ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

The Impact of Seeding Dates and Depth on the Productivity of Common Fennel *(Foeniculum vulgare Mill.)* under the Conditions of the Southern Steppe of Ukraine.

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ABSTRACT

In recent years, the popularity of common fennel (*Foeniculum vulgare Mill.),* a valuable medicinal, spice, aromatic, melliferous, vegetable and ornamental plant, has grown in the world. Fennel belongs to promising highly profitable crops of a wide range of use. It finds application in medicine, cookery, various industries, in veterinary medicine, animal husbandry. In Ukraine, fennel is traditionally grown in the western regions where the climate is moderate; its cultivation under arid conditions of the southern Steppe of Ukraine will significantly improve the performance of agricultural enterprises of different types of ownership, especially farms. Our field experiments were carried out in 2015-2017 in the Kherson region on dark chestnut soils typical of the zone. The target of research was the common fennel variety Oksamyt Krymu. The objectives of the present study included determining the effect of seeding dates and depth on the duration of interphase and vegetative periods, biometric characteristics of plants, yielding capacity and seed quality features under arid conditions of the southern Steppe of Ukraine. In the south of Ukraine, fennel seeds are formed during one vegetation period, therefore fennel was grown as an annual crop. In the experiment, the biometric characteristics of plants reached their maximum values in the variant of early spring sowing in the third ten-day period of March, with a seeding depth of 2-3 cm: plant height was 97.8 cm; leaf surface area made up 27.6 thousand m^2/ha; central umbel diameter was 9.4 cm; first order umbels diameter was 7.0 cm. The highest crop productivity and seed quality indices were also recorded under early spring sowing at a depth of 2-3 cm: crop yield was 1.31 t/ha, 1000-seed weight – 5.21 g, essential oil content in seeds – 5.87% in dry matter, relative yield of essential oil – 67.7 kg/ha. Later sowing (in the first or second ten-day periods of April) and any changes in the seeding depth against 2-3 cm led to a decrease in the above-mentioned parameters. Thus, on dark chestnut soils of the southern Steppe of Ukraine, the most favourable conditions for the growth and development of fennel plants, seed formation and the accumulation of essential oils were provided by the interaction of the following parameters of the technological practices investigated: early spring sowing in the third ten-day period of March at the right soil tilth stage and a seeding depth of 2-3 cm.

Keywords: common fennel, seeding dates, seeding depth, biometric characteristics of plants, seed yield, essential oil content in seeds.

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ISSN: 0975-8585

INTRODUCTION

Common fennel (*Foeniculum vulgare Mill.*) is a crop of inexhaustible potential of beneficial properties and extensive use; it is a medicinal, spice, aromatic, melliferous, vegetable and ornamental plant. Fennel finds application in official and folk medicine, cooking, food, pharmaceutical, perfume and cosmetics and other industries, as well as in veterinary medicine, animal husbandry. All organs and derivatives of the plant have valuable properties: leaves, stems, roots, seeds, essential and fatty oils, anethole, fenchone [1, 2].

The popularity of fennel in the world is increasing; it is widespread in almost all the countries, but not grown on a wide scale. The main fennel-producing countries are India, Russia, Mexico, Iran, China, Pakistan, Argentina, Indonesia, and others [3]. In India, seed spice fennel (*Foeniculum vulgare Mill.*) is grown covering an area of about 100 thousand ha with the production of 143 thousand tonnes in 2012-2013 [4].

The priority areas of scientific research on fennel in the world are the study of the chemical composition and possibilities of practical application of plants and their derivatives. Numerous chemical components and various therapeutic properties of fennel plants are described by many researchers [5].

In recent years, in many countries of the world (India, Pakistan, Iran, Egypt, etc.), considerable attention has been paid to improving the elements of the growing technology of this crop as well as to studies of varietal composition, fertilizers, irrigation, sowing dates and methods, plant density, resistance to diseases, weed control, etc. [6-14].

In Ukraine, fennel is traditionally grown in temperate climates in the western regions. Since 2011, scientific research and the introduction of common fennel into cultivation under arid conditions in the southern Steppe of Ukraine have been conducted. Fennel belongs to promising, highly profitable crops, therefore its cultivation, even on small areas, will significantly improve the performance of agricultural enterprises in the region, especially farms tending to produce environmentally friendly products, and allow using it as a backup crop against potential economic risks.

Major factors determining the economic efficiency of fennel cultivation in the southern steppe region of Ukraine are high purchase prices; stable demand for raw material connected with insignificant volumes of its production due to the local scale of sown areas; possibility of multi-purpose use of raw materials and their export to other countries; growth in the popularity and value of products made from components of natural origin [15].

The cultivation of common fennel in the southern steppe region of Ukraine requires scientific substantiation and improvement of separate elements of growing technology, taking into account specific soil-climatic conditions of the zone and their effect on the growth, development, productive processes of plants. Under moisture deficiency, particularly relevant is the study of cultivation technology elements that indirectly influence moisture supply of plants in the sprouting phase, at the initial stages of growth and development, affect the dates and hydrothermal conditions of the interphase periods.

MATERIALS AND METHODS

The experiments (2015-2017) were carried out in the southern steppe zone of Ukraine on the fields of Nadiia farm of Velyka Oleksandrivka district in Kherson region, meeting generally accepted requirements and recommendations [16].

The soil of the experimental plot is dark chestnut weakly alkaline medium loamy, typical for the zone. The arable layer of the soil contains humus (2.28%), nitrates (26), movable phosphorus (34), exchangeable potassium (250 mg/kg of soil), pH of water extract (7.0-7.2).

The climate of the zone is continental, hot and dry, characterized by low and unevenly distributed precipitation, low air humidity, frequent droughts and strong dry winds, a lot of heat and light. The sum of active temperatures above 10°C is 3200-3400°C, average annual precipitation is 340-400 mm, and the hydrothermal coefficient is 0.5-0.7.

Weather conditions during the years of research differed somewhat in the temperature regime, amount and distribution of atmospheric precipitation, but overall were typical for the zone of the southern Steppe of Ukraine.

There were used generally accepted agricultural practices of fennel cultivation, except for the factors and variants studied. Winter wheat was the preceding crop in the experiment. We applied 60 kg of the active ingredient of ammonium sulphate per ha. The target of research was the common fennel variety Oksamyt Krymu. Seeding rate was 5 kg/ha, inter-row spacing – 45 cm, plant density – 600 thousand/ha. Fennel seeds were harvested when the fruits reached maturity on the central umbel and first-order umbels.

The experimental design included the following factors and their variants: Factor A – seeding date: early (the third ten-day period of March at the right soil tilth stage); mid-time (the first ten-day period of April); late (the second ten-day period of April); Factor B – seeding depth, cm: 1-2; 2-3; 3-4; 4-5. The trial was based on a split plot method with a four-fold replication. The sown area of the second-order elementary plot was 70 m^2; the record plot was 55 m^2.

The research tasks included determining the impact of seeding dates and depth on the duration of interphase and vegetative periods, biometric characteristics of plants, yielding capacity and quality traits of fennel seeds under dry conditions of the southern Steppe of Ukraine.

Phenological observations, biometric measurements, harvesting and yield record, determining the 1000-seed weight and essential oil content in seeds were done according to the relevant methods [16-18].

RESULTS AND DISCUSSION

Common fennel is a perennial polycarpic plant with a perennial root and annual (monocyclic) shoots, the cycle of development of which ends during one vegetation period. Shoots die each year, successively replacing one another. Depending on the soil-climatic conditions of the zone, heat resources availability, winter period specifics, fennel is grown as an annual or biennial crop. In dry conditions of the southern Steppe of Ukraine, fennel seeds are formed during one vegetation period, therefore the crop is grown as an annual plant. The cultivation of fennel as a biennial crop in this zone is connected with the risk of plant death and thin stand under the influence of a complex of adverse factors of the winter period [19].

The range of variation in the length of the sowing-sprouting period was 21-31 days depending on the seeding dates and depth. On average by factor A, the phase of fennel sprouting under early spring planting was observed after 29 days, under mid-time and late seeding, sprouts appeared after 27 and 24 days, respectively. The mean factor value of the length of the sowing-sprouting period in the variant of 2-3 cm deep seeding was 24 days. An increase in the depth of sowing to 3-4 cm led to the elongation of the above mentioned period by 2 days, in case of 4-5 cm – by 4 days. On plots with 1-2 cm-deep seeding, fennel sprouts were observed 4 days later than at a depth of the seed layer of 2-3 cm.

The duration of the interphase and vegetation periods is a genetically determined trait of a crop and variety, which can vary within certain limits under the influence of soil-climatic conditions of the zone, specifics of weather conditions of individual years, factors under investigation. The analysis of the duration of the main interphase and vegetation periods of common fennel revealed different regularities and degree of effect of agrotechnical practices under study on their length.

The range of variation in the length of the sprouting-stem formation period in the variants of the experiment was 55-63 days, and 18-23 days for the stem formation-flowering stage. Among the main interphase periods, the period of flowering-maturity turned out to be the most stable and autonomous in respect to the studied factors: its duration on the plots of early and middle dates of seeding was 55 days; under late spring sowing it was 54 days. The length of the vegetation period of fennel was 127-141 days.

Seeding dates had the greatest influence on the values of the studied parameters (Fig. 1). On average, planting in the first and second ten-day periods of April resulted in shorter main interphase stages and, as a consequence, in a shorter growing season compared to early spring sowing by 5

and 8 days, respectively. The accelerated development of plants may be related to a more intense increase in the sum of active and effective temperatures in the variants of mid-time and especially late sowing.

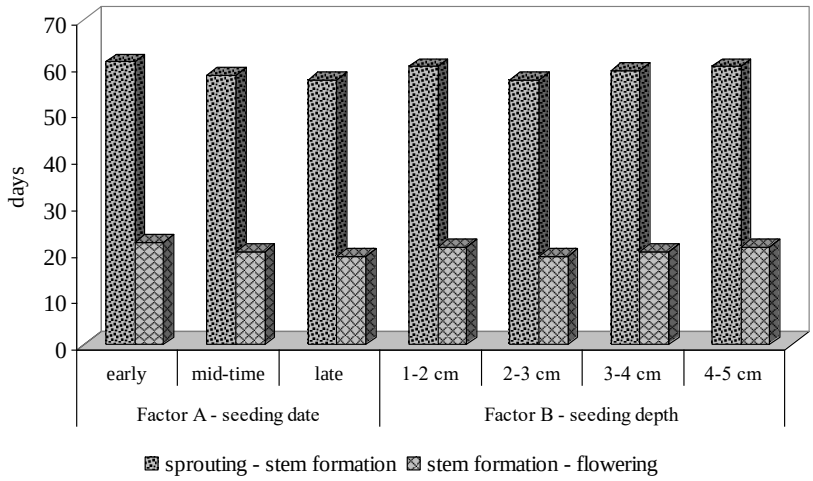

Figure 1: Average factor duration of interphase periods of common fennel depending on the factors under study, days

An increase in the seeding depth from 2-3 to 3-4 cm led to a longer vegetative period of fennel by an average of 3 days. Seeding at a depth of 1-2 and 4-5 cm prolonged the vegetation period of the crop by 5 days.

Examining the change in the basic biometric characteristics of fennel depending on agrotechnical measures is important for the analysis of the influence of the factors studied on the productive processes in the crop.

The height of fennel plants was minimal in the variants of the interaction of late spring planting and seeding depth of 1-2 and 4-5 cm and was 70.4 and 71.6 cm, respectively. The most favourable conditions for the linear growth of plants at 97.8 cm were provided by a combination of the following parameters of the investigated technological practices: sowing in the third ten-day period of March, seeding at a depth of 2-3 cm (Table 1).

Table 1: Height of fennel plants depending on the factors under study, cm (average for 2015-2017)

Seeding date, factor A	Seeding depth, cm, factor B				Average for factor A
	1-2	2-3	3-4	4-5	
Early	92.7	97.8	93.4	90.1	93.5
Mid-time	81.2	85.3	82.7	79.8	82.3
Late	70.4	76.7	74.2	71.6	73.2
Average for factor B	81.4	86.6	83.4	80.5	83.0
LSD_{05}, cm (assessment of significance of partial differences): A=2.73; B=1.89					
LSD_{05}, cm (assessment of significance of mean (main) effects): A=0.68; B=0.52					

The research results indicate a clear tendency to a lower height of common fennel plants from early to late sowing. The average factor value of the investigated feature under early plant sowing was 93.5 cm. The seeding postponing by one ten-day period led to a decrease in plant height by 12.0%, postponing by two ten-day periods resulted in a 21.7% decrease.

The biggest mean factor value of fennel plants height of 86.6 cm was recorded at a seeding depth of 2-3 cm. With a decrease in the depth of seeding to 1-2 cm, we observed a 6.0% height decrease. Fennel was sown at a depth of 3-4 and 4-5 cm, its height decreased by 3.7 and 7.0%, respectively.

ISSN: 0975-8585

The leaf surface area of fennel plants varied in the context of variants from 21.3 to 27.6 thousand m^2/ha (Table 2). The highest value of this character was obtained on plots after early spring seeding at a depth of 2-3 cm. The minimum value was recorded after sowing in the second ten-day period of April at a depth of 1-2 and 4-5 cm – 21.3 and 21.8 thousand m^2/ha, respectively.

Table 2: Leaf surface area of common fennel depending on the factors under study, thousand m^2/ha (average for 2015-2017)

Seeding date, factor A	Seeding depth, cm, factor B				Average for factor A
	1-2	2-3	3-4	4-5	
Early	26.2	27.6	26.5	25.1	26.4
Mid-time	24.0	25.4	24.3	23.2	24.2
Late	21.3	23.9	23.2	21.8	22.6
Average for factor B	23.8	25.6	24.7	23.4	24.4
LSD_{05}, thousand m^2/ha (assessment of significance of partial differences): A=1.04; B=0.89					
LSD_{05}, thousand m^2/ha (assessment of significance of mean (main) effects): A=0.23; B=0.26					

The leaf surface area of fennel reduced when seeding was postponed by one or two ten-day periods compared to the early dates. On average, by factor A, when planting was done in the third ten-day period of March, the parameter under study was 26.4 thousand m^2/ha. On the plots of mid sowing time, there was an 8.3% reduction in the leaf surface area compared to early seeding; this reduction was 14.4% in the late-sown variants.

On average, by factor B, the leaf surface area of common fennel reached the highest value – 25.6 thousand m^2/ha under sowing at a depth of 2-3 cm. On the plots with 1-2 cm-deep seeding, there was a 7.0% decrease of the investigated indicator. Deepening the sown layer to 3-4 and 4-5 cm led to a decrease in the leaf surface area of plants by 3.5 and 8.6%, respectively.

The diameter of the central umbel of fennel reached its highest value of 9.4 cm on the plots of early spring 2-3-cm-deep sowing in the third ten-day period of March. The diameter of the first-order umbels was also maximal in this version and made up 7.0 cm. Transferring the sowing date to the first-second ten-day period of April and changing the depth of the sown layer compared with 2-3 cm led to a decrease in the studied parameters (Fig. 2).

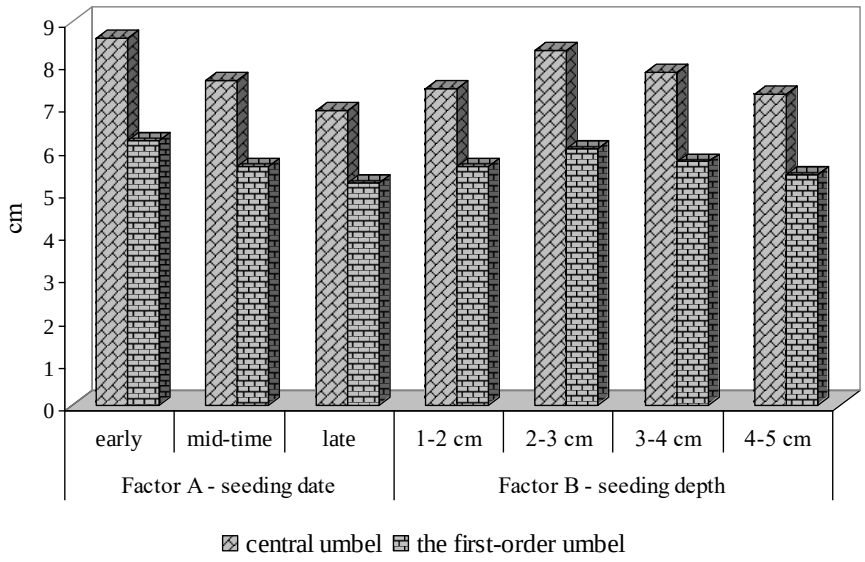

Figure 2: The diameter of productive umbels of common fennel, average for the factors under study, cm

Creating the environment for implementing the potential of fennel productivity and obtaining stable crops of seeds with high content of essential oils is connected with the improvement of the elements of growing technology of this crop.

The yielding capacity of fennel seeds varied depending on the interaction of the investigated elements of the growing technology in the range from 0.86 to 1.31 t/ha. Seed productivity of fennel was minimal on the experimental plots of late spring planting at a depth of 1-2 and 4-5 cm and made up 0.86 and 0.88 t/ha, respectively. The highest level of crop productivity (1.31 t/ha) was recorded in the variant of the interaction of sowing in the third ten-day period of March and seeding depth of 2-3 cm (Table 3).

Table 3: Seed yield of common fennel depending on the factors under study, t/ha (average for 2015-2017)

Seeding date, factor A	Seeding depth, cm, factor B				Average for factor A
	1-2	2-3	3-4	4-5	
Early	1.22	1.31	1.24	1.16	1.23
Mid-time	1.03	1.12	1.08	1.01	1.06
Late	0.86	0.98	0.94	0.88	0.92
Average for factor B	1.04	1.14	1.09	1.02	1.07
LSD_{05}, t/ha (assessment of significance of partial differences): A=0.041; B=0.019					
LSD_{05}, t/ha (assessment of significance of mean (main) effects): A=0.010; B=0.006					

The results of the studies indicate a clear preference for early fennel sowing compared to other sowing periods under study (in the first and second ten-day periods of April). The mean factor value of seed yield on early-sown plots was 1.23 t/ha. In mid-sown and late variants, this parameter was lower by 13.8 and 25.2%, respectively.

Postponing sowing to the first or second ten-day period of April causes deterioration in the conditions of moisture supply of plants in the sprouting phase and in the initial stages of development. When germinating, fennel seeds absorb a significant amount of water (150% of dry matter during 3 days of germination in laboratory conditions); therefore, postponed sowing, which is accompanied by loss of moisture from the surface layer of the soil, can adversely affect the formation of young growth and further development of the crop. In addition, with delay in sowing, there is deterioration in the conditions for the progress in productive processes of plants under the influence of a more intensive increase in the sum of active and effective temperatures, the negative impact of summer drought on flowering and fruit-set, and that of autumn rains on maturing [20, 21].

The most favourable conditions for productive processes of plants were observed under sowing at a depth of 2-3 cm. In this variant, the yield of fennel reached the highest mean factor value of 1.14 t/ha. Reducing the depth of the sown layer to 1-2 cm caused an 8.8% loss of yield. With an increase in the seeding depth to 3-4 and 4-5 cm, yield loss was 4.4 and 10.5%, respectively.

The problem of high-quality planting material is especially timely in the cultivation of common fennel. It is connected with the morphological and biological characteristics of its seeds: a dense hull, small size, low germinating capacity and energy compared to other crops [21].

The weight of 1000 fennel seeds was minimal in variants of late sowing at a depth of 1-2 and 4-5 cm and came to 3.93 and 3.98 g, respectively. The investigated index reached the highest value of 5.21 g under early spring sowing at a depth of 2-3 cm (Table 4).

ISSN: 0975-8585

Table 4: Weight of 1000 seeds of common fennel depending on the factors under study, g (average for 2015-2017)

Seeding date, factor A	Seeding depth, cm, factor B				Average for factor A
	1-2	2-3	3-4	4-5	
Early	4.87	5.21	4.89	4.65	4.91
Mid-time	4.38	4.73	4.61	4.34	4.52
Late	3.93	4.36	4.23	3.98	4.13
Average for factor B	4.39	4.77	4.58	4.32	4.52
LSD_{05}, g (assessment of significance of partial differences): A=0.194; B=0.126					
LSD_{05}, g (assessment of significance of mean (main) effects): A=0.049; B=0.037					

Larger seeds are characterized by better sowing qualities (higher laboratory germinating capacity and energy), which may be due to better embryo development and accumulation of more nutrients in the endosperm [21].

The experiment showed a tendency to smaller weight of 1000 fennel seeds with postponing sowing from the third ten-day period of March to the first and second ten-day periods of April. The mean factor value of this character on the early sown plots was 4.91 g. The sowing one or two ten-day periods later led to a decrease in the weight of 1000 seeds of the crop by 7.9-15.9%, respectively.

The highest factor average of the investigated index – 4.77 g was observed under sowing at a depth of 2-3 cm. Changes in the depth of the seeded layer both towards its increase and decrease negatively affected the mass of 1000 seeds of fennel. The range of reduction of this parameter for all gradations of factor B compared with the variant of seeding at a depth of 2-3 cm was 4.0-9.4%.

The content of essential oil in seeds and its relative yield from 1 hectare of the crop area are important qualitative indicators in the cultivation of common fennel.

The most favourable conditions for the accumulation of essential oil in seeds at a level of 5.87% in dry matter were observed under early spring planting at the depth of 2-3 cm. The lowest investigated index was in variants of the interaction of late sowing and 1-2 and 4-5 cm-deep seeding – 5.20 and 5.26%, respectively.

The mean factor value of the mass fraction of essential oil in fennel seeds sown in the third ten-day period of March amounted to 5.73%. When sown by one or two ten-day periods later, the investigated index reduced by a factor of 1.03-1.07 (Fig. 3).

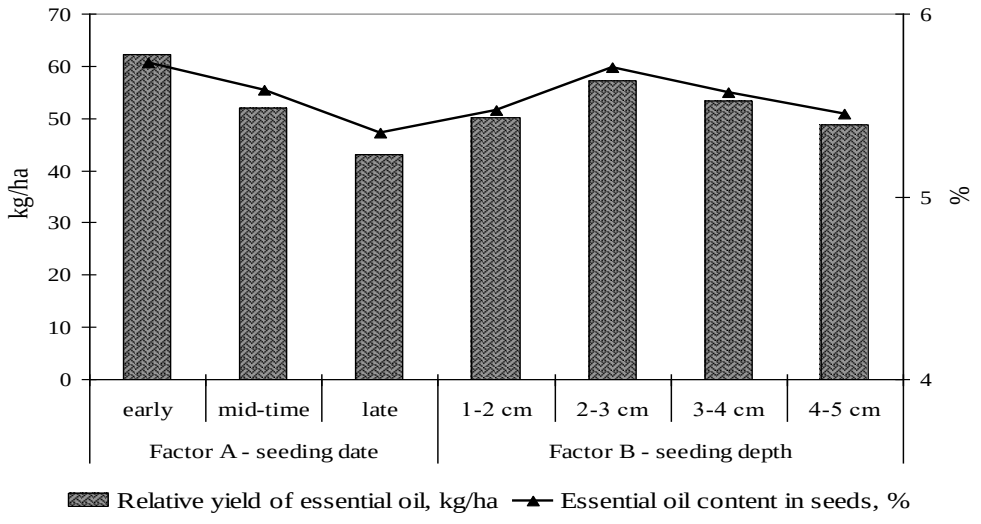

Figure 3: Content in seeds and relative yield of essential oil of common fennel, average for the factors under study

The average factor content of essential oil in fennel seeds in the variant of 2-3 cm-deep sowing was 5.71%. Changing the seeding depth led to a 1.03-1.05-fold decrease in its value.

The relative yield of essential oil from 1 hectare of the crop area, as an integral index, reflected the basic patterns of the influence of the factors under study on the seeds yielding capacity and content of essential oil in fennel seeds (Fig. 3).

The range of variation in this index, depending on the interaction of sowing dates and depth, was 39.4-67.7 kg/ha. The relative yield of essential oil was minimal under late sowing at a depth of 1-2 and 4-5 cm – 39.4 and 40.7 kg/ha, respectively. The maximum value (67.7 kg/ha) was recorded under sowing in the third ten-day period of March, the depth of seeding being 2-3 cm.

Among the sowing dates studied, the highest relative yield of essential oil (62.2 kg/ha) was provided by early spring fennel sowing. On the plots of mid-time and late seeding, there was observed a reduction in its value by 16.4 and 30.5%, respectively.

When fennel was sown at a depth 2-3 cm, average relative yield of essential oil amounted to 57.3 kg/ha. Sowing at a depth of 1-2 cm led to a decrease of this indicator by 12.6%. With an increase in the depth of seeding up to 3-4 and 4-5 cm, the relative yield of essential oil decreased by 6.8 and 14.7%, respectively.

CONCLUSIONS

The research findings show that the most favourable conditions for fennel plant growth and development, seed formation and accumulation of essential oil on dark chestnut soils of the southern Steppe of Ukraine were ensured by the interaction of such parameters of the investigated technological practices as early spring sowing in the third ten-day period of March and a seeding depth of 2-3 cm. In this variant, plant height and leaf surface area of fennel reached their maximum values of 97.8 cm and 27.6 thousand m^2/ha, respectively. The highest level of crop productivity and seed quality was also recorded under early spring sowing at a depth of 2-3 cm: yielding capacity was 1.31 t/ha, weight of 1000 seeds reached 5.21 g, essential oil content in seeds amounted to 5.87% in dry matter, relative yield of essential oil being 67.7 kg/ha.

We recommend that agricultural producers, when growing common fennel, carry out early spring seeding at a depth of 2-3 cm at the proper soil tilth stage in the third ten-day period of March. The introduction of the improved technology of fennel cultivation will allow increasing its productivity under arid conditions of the southern Steppe of Ukraine.

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