first and the last developed leaf increased. The content of dry matter and volatile oils also increased in all the parts with the exception of the stem, where this content did not change or varied only to a small degree. The level of vitamin C systematically decreased in all the parts with the exception of the petiole, where this level was stable. The content of chlorophylls and beta-carotene increased in the leaf and its parts and was fairly stable in the stem; however, it decreased in whole plants. The leaf blade had the greatest content of all the analyzed components, a smaller content being found in the whole leaf and whole plant, and the smallest in the petiole and stem.

INTRODUCTION

Dill (*Anethum graveolens* L.) is widely used in the countries of the temperate and even of the cooler climatic zone. The plants have an attractive appearance, pleasant fragrance and a rich chemical composition. Leaves and even whole young plants are used for decorating dishes, as a widely used condiment and also as a basic component of soups and sauces (Pszczola 2001). They can also be processed by drying and freezing. Mature plants with developed flower umbels are a basic condiment in cucumber souring. Volatile oils obtained from seeds are used in the food industry, pharmaceutics and cosmetics (Bauermann et al. 1994, Kurilich and Juvik 1999).

Dill cultivars grown in Poland are characterized by a desirable chemical composition from the standpoint of the consumer and the requirements of the industry (Kmiecik et al. 2004, Lisiewska et al. 2004, Słupski et al. 2005). The climatic and soil conditions are also favourable as shown by the obtained yields (Koźmicka 1990), hence Poland can be a potential competitor for such countries as Morocco, Turkey, Egypt, or Chile, which traditionally supply dried dill to markets of the European Union (Maftei 1992).

The aim of the work was to compare the level and the structure of dill yields, their phytometric traits and the most important components of the chemical composition of dill plants harvested at different heights.

MATERIAL AND METHODS

The investigated material was dill plants grown for green harvest, conducted when the height of a plant was 20, 30, 40, 50 and 60 cm. The cultivar ‘Amat’ used in the investigation, came from the SPOJNIA HiNO, a breeding company from Nochowo. Earlier studies by the authors (Lisiewska et al. 2001; Kmiecik et al. 2002) established this cultivar as the most valuable of all those grown in Poland from the point of view of technical utility.

Dill was grown in 2003 and 2004 in the experimental field situated on the western outskirts of Krakow, on brown soil developed from loess formations with the mechanical composition of silt loam. This soil of good horticultural quality was characterized by following traits in the successive years of 2003 and 2004: pH in H_2O - 7.08 and 7.09; humus - 1.66 and 1.56%; nitrogen NO_3 - 24 and 25 mg dm^{-3}; phosphorus - 53 and 46 mg dm^{-3}; potassium - 101 and 90 mg dm^{-3}; and calcium - 1020 and 960 mg dm^{-3}. Production was carried out in the third year after stable manure fertilization with broad bean as the forecrop in both years of the experiment. Since in the years of cultivation the fertility of soil did not vary, the fertilization remained the same throughout and all the fertilizers were applied during the spring preparation of the field before sowing. The nutritional requirements of dill and the fertility of soil being taken into account, the following doses of mineral fertilizers were used: N – 30 kg ha^{-1}; P_2O_5 – 20 kg ha^{-1}; and K_2O – 30 kg ha^{-1}.

The experiment was established in a random blocks design in four replications. The size of plots for harvest was 5 m^2. Dill was sown in rows spaced 25 cm apart, the seeds being distributed in belts about 2 cm in width. In the years of the experiment the density of seeding was 27 kg ha^{-1} in 2003 and 25 kg ha^{-1} in 2004, this corresponding to 200 seeds per 1 m as calculated for seeds of 100% germination capability. During the growth of plants cultural practices included mechanical weed control, spraying with insecticides and watering in case of reduced soil humidity, which might have affected the yield and its quality. Also mean temperatures, rainfall water and irrigation water were measured (Fig. 1).

In 2003 the sowing was carried out on April 19 and in 2004 on April 23. The harvest was conducted when about 80% of plants in a stand reached the size determined by the method: at a height of 20 cm after 50 and 47 days from sowing, at 30 cm after 55 and 52 days, at 40 cm after 59 and 56 days, at 50 cm after 64 and 60 days and at 60 cm after 69 and 64 days, respectively in 2003 and 2004. The size of 60 cm corresponded to the phase of growth when the umbels were setting. The harvest consisted in cutting plants 2 cm above the soil surface. During harvest the number of plants per 1 m^2 was ascertained.

After harvest the total yield and the marketable yield of all the healthy and normally developed plants were recorded. The yields of leaf blades, of petioles and of stems were separately determined.

During harvest the basic phytometric traits were established by measuring the height of the plant; the diameter of the basic part of the stem; altitude of the first and the last leaf; number of leaves per plant and the number of umbel sets in 100 randomly sampled plants (25 plants from each plot). Directly after harvest, an analysis of the chemical composition was carried out. The following components were ascertained using methods described in the literature as quoted below: dry matter (AOAC 1984, 32.019); volatile oils (AOAC 1980, 34.021); chlorophylls (Wettstein 1957); beta-carotene (ISO/6558-2 1992); and vitamin C (ISO/6557-2 1984). The results of yields and morphological traits were verified with the use of an analysis of variance and the chemical composition with the use of an analysis of variance for two factors.

RESULTS AND DISCUSSION

In the years of the experiment the pattern of weather conditions distinctly varied during the growth of dill (Fig. 1). In 2003 recorded temperatures and precipitation (including irrigation) were high. In 2004 the temperatures and precipitation were distinctly lower. However, the obtained yields were high and, in spite of the above differences, the conditions of dill growing can be described as favourable because neither drought causing poor germination nor an excess of humidity which might have caused the yellowing or dying of plants were recorded (Koźmicka 1989).

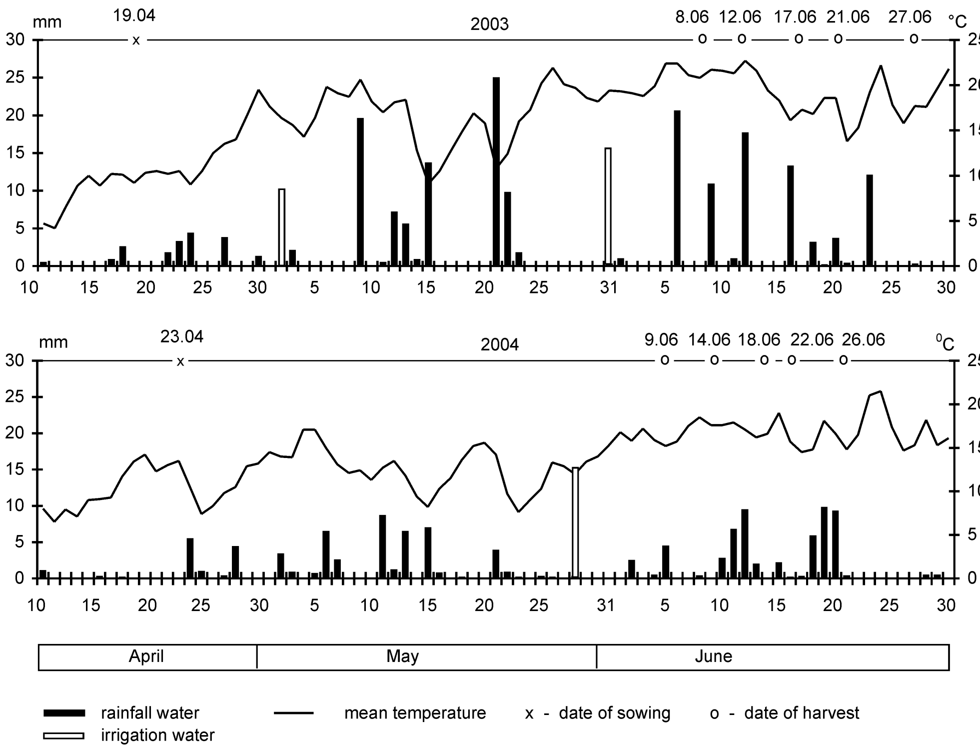

Figure 1. Mean air temperature and total rainfall during the vegetation season

Both the total and the marketable yield of green mass of dill significantly differed at the different plant sizes established by the method of the experiment (Table 1). Such differences were found in the successive years and also in the mean values from the years of the investigation. With the assumption that during the two years the mean yield obtained from plants 20 cm in height was 100%, the total and marketable yields obtained from plants harvested at the successive heights of 30, 40, 50 and 60 cm were 158% and 157%; 245% and 241%; 294% and 287%; and 363% and 355%, respectively. The recorded yields varied from 116.5-423.0 kg per 100 m^2 for the total yield and 115.0-408.0 kg for the marketable yield.

Table 1. The yield of dill (kg per 100 m^2) depending on the plant height

Year of investigation	Plant height (cm)	Total yield	Marketable yield	Yield of different parts of plant in marketable yield		
				leaf blade	petiole	stem
2003	20	108	107	57	26	24
	30	180	176	72	41	63
	40	279	271	80	46	145
	50	339	326	81	43	202
	60	431	415	90	46	279
$LSD_{0.05}$		17.0	10.0	4.4	2.3	10.7
2004	20	125	123	65	30	28
	30	188	184	83	37	64
	40	292	284	93	43	148
	50	345	335	102	44	189
	60	415	401	104	43	254
$LSD_{0.05}$		13.8	13.7	7.0	2.8	19.0
Mean	20	116.5	115.0	61.0	28.0	26.0
	30	184.0	180.0	77.5	39.0	63.5
	40	285.5	277.5	86.5	44.5	146.5
	50	342.0	330.5	91.5	43.5	195.5
	60	423.0	408.0	97.0	44.5	266.5
$LSD_{0.05}$		11.9	11.4	8.4	2.5	9.4

These results confirmed the observation reported by Singh et al. (1993), who found that the yield of green mass of dill increased up to the commencement of inflorescence. Kaufmann and Pölitz (1990) harvested dill at a height of 20 cm and, depending on various factors, obtained a yield of 95-243 kg per 100 m^2. At a plant height of 30 cm Hälvä (1987a) recorded a total yield of 138 kg per 100 m^2. In a different experiment Hälvä (1987b) recorded that the yields from plants in the phase of growth before the setting of umbels ranged from a few to about 300 kg per 100 m^2 depending on the year of the investigation, cultivar and site. In a yet another experiment (Hälvä and Puukka 1987), the yield from plants harvested at a height of 30-35 cm 53-55 days after sowing, was 110-325 kg per 100 m^2 depending on the year of the study and the applied fertilization. According to Arcakowa (1985), at 46-52 days after plant emergence, the yield of green dill varied from 190-270 kg per 100 m^2 depending on the cultivar. Bomme and

Regenhardt (1996) reported similar yields of 232-257 kg per 100 m^2 at a height of 43-52 cm. On the other hand, Boelt (1990) obtained only 110 kg per 100 m^2 from plants cut at a height of 60 cm, corresponding to the phase of growth before the appearance of umbels. This yield was similar to that obtained from plants of only 20 cm in the present experiment.

In Polish climatic conditions the yield of dill obtained just before the bolting of inflorescences, i.e. 42-66 days after sowing, was 38-520 kg per 100 m^2 depending on the location of plant growth and 198-367 kg per 100 m^2 depending on the year of the investigation (Koźmicka 1990). It should be stressed that as in the present work, the total and the marketable yield were nearly identical. According to Buczkowska (1994) the three-year mean yield of green mass of dill was 197 kg per 100 m^2. However, this author did not report the height of plants or the period from sowing to harvest. So many works are purposely quoted here in order to stress the wide range of recorded yields which, among other things, depended: on the time of sowing and harvest, density of sowing, spacing of rows, fertilization, number of plants per area unit**,** phase of plant growth and the height of plants at harvest.

From the point of view of use and processing technology, the most valuable part of dill is the leaf blade. An increase in the yield of leaf blades was parallel to the increasing height of plants. Hence in comparison with 20 cm, at a height of 30 cm the yields were higher by 27, at 40 cm by 42, at 50 cm by 50 and at 60 cm by 59% in two years on average. Udagawa et al. (1995) also reported that the yield of leaves increased along with the height of dill plants, while the height of dill above all depended on the doses of fertilizers.

In comparison with 2003, in the cool year of 2004 the average proportion of leaf blade crop in the marketable yield was higher at all cutting heights with the exception of 20 cm; correspondingly, the weight of petioles and stems constituted a smaller part in the crop of plants from that year. The years of the investigation show that the proportion of leaf blades reached 53% of the marketable yield; petioles 24%; whole leaves 77% and stems 23%. In the case of the highest plants of 60 cm, these values were 24, 11, 35 and 65% (Fig. 2). According to Hälvä and Puukka (1987) the percentage of leaves in the yield varied from 56-68%, depending on the height of cutting. Boelt (1990), before the appearance of inflorescences, recorded the participation of leaves in the yield at a level of 33% and Bomme and Regenhard (1996), at the same phase of growth, from 28-41%, depending on the year of the investigation.

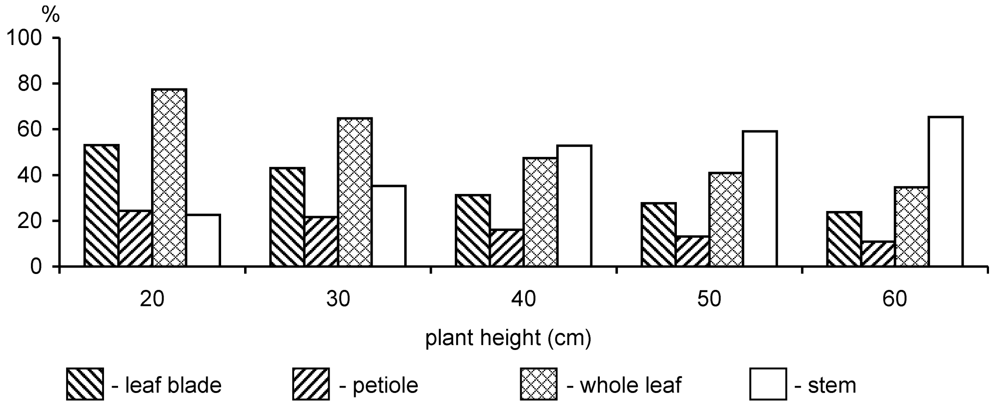

Figure 2. Percentage of the different parts of dill plants in the marketable yield depending on the plant height (mean for 2 years)

In the discussed experiment the total number of plants per 1 m^2 harvested when 20 cm high was 637 in 2003 and 702 in 2004. The number of plants of marketable value was practically the same (Table 2). As the growth of plants proceeded, a decrease in their number was noted, being slightly greater in the hot year of 2003 and in respect of plants of marketable value. For the two years of dill cultivation, compared with the first harvest, the total number of plants reached 94% and that of commercially valued plants 90% at the last harvest.

Table 2. Number of plants in total and marketable yield depending on plant height and year (per m^2)

Yield	Year of investigation	Plant height (cm)				
		20	30	40	50	60
Total	2003	637	631	623	603	570
	2004	702	705	700	684	687
	mean	670	668	662	644	629
Marketable	2003	637	614	609	593	560
	2004	701	701	689	663	648
	mean	669	658	649	628	604

The mean size of plants was established in the methodology of the experiment, individual deviations varying from the mean by 2-3 cm (Table 3). As the height of plant increased, the average diameter of the stem at its base also increased; however, the range of values of this trait widened within the same investigated plot. Hälvä (1987a) reported thinner stems but in his study plants were cut at a height of 7.5 cm, while in the present experiment the plants for measurements were pulled out. Słodkowski et al. (1999) reported that at a height of about 15 cm the number of leaves per plant was 4.3. In the present investigation, in 2003 the number of leaves per plant increased from 4.6 at a height of 20 cm to 7.4 at a height of 60 cm. In 2004 the maximum number of leaves reduced to 6.0; however, this had no bearing on the yield (Table 1) or on the proportion of the leaf mass in the yield (Fig. 2).

Table 3. Phytometric traits of dill depending on the height of plants (*a - mean, *b - range)

Year of investigation	Item		Plant height (cm)					$LSD_{0.05}$
			20	30	40	50	60	
2003	plant height (cm)	a	20.0	30.0	39.9	49.8	60.1	0.38
		b	19-22	29-32	38-42	48-52	58-63	
	thickness of the stem at its base (mm)	a	3.1	3.9	4.5	4.8	4.6	0.36
		b	2-5	3-5	3-6	3-7	3-8	
	number of leaves on plant	a	4.6	5.3	6.5	7.0	7.4	0.24
		b	3-5	4-6	5-8	5-8	6-9	
	height of the setting of the first leaf (cm)	a	0.6	0.6	0.6	0.5	0.6	ns
		b	0.3-1.1	0.4-0.9	0.3-0.9	0.4-1.2	0.3-1.0	
	height of the setting of the first fully developed leaf (cm)	a	2.3	2.2	2.5	4.2	4.0	0.66
		b	1.2-7.5	1.1-6.0	1.2-8.1	1.2-14.5	1.0-12.5	
	height of the setting of the last leaf (cm)	a	8.4	15.4	26.2	38.0	52.0	1.74
		b	5.1-12.1	9.5-23.4	18.0-33.0	30.0-46.0	41.0-57.0	
	percentage of plants with inflorescences	a	0	0	0	0	24	-
2004	plant height (cm)	a	20.9	30.0	39.9	49.9	59.9	0.59
		b	18-22	27-33	37-43	47-53	56-63	
	thickness of the stem at its base (mm)	a	3.4	4.1	4.3	4.8	5.0	0.34
		b	2-5	3-5	3-5	3-6	4-6	
	number of leaves on plant	a	4.5	5.0	5.3	6.0	6.0	0.26
		b	3-5	4-6	4-6	5-7	5-7	
	height of the setting of the first leaf (cm)	a	0.7	0.6	0.7	0.8	0.8	0.10
		b	0.4-1.5	0.4-1.1	0.4-1.5	0.5-1.3	0.6-1.3	
	height of the setting of the first fully developed leaf (cm)	a	2.4	2.6	2.8	4.5	5.6	0.64
		b	1.0-2.9	1.3-5.9	1.9-8.0	2.2-13.4	2.1-15.8	
	height of the setting of the last leaf (cm)	a	8.1	14.5	28.7	40.1	51.5	1.16
		b	4.8-12.0	9.2-21.5	25.0-34.0	34.0-45.0	45.0-57.0	
	percentage of plants with inflorescences	a	0	0	0	0	19	-

The first leaf was set at a level of 0.5-0.8 cm, while the setting of the first fully developed leaf – an important trait for dill mowing – occurred at a level of 2.2-5.6 cm, this being slightly higher than the height of cutting, which in the discussed experiment was about 2 cm above the soil on average. It was ascertained that the higher plants, the greater were the differences in the position of the first fully developed leaf setting in the plants included in the experiment. An increasing tendency was also recorded in the average height of the setting of this leaf. The average height of the setting of the last leaf, tantamount to the mean length of the stem, was alike in both years of the investigation and the differences in any given plant varied from 4.8-12.1 cm at a height of 20 cm to 41.0-57.0 cm at that of 60 cm. The value of dill as a condiment, except when used for souring, depends on the absence of inflorescences (Boelt 1990). Therefore the experiment was ended when umbels began to appear on the plants. At a height of 60 cm they appeared on 19-24% of plants, depending on the year of the investigation (Table 3).

The greatest content of the analysed components was found in the leaf blade, less in whole leaf and whole plant, the smallest content being noted in the petiole and the stem (Fig. 3). Bano et al. (2003) stressed a differentiation in the concentration of chemical components in different parts of the plant. Vallejo et al. (2003) and Yamada et al. (2003) demonstrated that these dependences varied in different species. The content of dry matter in the leaf blade of spinach and sweet potato also exceeded that in the petiole (Ishida et al. 2000, Beis et al. 2002). According to Lee et al. (1993), Randhawa and Gill (1995) and Seidler-Łożykowska and Kaźmierczak (1998) leaves of briquet, French basil and lovage contained more volatile oils compared with the remaining parts of the plant. In an earlier study by present authors (Kmiecik et al. 2001) the leaf of dill contained more chlorophyll compared with whole plant. As for the content of vitamin C, Oguchi et al. (1996) observed a similar difference between the leaves and the petioles of spinach and Ishida et al. (2000) in the level of carotenoids between the leaves and the petioles and stems of two cultivars of sweet potatoes.

In the individual parts of dill plants the content of dry matter showed a tendency to increase as the growth of plants proceeded, however usually the differences between the neighbouring values were not significant (Fig. 3). In the case of whole plants, no such tendency was observed. Huopalahti and Linko (1983) obtained slightly different results since in their study the content of dry matter in whole dill plants increased between the height of 10 and of 60 cm.

The level of volatile oils increased in all the parts of dill plants except for the stem, where it did not change. In the leaf and its parts the level increased about three times in the interval of 20 and 60 cm. Similarly Udagawa (1995) demonstrated an increase in the content of volatile oils in sweet basil along with the delayed harvest. Huopalahti and Linko (1983) and Senatore (1996) noted a varying level of these compounds in relation to the height of dill and thyme plants.

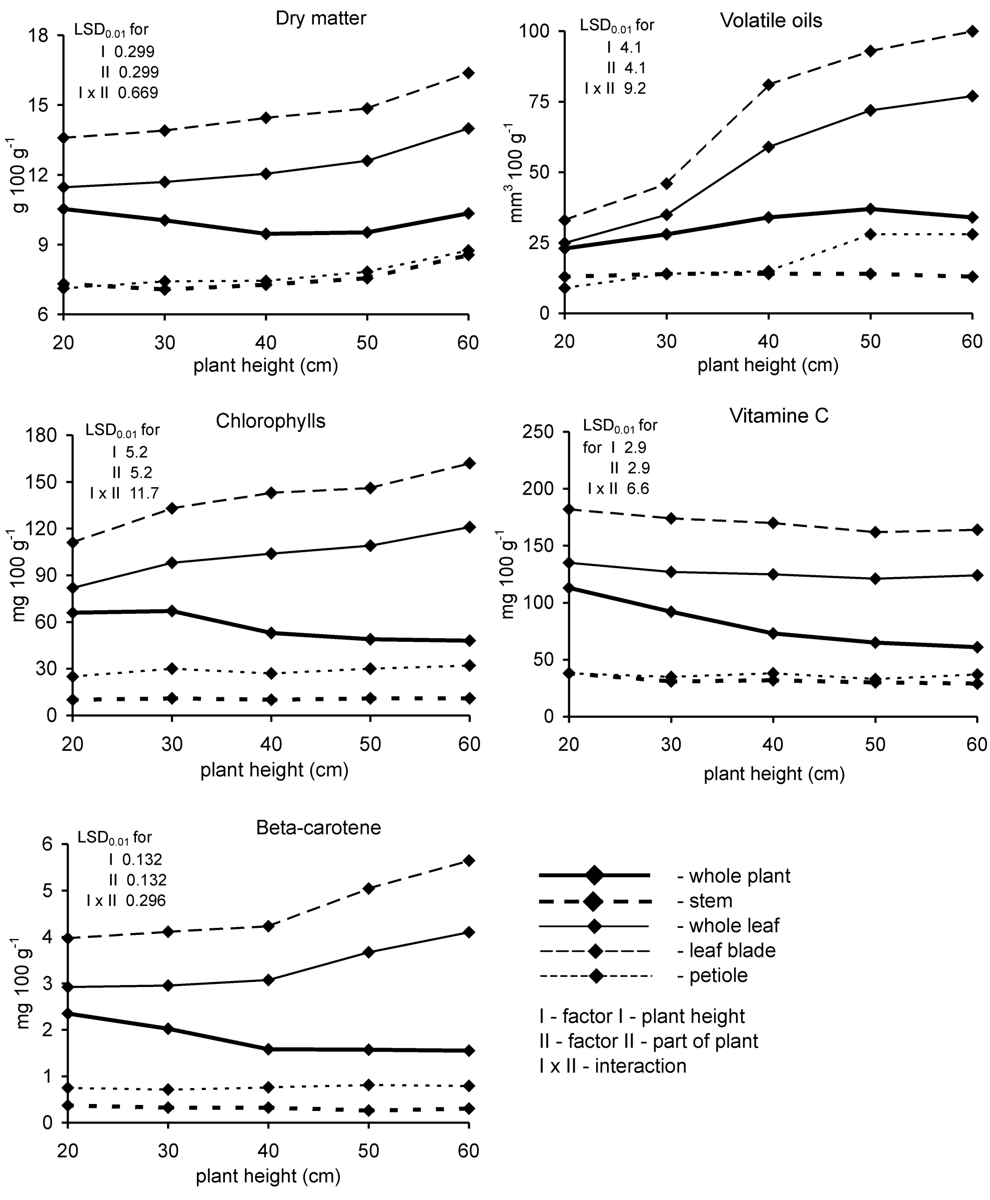

Figure 3. Content of dry matter, volatile oils, chlorophylls, vitamin C and beta-carotene depending on plant height and part of dill (mean for 2 years)

The content of chlorophylls increased in the leaf and its parts, was stable in the stem, but decreased in the whole plant along with its height, since the proportion of the stem to the whole plant increased faster than the other parts (Fig. 2). As in the investigated dill, Saric et al. (1990) showed a greater content of chlorophyll in older than in younger cabbage leaves.

Just as the content of chlorophylls in the leaf and its parts changed, so too did that of beta-carotene, except that a slight but significant decrease in the level of this component appeared between the extreme heights of the plant in stem. In the petiole the content of beta-carotene was fairly stable. As in the investigation of butterhead and ice lettuce conducted by Drews et al. (1995, 1997) the content of beta-carotene in the whole plant decreased as the growth of plants proceeded.

The level of vitamin C steadily diminished in all the parts of the plant with the exception of the petiole. A comparison of the lowest and highest plants showed that the greatest decrease of 46% was noted in the whole plant; a smaller one of 24% in the stem; that of 10% in the leaf blade and of 8% in the whole leaf. The concentration of vitamin C increased as the maturation of broccoli and spinach leaves proceeded (Omary et al. 2003; Yamada et al. 2003); however, it decreased in the leaves of ice and butterhead lettuce (Drews et al. 1995, 1997). Hälvä et al. (1993) and Oyama et al. **(**1999) stress that, apart from the developmental stage of the plant, temperature and light intensity also affect the level of chemical components in the plant.

The presented results (Table 1, Fig. 3) allowed the calculation of the yield of chemical components from an area unit. The yield of dry matter obtained from whole plants harvested on 100 m^2 steadily increased from 12.1 kg in the case of the lowest plants to 42.2 kg in the case of the highest ones. The yield of dry matter obtained from whole leaves also increased, but only by 94%. Ugadawa (1995) reported a much lower yield of dry matter, only 4.8 kg from 100 m^2 in the developmental stage of dill before the appearance of umbels. The yield of the remaining components also increased along with the height of the plants. Over the range of size between 20 and 60 cm, the yield of volatile oils from whole plants increased more than 5 times, of chlorophylls 2.5 times, of vitamin C about 2 times, and of beta-carotene more than 2 times. The yield of the above-mentioned components obtained only from the leaves constituted 79-84% of the yield of volatile oils in whole plants; 87-96% of the yield of chlorophylls; 92-96% of beta-carotene and 70-92% of vitamin C. In all these cases the higher the plants, the lower were the above-mentioned percentages. According to Udagawa (1995) the yield of volatile oils from dill leaves varied from 24 to 65 g per 100 m^2 depending on the height of the plant. It can be quoted for comparison that in the present investigation the yields of volatile oils varied over the range of 26.5 and 138.7 cm^3 from whole plants and 22.3 and 109.0 cm^3 per 100 m^2 from leaves.

CONCLUSIONS

1. The total, marketable and leaf blade yield steadily increased along with the height of plants between 20 and 60 cm from 116.5-423.0, 115.0-408.0 and 61.0-97.0 kg per 100 m^2, respectively.
2. The higer the plants, the greather were differences in the position of the first developed leaf setting. The mean thickness of the stem at its base, the number of leaves on the plant and the height of the setting of the first and the last developed leaf increased.
3. At a height of 20 cm the leaf blade constituted 53% of the marketable yield; the petiole 24 and the stem only 23%. Along with a steady decrease in the proportion of the leaf parts and an increase in the proportion of the stem in the marketable yield these values were 24, 11, and 65% in plants 60 cm in height, respectively.
4. The greatest content of dry matter, volatile oils, chlorophylls, beta-carotene and vitamin C was found in the leaf blade, a smaller content being noted in the whole leaf and whole plant, while in the petiole and the stem the smallest content was recorded.
5. As the growth of plants proceeded, in the whole leaf and its parts, the content of dry matter, volatile oils, chlorophylls and beta-carotene increased, whereas in the stem it did not change or varied only to a small degree. In the whole plant the content of chlorophylls and beta-carotene decreased and that of dry matter and volatile oils varied. The level of vitamin C steadily decreased in all the parts, except for the petiole, where it was stable.

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WYSOKOŚĆ I JAKOŚĆ PLONU KOPRU NA ZIELONO W ZALEŻNOŚCI OD WYSOKOŚCI ROŚLIN

Streszczenie: Porównano wysokość i strukturę plonu kopru, jego cechy fitometryczne oraz poziom suchej masy, olejków eterycznych, chlorofili, beta-karotenu i witaminy C w roślinach pozyskiwanych przy wysokościach 20, 30, 40, 50 i 60 cm. Wraz z wysokością roślin systematycznie rósł plon ogólny, plon handlowy i plon poszczególnych części roślin kopru, przy czym procentowy udział liścia i jego części obniżał się, a udział łodygi wzrastał. Im wyższe były rośliny, tym większe było zróżnicowanie osadzenia pierwszego wykształconego liścia w obrębie obiektu badawczego. Średnia grubość łodygi u nasady, liczba liści na roślinie, wysokość osadzenia pierwszego i ostatniego wykształconego liścia rosła wraz ze wzrostem wysokości roślin. Zwiększyła się również zawartość suchej masy i olejków eterycznych we wszystkich częściach, za wyjątkiem łodygi, gdzie zawartość tych związków nie zmieniała się lub ulegała niewielkim wahaniom. Poziom witaminy C systematycznie obniżał się we wszystkich częściach, za wyjątkiem ogonka liściowego, gdzie był stabilny. Zawartość chlorofili i beta-karotenu zwiększała się w liściu i jego częściach, była stosunkowo stabilna w łodydze, natomiast w całej roślinie zmniejszała się. Blaszka liściowa miała największą zawartość analizowanych składników, mniej cały liść i cała roślina a najmniej ogonek liściowy i łodyga.

Received March 30, 2005; accepted September 5, 2005