CORVINUS UNYVERSITY OF BUDAPEST

MAJOR PHYSICAL PROPERTIES OF SOIL MIXES FOR GROWING VEGETABLE SEEDLINGS

Doctoral Theses

by Noemi Kappel

Subject Leader:
Prof. Dr. Istvan Terbe

Department of Vegetable and Mushroom Growing
Corvinus University of Budapest

Budapest
2006

Background and Objectives

Formerly, the promotion of earliness and nowadays production stability and the aim to reach high yields all encourage the application of technologies that include, as a component, the raising of seedlings. The national seedling production has long traditions (such as the raising of melon seedlings in turf blocks) and earlier, everyone used to grow and produce the young plants on their own. More recently, seedling factories are seen to be making headway and growers tend to manage ever greater areas and they do not raise seedlings any more, but purchase them. This way, it is even more highlighted that seedlings, similarly to seeds, are an article of trust, therefore they should only be produced in high quality. For the initial self grown seedlings, the growers prepared the soil mixtures also themselves. These were generally mixed from cheap commodities of national origin, but of inadequate quality. Nowadays when the price of the seed may be as high as 100 HUF in the case of high value seedlings or one should only think of grafted seedlings, the soil mixture is only a fraction of the value of the seedling. Therefore one must not scrimp on the purchase of good quality medium.

It had long been customary to characterize a growing medium exclusively on the basis of its chemical properties, e.g. the pH value, the amount of available nutrients or the EC value. Still nowadays, the principal ingredient of seedling growing media is peat, owing to its favourable characteristics. Peats have low nutrient levels, plant requirements, however, can be met through controlled nutrient supply in the course of production. On the other hand, the medium should have optimal physical characteristics possibly already at the beginning of growing and these parameters are difficult to improve subsequently. A constant and high quality growing medium would be in great demand. A number of companies offer mixtures prepared according to their own recipes, the quality of these mixtures, however, are generally varying and the choice is complicated further by the use of several organic and inorganic materials which are offered for the substitution of peat, the major component.

Since only few investigations had been carried out before in Hungary into physical root media properties for my thesis I have set the objective to analyze the major physical properties and to determine the parameters of the media, as well as to study, in the light of these physical properties, the effect of the media made from different basic ingredients on the germination and early development of vegetables. Artificial soil mixes are very difficult to investigate in this direction, partly because of the scarcity of the national literature and partly because of the lack of exact analytical methods. It is a serious problem that the measurement methods elaborated for mineral soils cannot be fully adapted to the investigation of such media, besides reproducibility is hard to achieve, owing to the heterogeneity of the materials and the diversity of the measurement techniques.

In my work I grew the seedlings of 5 vegetable species with the tray method, containing species less susceptible to the physical properties of the root medium (tomato, cabbage) and ones more susceptible (cucumber, pepper and lettuce). Trays are filled with peat based media in large scale production too. Fibrous raised bog peat has recently been getting more and more widely used. Many growers buy national fen peat still now, primarily for making soil mixes for their own use. In the trial, besides the Northern raised bog peats some Hungarian fen peats were also tested. Owing to the world's diminishing peat resources more and more attention is being directed towards the search for peat substitutes. Accordingly, in my seedling raising experiments I tested different mineral materials (bentonite, zeolite, perlite and expanded clay pellets) as medium constituents, as well as coconut coir which is getting ever more popular, determining the physical parameters and their effect on seedling development.

In the world, several seedling raising technologies are known which utilize seedling trays. The major difference between them consists in the types of the trays used and the tray filling method. Therefore, I also carried out investigations to find out whether the choice between loose or compacted filling had any effect on the physical properties of the medium and on the development of the plants.

My aim was to select, taking into consideration the national commodities as well, the medium that suited best the vegetable species and the seedling raising techniques applied in the light of the most important physical properties.

Material and Method

In my experiment I raised seedlings in a manner to be suitable for planting outdoors with a technique involving the use of seedling trays. I used five vegetable species for test plants. These were as follows: pepper (Tizenegyes), industrial tomato (Uno), pickling cucumber (Dózer), cabbage (Bently, Amager) and lettuce (Garuda Rz, Moderna Rz, Mirette Rz).

In the course of the trial my attention was centred on the observation of seedling development and I also studied the most important physical parameters of the media. The analyses did not include the observation of the seedlings after outplanting, my aim was to judge the level of development of plants ready for outplanting raised for commercial purposes.

The seedlings were raised in expanded polystyrol trays measuring 40x60x6 cm, sold by the company KITE Rt. I grew lettuce in a tray with 126 cells, round at the top, while I grew pepper, tomato, cucumber and cabbage in a tray with 187 cells, square at the top. The types of the trays corresponded to the cell dimensions recommended for the production of seedlings intended for large-scale outdoor production. In the case of lettuce, the reason for the application of the tray with round cells providing greater plant spacing was the structure of the plant.

The trials were conducted for 4 years at the Experimental Farm of the Corvinus University of Budapest, under heated and unheated growing facilities in accordance with the heat demand of the species.

Since my intention behind the trials was to explore the effect of the physical properties of the seedling media, nutrients were supplied to the media in the same way according to a given technology.

I used the slow release fertilizer FERTICARE 13-15-17 microgranule PEAT-MIX developed for seedling growing and containing micro elements as well at a dose of 2 kg/m^3 with supplementary superphosphate given similarly at a dose of 2 kg/ m^3.

I used feed lime (Futor) at a dose of 3 kg/ m^3 for setting the pH of the acidic fibrous raised bog peat.

During the trials plant protection measures were carried out in the seedling nursery of the Experimental Farm by applying uniform treatments and the trays were irrigated using sprinkling cans during the period of early seedling development and hoses in subsequent stages.

All treatments were replicated 6 times in each trial and the trays were arranged in a completely randomized design. 1 tray corresponded to 1 treatment and I counted the germination on the whole tray, while for the purpose of the seedling measurements I selected 10 plants, giving a faithful picture of the development of the tray, per replicate and carried out the measurements on the aerial parts (shoot and leaves).

In order to characterize root development, I washed out the media from the roots of 5 seedlings per replicate.

The control treatment applied in each trial was a mix that had already been tried before and used also by a company engaged in growing commercial seedlings. The media used in the individual treatments were as follows:

<u>Spring 2002:</u> *Investigation of different fen peat and raised bog peat ratios, as well as mixes containing bentonite.*

I prepared 5 different mixes to study the effect of the difference in peat ratios and observed the development of the seedlings of the 5 vegetables in a spring seedling raising trial. The fen peat used in the trials was a peat originating from Pötréte, provided by the company KITE Rt, while the raised bog peat was pure peat packed in bags and sold by the company AgroCs. In parallel to the peat ratio trial, as a preliminary investigation for the autumn trial, I added different amounts (5-10-15 V%) of Ca-bentonite to a 1:1 mix of fen peat and raised bog peat. The media was put in the trays by applying loose filling.

<u>Autumn 2002:</u> *Investigation of soil mixes containing bentonite and zeolite.*

Similarly to the spring trial I studied the effect of different amounts of Ca-bentonite (5-10-15 V%), zeolite (5-10-15 V%) and Ca-bentonite combined with zeolite (5 V% bentonite + 5 V% zeolite; 10 V% bentonite + 5 V% zeolite; 15 V% bentonite + 5 V% zeolite) added to a 1:1 soil mix of fen peat and raised bog peat. The media was put in the trays by applying loose filling.

<u>Spring 2003:</u> *Trial of expanded clay pellets as seedling medium.*

Seedling soil mixes were made by mixing together different ratios of fen and raised bog peat, expanded clay pellets and perlite. Ingredients used: fen peat originating from Pötréte, raised bog peat sold by the company AgroCs, horticultural perlite and uncrushed and crushed expanded clay pellets. In this trial, too, the media were put in the trays by applying loose filling.

Spring 2004: *Investigation of the effect of tray filling (loose and compacted) with media tested before.*

The purpose of this seedling trial was to see if seedling development was influenced by applying loose filling or compacted filling to the seedling trays. I used the two types of peat applied in the previous years and bentonite as ingredients for the mixes. When filling the trays I put the mixes into the cells with loose filling in the one case and by applying compaction in the other. Since the Experimental Farm had no tray filling machine also the compaction of the media was carried out manually (according to a method already applied before). Ingredients used: fen peat originating from Kecel, raised bog peat sold by the company AgroCs and Ca-bentonite.

Spring 2005: *Investigation of method of tray filling (loose and compacted) with further media.*

The trial again was aimed to see if seedling development was influenced by applying loose filling or compacted filling to the seedling trays. I used 4 types of peat (fen peat originating from Kecel, raised bog peat sold by the company AgroCs, Novobalt peat and Hels peat) and coconut coir for the purpose of seedling media.

Investigation of seedling media

In determining the major physical parameters, sampling and sample preparation have an influence on measurement results. In each trial, I sampled the individual media when filling them into the trays and carried out the measurements. Since the bulk density of the media may vary considerably, I used heat resistant plastic tubes of 100 cm^3 for the analysis of the samples and the uniform filling of the cylinders was performed by the help of a special volume measuring device. Out of the physical parameters the following ones were determined:

- texture (particle size) [%],
- hygroscopic property,
- capillary rise [mm],
- determination of water capacity (capillary, maximum and minimum) [weight % and volume %]
- pF value (determination of moisture fractions bound with different strengths) [V%-volume%]
- bulk density (Ts) [g/cm^3],
- density (Fs) [g/cm^3],
- total porosity ($P_ö$) [V%],

- determination of capillary and non-capillary pores [V%],
- porosity conditions (differentiated porosity, qualitative distribution of pore space) [%],
- determination of moisture content (N) [%].

Analyses carried out on seedlings

Results were evaluated from the following points of view:

Based on the measurements carried out on seedlings:

- rate of germination (germination dynamics) [%],
- stem diameter [mm],
- plant height / leaf length [cm],
- dry matter content of the aerial parts [%],
- fresh (foliage) weight of 1 seedling [g],
- dry (foliage) weight of 1 seedling [g],
- dry matter content of the roots [%],
- fresh weight of 1 root system [g],
- dry weight of 1 root system [g].

Ratios and values obtained from the measurements by calculation:

- Root and shoot ratio: fresh root weight of 1 seedling / aerial part (shoot) fresh weight of 1 seedling. The higher the ratio the bigger is root system of the seedling as compared to the shoot.
- Total fresh weight of 1 seedling [g] : shoot fresh weight + root fresh weight of the seedling.
- Total dry weight of 1 seedling [g] : shoot dry weight + root dry weight of the seedling.
- Total fresh weight : height ratio: total fresh weight of 1 seedling / seedling height.
- Total fresh weight : height ratio: total dry weight of 1 seedling / height.
- Root fresh weight : total fresh weight ratio: root fresh weight of 1 seedling / total fresh weight of 1 seedling.
- Root dry weight : total dry weight ratio: root dry weight of 1 seedling / total dry weight of 1 seedling.

Results

<u>Physical properties of seedling media</u>

In terms of the dry bulk densities (g/cm^3) of the media, according to my measurements, fen peats have greater bulk densities (0.22-0.26 g/cm^3) than fibrous raised bog peats (0.08-0.1 g/cm^3). By mixing mineral materials (bentonite and zeolite) bulk density was increased even further. Coconut coir had a density (0.08 g/cm3) similar to that of raised bog peat. When characterizing the pore space of the media I came to a conclusion similar to that of other researchers, i.e. that the higher the bulk density the lower the total pore space.

Particle size, i.e. texture has a major influence on capillary rise and on water capacity values. The majority of the media were characterized by the dominance of the particles of 4-2 mm and 1.6 mm-400 µm.

Fen peat showed a very good water rise. Zeolite powder had an exceptionally high 24 hour and 48 hour capillary rise, which was already apparent in the treatments when mixed to the peats at a ratio of 15 V%. Favourable results were obtained for the crushed type of the expanded clay pellets where statistically significant higher values were measured already for the 1 hour water rise, as compared to the other media. Perlite had a water rise similar to that of fen peat, but when mixed with peat came near to the values of the clay pellets. The poorest water rise was seen with the pure bog peat, hardly reaching 50 mm in 48 hours. Coconut coir had the statistically significantly best water rise.

Peats were characterized by high total porosity and this value was over 80% in each mix. The great capillary pore space of the fen peat was in harmony with the 48 hour capillary rise. The ample macropore space is important in allowing faster water movement. Porosity conditions were not significantly affected by mixing bentonite to the peats. In characterizing the porosity conditions, among the peats used, particular note should be given to the high air content of the fen peat (33%), as well as to the ample capillary pore space of the zeolite powder (28%). Clay pellets had a total porosity of 70%, while the perlite, similar to the fen peat and coconut coir, had a total porosity of 94%. For the uncrushed clay pellets I measured an air content ratio in the pores (~35%) identical with that of raised bog peat and perlite. When determining the differentiated porosity I found that the peats (in particular the fen peat and the strongly decomposed Sphagnum peat) and the coconut coir had considerable capillary-macropore space providing good water permeability.

According to literature data the optimal condition for seedling growing is when the capillary and non capillary ratio is 50:50 %. I observed different distributions for the constituents of my media. The values that I obtained for the size of capillary pore space were as follows: raised bog peat 30-34%, expanded clay pellets 39-44%, perlite 40%, zeolite 60%, bentonite 65%, coconut coir 75% and fen peat 73-75%.

The suction force corresponding to the pF value holds the given amount of water in the media expressed in volume%. The value 1.5 pF denotes the content of readily available water which was 36-41 V% in the case of the peats, while I obtained a much higher value of 78.5 V% for the bentonite. The value 4.2 pF indicates the content of unavailable water, the so-called ‘dead water’, which was 22 V% in the raised bog peat, 25 V% in the fen peat and 47% in the bentonite.

The compaction of the media had no effect on particle size distribution or on the capillary rise according the method of the analysis. Compaction, on the other hand, increased bulk density and the water content expressed in proportion to weight% of dry medium and thereby also the level of saturation. Porosity conditions, at the same time, were greatly influenced by filling. In response to compaction each medium had lower total porosity and porosity conditions were also changed. I registered an average total porosity decrease of 4-8% with the utilized volume measuring device in the samples subjected to compaction. The proportion of non capillary pores was decreased while the proportion of capillary pores was increased and this way the moisture retention capacity of the media was also increased. The water capacity values also changed accordingly and capillary and maximum water capacity values expressed in weight% were increased in response to compaction.

<u>Seedling growing trials</u>

My experience with growing the **pepper** seedlings was that better germination was obtained in the media containing fen peat than in the raised bog peat. This could be explained by the better water retention capacity of the fen peat. Compaction resulted in greatly improved germination dynamics with the raised bog peat and coconut coir, as this manner of tray filling increased the proportion of capillary pores which also contributed to the improved water retention capacity of the media. The mixing of bentonite and zeolite into the peats had a negative influence on germination. In evaluating the seedlings I found that by mixing 10-15 V% bentonite and zeolite into the peats had already resulted in diminished fresh seedling weight, while on the other hand dry matter content was increased, in agreement with the findings of other researchers. The mixing of bentonite and zeolite into the peats decreased the total porosity and maximum water capacity of the media and these soil physical parameters had an influence on seedling development. On the other hand, as a result of adding 5 V%

zeolite, seedling development was accompanied by an increased growth of the aerial parts. The medium containing perlite gave rise to particularly well developed seedling root systems which can be explained by the high air capacity of perlite. I found a diminishment in the dry matter content of the shoots and roots in response to compaction. At the same time, compaction had a favourable effect on the development of the shoots (height, shoot fresh weight), though the extent varied from media to media, where the strongest effect was observed with raised bog peat and coconut coir. As a result of compaction, the proportion of capillary pores, ensuring greater water retention, was also increased.

In the case of the **tomato**, the mixing of bentonite and zeolite into the peats did not have any influence on germination, except for the higher zeolit doses (15 V%) which negatively affected seed emergence. Seed emergence was slow to start in the medium containing perlite. Compaction had a notably more beneficial effect on the dynamics of seed germination in the trays that contained the raised bog peat or coconut coir. No statistically significant difference could be observed in seedling development in the media containing bentonite or zeolite. I did not manage to grow normally developed seedlings in the pure expanded clay pellets, on the other hand, the clay pellet treatments that contained perlite and peat gave rise to seedlings similar to the control. In the case of each medium (except for the peat mix containing 10 V% bentonite) compaction gave rise to seedlings with an increased shoot weight but with smaller root systems.

The **cucumber** was characterized by a better germination when grown in the media containing fen peat and bentonite and zeolite did not influence seed emergence. Seedling dynamics were favourable in the clay pellet-peat mix. The beneficial effect of compacting the trays on the rate of germination could only be registered in the fen peat and coconut coir. The mixing of mineral material (bentonite or zeolite) to peat resulted in increased seedling root weight. The mixtures that contained both clay granules and peat gave rise to seedlings with statistically significantly increased weight, as compared to the control. Compaction gave rise to seedlings with an increased shoot weight but with smaller root systems.

Lettuce seeds, in a similar manner, showed the best germination in the mixes containing fen peat. The mixing of 5 V% bentonite and 5 V% zeolite, both separately and in combination, to peat resulted in improved germination %. Seedling dynamics were favourable also in the mixtures containing clay pellets and peat. These mixes had high air capacity, this way I came to conclude, similarly to other researchers, that lettuce germinated better in a more porous medium. Compaction had a beneficial effect on seed emergence in the case of the raised bog peats and the coconut coir. The fen peat and the mixtures containing bentonite gave rise to shorter but sturdier seedlings with an increased dry matter content and having a greater root system in terms of root:shoot ratio. The mixtures containing zeolite were characterized by seedlings with greater shoot fresh and dry weights, as well as with a big root system, where the most favourable mixing ratio was found to be 5 V%. The expanded clay pellets alone did not seem to be a suitable medium for growing lettuce seedlings, while the crushed form mixed with peat gave rise to seedlings with a greater fresh weight but with a smaller root weight. In the case of each medium (the raised bog peat and the coconut coir, in particular) the compacted filling of the trays increased the aerial size and weight of the seedlings, but had an adverse effect on root system development.

In the case of the **cabbage**, the mixing of various peats in different ratios and the addition of minerals had no influence on seed germination. The dynamics of germination were the same in the peat media containing perlite and clay pellets as in the control. Only little improvement of germination % was achieved by subjecting the media to compaction. The mixing of bentonite to peat gave rise to shorter but sturdier seedlings with a relatively greater root system in terms of seedling dimensions. The best results were shown by the mix containing 10% bentonite. I raised seedlings with a big aerial mass, a good root system and with a high dry matter content in the mixes containing 5 V% zeolite. The clay pellets mixed with peat gave rise to seedlings similar in development to the control. The seedlings in the mix containing perlite were characterized by statistically significantly higher shoot and root weights, as compared to the control. In the case of each medium compaction gave rise to seedlings with an increased shoot weight but with smaller root systems. The coconut coir was an exception where compaction had a beneficial effect on root development, too.

Peat and coconut coir have higher water capacities which are necessary for optimal germination. The readily available water content of perlite and expanded clay pellets is higher than that of peat, while their water retention capacity is lower. Coconut coir has a higher water retention capacity than the fibrous raised bog peat which I tested. The mixing of mineral material (bentonite or zeolite) to raised bog peat can improve the water retention capacity.The compacted filling of the trays can also improve the water retention capacity of the media. Compaction can be a means to alter the porosity conditions of the media. In the case of each test plant, the compaction of the media gave rise to seedlings with an increased shoot weight but had negative influence on root development. This suggests that we can influence the water holding characteristics of the seedling media and thereby seedling development either by the choice of the ingredients or by compacting the media.

New scientific results

The results of the experiments carried out confirm the observation that the physical properties of an artificial medium have a great influence on plant development. Based on the knowledge of the physical properties, seedling development can be influenced in a targeted manner by the choice of the media. I made a selection among the soil physical parameters of the media tested and the seedling properties, choosing the ones giving the best representation of their interconnections. I found correlative relationships between the properties, confirmed by traditional factor analysis. The five test plants used showed different susceptibility to the physical properties of the media.

1. In the case of pepper seedlings, the capillary pore ratio of the medium has a significant influence on plant height, on fresh weight and on dry weight. Of the water holding parameters, the capillary capacity and the minimum water capacity have some influence an seedling development.
2. Among the five vegetables used as test plants it is the tomato that shows the least response to changes in the individual soil parameters. A higher proportion of the capillary pores will result in a statistically significant increase in the height of tomato seedlings, as well as in the shoot fresh weight, while reducing the dry matter content of the aerial parts.
3. In the case of cucumber seedlings the proportion of the capillary pores has a considerable influence on the seedling parameters studied except for the shoot dry matter content and for the root:shoot ratio.
4. Among the species investigated, the closest relationships between the soil physical parameters and the individual seedling properties were found in the growing of lettuce seedlings. The growing proportion of the capillary pore space of the seedling media has a statistically significantly positive effect on the development of seedling aerial parts, on the other hand, has a negative effect on the shoot dry matter content and on the root:shoot ratio. Among the water retention parameters of the media it was the capillary capacity and minimum water capacity that influence seedling properties.
5. In the case of cabbage, the growing proportion of the capillary pore space has statistically significantly positive effect only on seedling height and consequently, on shoot fresh and dry weights.

When growing vegetable seedlings in seedling trays it is necessary to give due consideration to the physical properties of the media used since seedling development can be influenced both by the choice of the ingredients and, on the other hand, by compacting the media. After determining the physical properties of the media used in the experiment I have come to the following conclusions:

6. The national fen peats are characterized by ample capillary pore space and good water storage capacity which permit vegetables to germinate well and to develop favourably.
7. Fibrous raised bog peats have less capillary pore space and therefore a poorer water storage capacity, as compared to fen peats.
8. Coconut coir is characterized by a bulk density and total porosity that are identical to fibrous bog peat, but its water retention capacity is much better than that of the latter owing to having ample capillary pore space in a similar manner to fen peat.
9. Of the mineral ingredients, the pore space of the perlite and the expanded clay pellets is dominated by non capillary pores which are responsible for aeration, while in the case of the bentonite and zeolit the ratio is just the contrary and it is capillary pores that dominate.

As far as the media used for growing pepper, industrial tomato, pickling cucumber, lettuce and cabbage seedlings in seedling trays are concerned, the following observations can be made:

10. The mixing of bentonite or zeolite to peat will increase the root weight and root dry matter content of the seedlings. For zeolit a 5 V% mixing ratio is recommended in the case of pepper, lettuce and cabbage. Bentonite is recommended to be mixed at 10 V% in cabbage seedling growing.
11. Both the perlite and the expanded clay pellets have proved to be favourable ingredients as a peat substitute mixed to peat at a rate of 50 V%.
12. By means of compacting the media in the trays, seed germination dynamics can be influenced favourably and seedling shoot mass can be increased while the root:shoot ratio will become less favourable.

Conclusions and Recommendations

The physical properties of the artificial media used in seedling growing have a great influence on germination and on young plant development. The national literature is very scarce in methods for the determination of the physical properties of the predominantly peat based media. The measuring methods elaborated in detail for mineral soils are not fully adaptable to soil mixes.

The greatest problem consists in sampling. The most crucial parameters (bulk density, porosity conditions and water capacity) are dependant on the compaction of the sample.

When determining the physical properties of the media it is advisable to consider the following:

- Porosity conditions should be determined by using a volume measuring device (this way the measurement is easier to reproduce)
- For the determination of the pF value it is sufficient to determine the following parameters
    - air volume (V%): total porosity minus water V% measured at 10 cm water column
    - readily available water (V%): water V% measured between the 10 and 50 cm water columns
    - water storage capacity (V%): water V% measured between the 50 and 100 cm water columns
- In determining the differentiated porosity as elaborated for mineral soils, porosity conditions provide only approximate values to characterize the water-retention properties of a medium.
- In the case of a medium, the determination of the ratio of the capillary and non-capillary pores gives a better indication of the water-retention parameters required for successful production.
    - the non-capillary pores absorb the water fraction corresponding to pF 1 - pF 1.7 and therefore constituting the readily available water
    - the capillary pores with their the water fraction over pF 2 are responsible for the water transport and the water storage of the medium

Publications belonging to present theses

Peer reviewed articles in journals:

1. **Kappel N.**, Slezák K., Tóth K. és Terbe I. (2002): Palántanevelő közegek hatása az uborka fejlődésére. Kertgazdaság 34(2):17-20.
2. **Kappel N.**, Zsivánovits G., Slezák K. and Tóth, K. (2003): Research of the elasticity of transplant – growing substrates after watering. International Journal of Horticultural Science 9(1):67-70.
3. Tóth K., **Kappel N.**, Slezák K. and Irinyi B. (2003): The effect of soil mixtures of different consistance and phosphorus content in tray transplant-growing. International Journal of Horticultural Science 9(1):71-76.
4. **Kappel N**., Sári Sz., és Forró E. (2003): Talajtani és agrokémiai talajtulajdonságok időbeli változásainak vizsgálata kertészeti földkeverékekben. Kertgazdaság 35(4):13-21.
5. **Kappel N**. and Slezák K. (2004): Peat substitutes in growing cucumber transplants. International Journal of Horticultural Science 10(1):115-118.
6. **Kappel N**. and Terbe I. (2005): Effect of physical properties of horticultural substrates on pepper transplant development. International Journal of Horticultural Science 11(4):75-78.

Other scientific articles:

1. **Kappel N.** és Tóth K. (2001): Palántanevelésre használt földkeverékek szerkezeti- és tápanyag-összetétele. Gyakorlati agrofórum 12(13):16-18.
2. **Kappel N.**, Slezák K., Tóth K. és Terbe I. (2002): Bentonitos kezelés hatása az uborka palánta fejlődésére. Hajtatás korai termesztés 33(2):19-22.
3. **Kappel N.** (2004): Palántanevelés különböző földkeverékekben. Hajtatás korai termesztés 35(2):12-17.

Conference publications (Hungarian, full papers):

1. **Kappel N.** (2002): Bentonit hatásának vizsgálata a palántanevelő földek fizikai tulajdonságára. Proceeding of „The 9th Symposium on Analytical and Environmental Problems" Szeged, 30 September 2002. 130-135.
2. **Kappel N.**, Tóth K., Irinyi B. és Sári Sz. (2003): Foszforellátás és talajszerkezet hatása a paprika tálcás palántanevelésében. MTA Növénytermesztési Bizottság III. Növénytermesztési Tudományos Nap, Budapest, Proceedings 391-395.
3. **Kappel N.** (2003): Egy új közeg a palántanevelésben. A Szegedi Akadémiai Bizottság Mezőgazdasági Szakbizottság Kertészeti Munkabizottságának tudományos ülése „Integrált Kertészeti Termesztés". Tessedik Sámuel Főiskola, Szarvas, 2003. október 17. Proc. 17-23.
4. **Kappel N.** (2004): Paradicsom és uborka palánták makroelem tartalma különböző földkeverékekben. Proceeding of „The 11th Symposium on Analytical and Environmental Problems" Szeged, 27 September 2004. 242-246.

Conference publications (Hungarian, abstracts):

1. **Kappel N.**, Tóth K., Forró E. és Sári Sz. (2002): Zöldségpalánták nevelésére alkalmas földkeverékek legfontosabb fizikai paraméterei. JUTEKO 2002 „Samuel Tessedik Jubilee Agricultural, Water and Enviromental Management Scientific Days" Szarvas, 29-30. August 2002. Abstract of papers 240-241.
2. **Kappel N.** és Zsivánovits G. (2003): Palántanevelő földek tömörödésének vizsgálata az öntözés hatására. MTA XXVII. Kutatási és Fejlesztési Tanácskozás, Gödöllő, 42-43.

3. **Kappel N.** (2003): Palántanevelés különböző tőzegféleségekben. Lippay János - Ormos Imre - Vas Károly Tudományos Ülésszak. Budapesti Közgazdaságtudományi és Államigazgatási Egyetem Budai Campus, 2003. november 6-7. Budapest, 648-649.
4. **Kappel N.** (2005): Zöldségpalánták nevelése különböző tömörségű tőzegekben. Lippay János - Ormos Imre - Vas Károly Tudományos Ülésszak. Budapesti Corvinus Egyetem, 2005. október 19-21. Budapest, 398-399.

International conferences (English, full papers):

1. **Kappel N**., Zsivánovits G., Tóth K. and Slezák K. (2003): The compaction of transplant-growing substrates after irrigation, Cercetări ştiinţifice, Horticultură, Scientifical research, Horticulture, Seria A VII-A, Agroprint Timişoara, 41-48.
2. **Kappel N**. (2005): The effect of peat compactness on growth of vegetable transplants. XL. Croatian Symposium on Agriculture. 15-18. February 2005. Opatija, Croatia, 351-352.