Root development of container-cultivated winter lime trees (Tilia cordata)

By Axel Schneidewind

Summary

In an eight year experiment the rooting behaviour of Winter Lime trees, which had previously been cultivated in five different types of container, was examined. When the trees were planted four out of the five container types showed ring root formation at the container walls, which persisted even after rooting into the surrounding soil. Regular examination by digging up the trees has shown that the original root circling has continuously increased.

After eight years constrictions of the trunk combined with bead like thickening were observed in two trees. It is expected that this spike like growth will increasingly endanger tree vitality and thus increase the the risk of early die back. The death of one Linden tree confirms this assumption. Only the Air-Pot system did not cause ring rooting.

1. Introduction

The use of trees and shrubs in public spaces, that were cultivated in containers while they were in the nursery, has increased significantly over the past few years. The main reason for this is that container grown trees can be planted throughout the entire year, even during the summer months. While spading and packing with machines is always connected with the loss of roots, trees cultivated in containers hardly experience root loss. If the container is removed professionally during the planting process, the entire root system of the tree is preserved, thereby minimizing transplanting shock.

In addition, container production also offers the possibility of soil-independent cultivation, which is an advantage from a phztosanitary point of view. Soil-borne pathogens, such as Verticillum, Phztophthora or Fusarium species, can then not pose a threat to the trees,

Image 1: Trial planting 2009

provided that the substrates used are uncontaminated. By developing special container substrates with high percentage of minerals, good growing conditions are created that lead to faster tree growth while they are being cultivated in a nursery.

The disadvantages of container production consist of the high cost for the container itself and for preparing the installation area of the container trees, which are usually above ground, including the scaffolding anchors or holding devices. On the other hand, these plants have no surrounding soil that can serve as a compensatory buffer for fluctuations in temperature, water and nutrients, including the pH of the soil. For sensitive tree species, additional winter protection of the root area may be necessary. Production in containers is associated with a higher effort and expenditure because the cultivation control must be much more precise. For years, drip irrigation systems have been commonly installed, which in turn require good water quality and/or treatment. Higher costs are also incurred for specific fertilisation and the substrates used.

2. Experiment background

The main problem in container production of trees is the long-known risk of undesirable ring or spiralling root formation in the containers. This phenomenon is also known as the pot effect. The longer the plants are in containers, the higher the probability of them having ring root characteristics. The extent to which these have been created only becomes apparent during the planting process on externally visible surfaces (TAEGER 2017).

The further development of these root systems, the actual rooting behaviour of container trees, the subsequent root growth at the final location and the resulting development in lime trees over several years has not yet been investigated under practical conditions.

3. Materials and methods

3.1 Experiment facility and data collection

In 2009, a joint trial was launched with the Kompetenzzentrum Baumschule nursery in Ellerhoop, where this experiment with tree planting had already been started in autumn 2008. At both locations, winter lime trees (*Tilia cordata* 'Greenspire'), which had previously been cultivated in one nursery, for three years in five different container types, with the same container substrate, served as test trees. Four trees per container variant were planted at both locations, i.e. a total of 20 high-stemmed winter lime trees, trunk circumference 14 cm to 16 cm (Image 4). In Quedlinburg, the experiment began in late spring 2009 on a flat surface with homogeneous soil conditions. The pits carried out there to a depth of 1.20 m showed a naturally grown soil with a pronounced loesslehm soil profile, which became increasingly skeletal from about 80 cm onwards.

The test trees transported with the containers looked good and healthy upon visual inspection. During the planting process, the root areas of the lime trees could be inspected for the first time. As is common practice, before planting, the root balls were each cut about 2 cm deep on four sides to promote root regeneration in the surrounding topsoil. The root system was not flushed with an additional single tree per container variant, as was done in Ellerhoop. After a professional pruning, the trees were planted in rows, each five metres apart, into the existing soil. The edges of the planting holes were roughened mechanically beforehand in order to achieve a good interlocking between the root ball and the surrounding natural soil (FLL 2010). A triple trestle scaffold with a standard coconut rope connection served as a tree anchorage. The coconut mat Cocoprotec® was installed above and below the tree connection to protect the trunk so that the entire trunk area was protected up to the crown. The irrigation of the trees was ensured by means of watering edges from topsoil. During the entire trial period, neither fertilisation nor cutting measures were carried out (FFL 2015).

During planting, the initial values of the 20 winter lime trees (trunk circumferences, tree, and trunk and crown heights) were measured. During the experiment, these growth data were recorded annually, except for trunk heights. Since the lime trees were not clipped on, they remained the same.

Per container type, one of the four lime trees were excavated every two years. Due to the late planting in 2009, the first time a tree was excavated was in autumn 2011, then, after the vegetation periods of 2013, 2015 and 2017. The main focus was the investigation of the rooting behaviour of winter lime trees in relation to the original culture container, as well as the determination of possible ring root formations. Therefore, the complete root areas of all excavated trees were intensively rinsed in order to document root development and measure root strength. The roots were

Image 2a: The pot-in-pot system in the nursery

Image 2b: Lime tree in a hard-walled container before planting

Image 2c: Planting a lime tree from a hard-walled container

counted in the three groups commonly used in arboriculture: strong root (Ø > 5.0 cm), coarse root (2-5 cm) and weak root (0.5-2 cm) (FLL 2017). To be able to analyse the root development of the lime trees in relation to container cultivation more precisely, wood-biological processing and investigations were carried out after the end of the experiment.

3.2 Test types

During their nursery cultivation period, four of the 20 experimental lime trees were placed above ground on scaffolding supports and one was sunk into the ground (pot-in-pot system, Image 2a). The five types of culture containers can be divided into three groups: hard-walled tubs (Image 2b, c), plant bags and the Air-Pot® system (Table 1).

The hard-walled single tub used is made of black polyethylene (PE) without a handle and with a raised base that has holes with a diameter of 2 cm, as well as other openings in the corners. The non-perforated pot wall is impermeable to water and light. The robust container is very sturdy and stable; it is therefore often used in nurseries for above-ground cultivation on scaffolding supports. After planting, it is possible to be freely reused at the final location. The hard pot edges and recessed grips can be a disadvantage when transporting plants to the final site, as there is a risk of bark damage.

The pot-in-pot system consists of two hard-walled tubs of the same size, also made of black PE, which can be placed inside each other. The outer base pot remains permanently in the soil and closes only slightly above the edge of the soil. The second tub potted with the tree is lowered into it. This second tub also has corner openings from the flat base of the pot to the side walls. Spacers between the two container floors and walls prevent them from wedging. A functional drainage system must be installed under the base tub in order to avoid backwater and to drain off excess water quickly. All other properties are analogous to the hard-walled single tub.

Two trial variants belong to the group of planting bags made of flexible, partially recycled material, of which there is now a wide range of sizes, colours and suppliers. The products are made of weather-resistant polyethylene or polypropylene fabrics with carrying loops. The breathable, water-permeable fabric is designed to prevent the formation of ring roots and waterlogging. The plant sacks can be washed and sterilised; therefore, they can be reused. Folded flat, they require little storage space and can be easily transported. Due to the soft pot walls, planting bags do not damage the stems when loading and transporting trees. The prices per plant bag are more favourable when compared to the other brands (Table 1).

The following products were tested: PlantinBag®, from Gartenbaubedarf Bosse, and ARBO-Perf®, from MARTEX. The green PlantinBag® nursery container has a volume of 53 l (Image 3a). Its diameter is 46 cm and has a height of 32 cm.

Table 1: Overview of the container types used

Type	Make	Colour	Volume in l	Ø in cm	Height in cm	Individual price in€
1	Hard-walled tub	Black	50	45	35	3.76
2	Pot-in-pot	Black	50	45	35	7.52*
3	PlantinBag®	Green	53	43	32	1.55
4	ARBO-Perf®	White	59	46	31	2.85
5	Air-Pot®	Black	45	39	40	7.74
*Price corresponds to two hard-walled tubs (base pot remains in the soil)						

Image 3a: Lime tree after unloading in PlantinBag®

Image 3b: Lime tree in ARBO-Perf® before planting

It consists of non-degradable but recyclable polyethylene fabric with two handles or transport loops and is breathable and UV-resistant. There are 24 punched holes with a diameter of 4 mm evenly distributed over the entire container wall and a further eight punched holes in the container floor. In addition, there are four larger holes of 1 cm in diameter at the bottom edge of the sack to allow excess for water to escape.

The ARBO-Perf® has a volume of 59 l, a diameter of 46 cm and a height of 31 cm, making it somewhat wider (Image 3b). It also consists of non-degradable but white PE-fabric of the side walls with a sewn-on black container bottom of the same material and four evenly distributed transport loops. According to the manufacturer's specifications, this is also breathable and UV-resistant. The whitish colouring of the container walls is intended to reduce soil temperatures in the tree substrate during the cultivation period by reflecting sunlight. Arranged in four rows, there are a total of 104 punched 4 mm holes in the bottom half of the sack, which look like perforations. There are no other perforations as with Plantinbag®.

Nevertheless, tree roots are able to grow through the container floor of ARBO-Perf®.

The Air-Pot® (Caledonian Tree Company Cowbraehill, Distribution: Herman Meyer KG) is a fundamentally different system to the previously presented culture containers of woody plants and is also known as a spring ring. The product is made of recycled black HPDE and consists of a special pot wall, a grid-like floor insert and green wall mounting screws. The Air-Pot® container used for the test plants had a diameter of 39 cm and a height of 44 cm (Image 4). The base plate was installed 6 cm above the bottom edge of the pot. This also ensures permanently good ventilation and drainage of the root system from below. This construction method results in a total volume of 45 l. The container wall has a three-dimensional structure with directly adjacent conically shaped 4 cm deep cone-like protuberances. Half of the cones are directed inwards and closed. The cone tips pointing outwards are cut off precisely, i.e. open, with the exception of the upper three rows of cones. This closed container edge with a width of 6 cm serves as a watering edge and prevents the surface of the tree substrate from being

Image 4: Lime tree after unloading in Air-Pot®

washed away. As the container walls did not have any flat surfaces, the roots are directed into the open cones projecting outwards until the root tips dry up due to the increasing air content. This natural way of cutting the roots with the air is also called air-pruning. At the same time, this provides intensive aeration of the embedded tree substrate. The costs per set are the highest in comparison to other container types. A dispatch of trees even without the Air-Pot® container is possible, according to production information. Other materials, such as jute baling fabric, can then be used to protect the root system during transport.

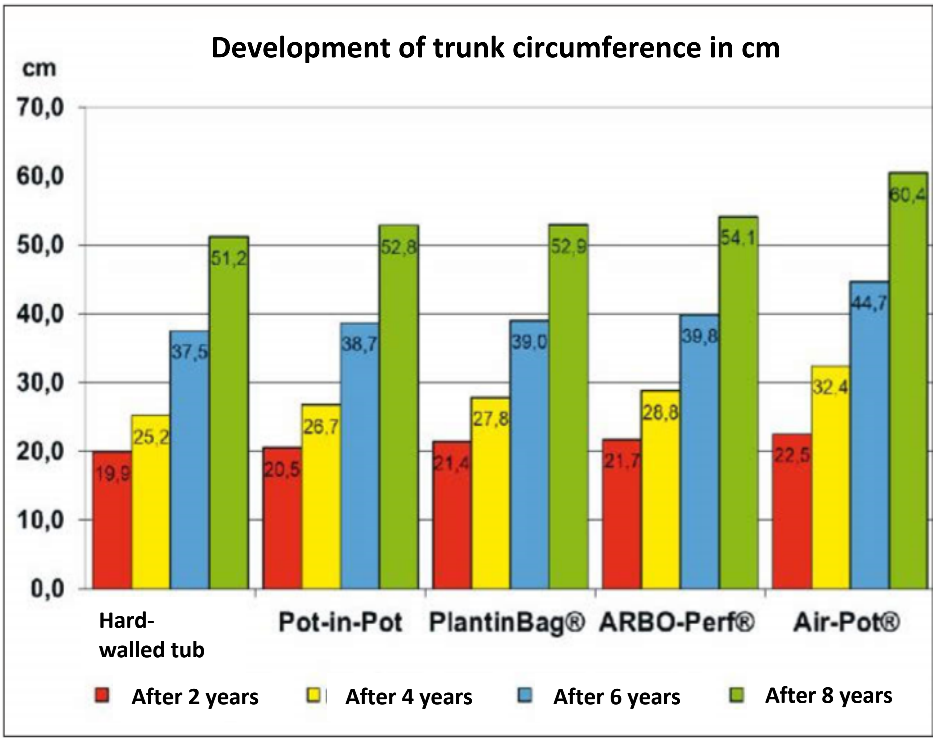
Table 1 shows an overview of the container makes with the product data. The unit prices are from 2019. ARBO-Perf® is now no longer sold. It is therefore the price at that time of planting.

4. Results and discussion

4.1 Trunk circumference and growth performance during the experiment

When the trunk circumferences (TC) were first recorded after planting (measured at a height of 1 m), the values hardly varied at all within one container type and only slightly between the variants. The TC of the lime trees from the hard-walled tubs were between 14.9 cm and 16.3 cm, the two planting bags PlantinBag® and ARBO-Perf® between 15.1 and 15.9 cm and Air-Pot® between 15.2 and 16.6 cm. Since cultivation was carried out in a tree nursery during the growing period under

Image 5: Measurement results of stem circumferences as a function of the culture container (average per test variant)



analogous conditions, especially regarding water and fertiliser supply, the informative value of these measurements is limited. It is known that greater evaporation losses occur in containers with walls that are permeable to air and water, which must be compensated for with additional water. It can therefore be assumed that an irrigation control system adapted to the respective container system would produce better growth results (WREDE et al. 2017).

In the following years, the development of the TC in relation to the original cultivation container became more obvious. In the last test trees taken from the hard-walled tubs and planting bags, the differences in the values measured were less than 3 cm. The trunk growth of the winter lime trees from the Air-Pot® containers was consistently stronger throughout the test period. At the end of the experiment, the last lime tree of this variant was the only tree at all that had a trunk circumference of over 60 cm. Image 5 shows the respective average per test variant.

These results are confirmed by the measurements of the tree heights. At the start of the experiment, the tree heights per container variant averaged between 4.48 and 4.73 m and the crown heights between 2.04 and 2.47 m. Although the crown heights were still recorded annually, the values are only of limited significance due to the increasingly varying slope growth of the lower branches of lime trees. A better assessment for growth performance of all test trees can therefore be derived from the development of tree heights. After eight years, the highest total tree height was 8.12 m (Air-Pot®) and the lowest 7.07 m (pot-in-pot). Image 6 shows the average values per variant.

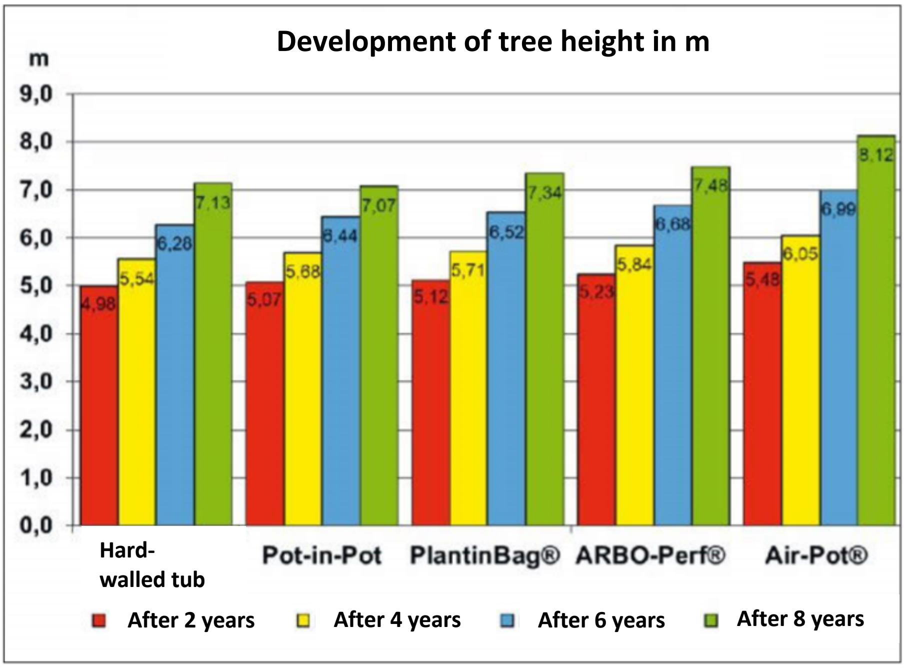


Image 6: Measurement results of tree heights depending on the cultivation container (average values per variant)

4.2 Root development during the experiment

After removing the culture containers immediately before planting the lime trees, the root system on the outer surfaces of the balls could be inspected for the first time (Image 7a-d). Visually, a heterogeneous root image became visible, depending on the container type. With the exception of the trees from the Air-Pot®, ring roots of different thickness and length were found in all other variants, the longest and thickest in the hard-walled tubs (variants 1 and 2). Some of these roots ran around the entire ball. However, these root

Image 7a: Root ball after removal of a hard-walled tub

Image 7b: Root ball after the removal of a PlantinBag® plant sack

Image 7c: Root ball after removal of an ARBO-Perf® plant sack

Image 7d: Root balls after opening an Air-Pot® container

features could also be found on the smooth outer surfaces of the plant bags (variants 3 and 4). In the hard-walled tubs, the ring roots were more often visible in the upper third of the ball; while in the planting bags, they were more visible in the lower half. It was not possible to count the roots exactly as the root balls should be planted as a whole and intact. In contrast to variants 1 to 4, the root system of the trees from the Air-Pot® looked significantly different. Corresponding to the system structure, the honeycombed-like wall structure became visible on the root ball, which shows a densely branched weak-root network without any signs of root spiralling.

Already after the excavation of the first five winter lime trees with subsequent root rinsing at the end of 2011, the full rooting behaviour of the lime trees became apparent (Image 8a-e). Counting the ring roots caused by the container confirmed the visual impression during planting. The largest number of these roots, all of which now had coarse root strength (Ø >2 cm), were found in the hard-walled tubs with 17 and 18 respectively, followed by ARBO-Perf® with 12 and PlaintinBag® with 10. This result was also confirmed after all further clearing with individual tree deviations.

In the most recently removed test trees, the count for variant 1: 15, for variant 2: 17, for variant 3: 8 and for variant 4: 10 detectable ring roots, which in the meantime had continuously reached a strong root strength (Ø >5 cm). Over the years, block-like rootstocks had developed from ingrown strong roots,

Image 8a: Rooting after 4 years (former hard wall bucket)

Image 8b: Rooting after 4 years (former pot-in-pot system)

Image 8c: Rooting after 4 years (former hard PlantinBag®plant sack)

Image 8d: Rooting after 4 years (former ARBO-Perf® plant sack)

Image 8e: Rooting after 4 years (former Air-Pot® container)

which still showed the original container dimensions. Due to progressive thickness growth, the exact counting of original ring roots became increasingly difficult.

Therefore, the emerged roots had to be cut off at the transition point to the point where they emerged in the existing soil. This made the ring-shaped root growth, caused by the culture containers used, even more visible. Image 9 shows the results.

1.1 Root development after cultivation in hard-walled tubs and plant sacks

The actual rooting at the final location took place in a radial direction from the former container wall in the case of the hard-walled tub and plant bag trees. This process can be described as follows: The root of a potted young tree in a smooth-walled container reaches the container wall, begins in this case the unavoidable rotation growth at this area, thickens according to the duration of cultivation, reaches the final location after nursery cultivation and can grow into the surrounding soil from this location. The ring-shaped root development is thus overcome, but the ring roots, which have been pronounced until then, remain unchanged (WATSON 2011). Due to the secondary thickness growth, they grow together. With increasing tree age, a block-like, overgrown rootstock develops.

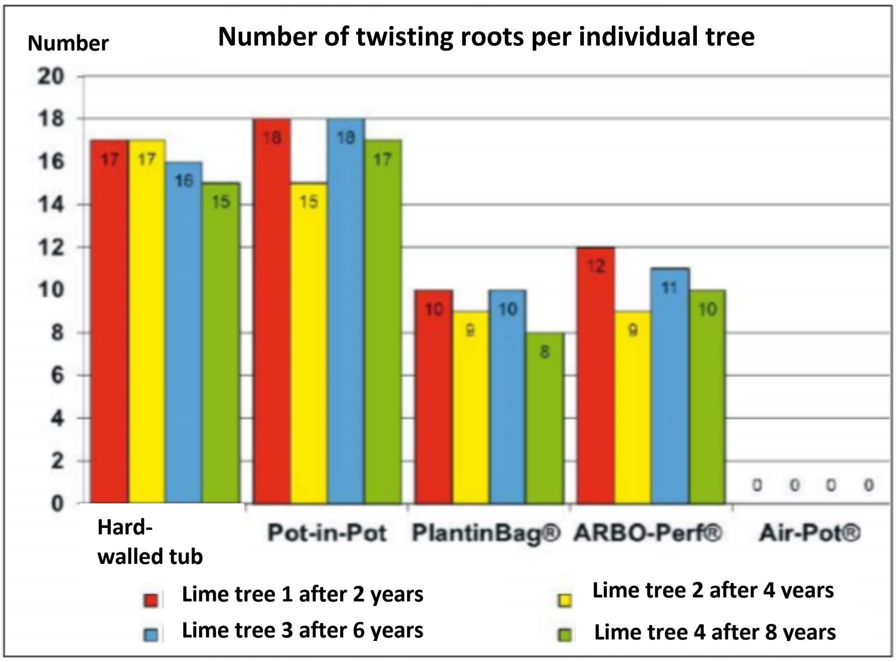


Image 9: Established number of spiral/ring roots per single tree and year

Image 10: Constriction of the trunk foot by roots after six years (former pot-in-pot system)

Image 11b: Rootstock from block-like grown ring roots after 8 years (former PlaintinBag® plant sack)

This progressive development could already be observed after the second excavation of the lime trees.

In the 6th year of the experiment, a lime tree from the former pot-in-pot system became increasingly dry in the crown area and gradually died off without any evidence of phytosanitary or problems with the site. After rinsing the root system, 18 ring roots were found in the area of the former hard-walled tub. The uppermost roots had begun to constrict the base of the trunk, similar to a classical constricting root (Image 10). Before the excavation, this constricting-root-like condition could not be identified. Only when

Image 11a: Bulbous growth of the trunk base due to advanced thickness growth of ring roots (former hard-walled tub)

Image 11c: Rootstock of block-like grown ring roots after 8 years (former ARBO-Perf® plant sack)

the root necks were uncovered during the excavation did the twisted roots that were up to 8 cm in diameter, lying at right angles to the direction of growth of the trunk, become completely visible.

After eight years of the experiment, the winter lime trees from the former hard-walled tubs (variants 1 and 2) showed, in addition to the block-like fused rootstocks, unnatural and strong bulge-like thickening of the trunk base up to a diameter of 14 cm. The now completely ingrown twisted strong roots considerably constricted the trunk feet of these two lime

Image 12: Normal radial rooting after eight years (former Air-Pot®container)

trees and increasingly hindered the secondary thickness growth of the trunks (Image 11a). In the case of the plant bag variants, the development of the spiralling roots after eight years showed a slightly modified pattern. Since the ring roots originally formed during cultivation were mainly located in the lower half of the containers, they led to block-like root growth, especially in the lower half (Image 11b). In the case of the lime tree from the ARBO-Perf® sack, an emerging constriction of the trunk foot by the roots of the lime tree was detected (Image 11c). Since it is impossible to remove ingrown ring roots from a standing tree, progressive damage or the risk of trunk breakage must be assumed at this point.

4.3 Root development and rooting behaviour after cultivation in Air-Pot®

The rinsed root areas from the Air-Pot® system were completely different. As described, no external spiralling roots could be detected even before planting. After the excavation of these lime trees according to the test procedure, a normal root development was shown, independent of the tree age. From the densely branched root systems at the container edges of the Air-Pot®, a uniform star-shaped root system developed in all directions. The roots grew largely unhindered into the surrounding topsoil without prior twist fixation and quickly reached strong root strength (Image 12).

Search pits carried out on the last five standing winter lime trees revealed that the tree cultivated in the Air-Pot® system had developed the most extensive root system compared to the other varieties of container. The root washing proved the uniform quality of the entire root system. Occasional root growth in the soil outside the former containers was observed in all test trees and cannot be attributed to the influence of the culture containers. The central separation of the rootstocks of the five experimental trees that were last excavated allowed the development of ring roots of variants 1 to 4, which has been progressing for years, to be demonstrated. This work also enabled cross-sectional measurements of the root thicknesses at their points of origin. Furthermore, several root areas with an enclosed non-rooted tree substrate were identified. In the rootstock of the hard-walled tubs, these were particularly large at up to 8 x 14 cm, the maximum diameter of the plant bags was 9 cm and 5 cm for the Air-Pot®.

From this, different growth reactions at the boundaries of the container models can be derived. Comparatively larger root-free areas inside the root balls indicate that the smooth inner surfaces of the container variant 1 to 4 were more attractive for roots during nursery production than the available tree substrate. This could be the actual cause of ring root development. The trees from Air-Pot® did not have this growth stimulus due to the hole-like structured wall, which caused the air-pruning. As a result, the existing tree substrate was more evenly rooted through without the development of ring roots. The following somewhat better growth results of the lime trees from the former Air-Pot® system can be explained by this, although compared to the other container variants, less substrate was available during the nursery culture (Table 1 and images 5 and 6).

5. Final review

In four out of five test variants, the investigations show very clearly the extent of ring root formation as a factor of the culture vessels used in the nursery. It has been confirmed that the primary spiralling roots formed during container production are preserved in the rootstock of a tree for life (WATSON 2011). The formation of rings or spiralling roots and thus the increasing danger of bulbous-root-like growth processes in the immediate vicinity of the tree trunk represent a fundamental problem for the development of trees. In perspective, progressive constriction can lead to premature death of a tree or at least to an incalculable increase in the risk of breakage at the base of the trunk. **That the subsequent rooting behaviour of the lime trees from the former container wall took place in a normal way can be concluded that under favourable site conditions for trees, it is more likely that the period of increasing risk of trunk breakage will occur.** The lime tree dying in the 6th year of the experiment proves this point. As a result, it is not the rooting behaviour of the trees that is the actual problem, but rather the ring root characteristics, which are fixed due to cultivation and are caused by the preferential growth of roots at the interfaces of smooth or flat container walls. Regarding the root development over the eight years of the experiment, only the variant from the former Air-Pot® system can be assessed as recommendable. It has been proven that this culture container allows the formation of a densely branched root network without ring root formation and that the trees at the final location start rooting evenly without restrictions. In comparison with the other four container variants. It was from these containers were the largest trees developed during the experiment.

At the Ellerhoop site, ring root formations were also detected in a parallel experiment (WERDE et al. 2017). The growth conditions at the experimental site there, especially the soil conditions, could lead to somewhat modified results that are important for the overall assessment of the individual products. The reconciliation of the Quedlinburg results with those from Ellerhoop is still pending. A joint final report is planned for 2020.

The present results refer exclusively to the tree species *Tilda cordata* and the presented culture containers at the Quedlinburg site. It would be desirable to include other experimental sites and tree species in similar practical studies. The same also applies to new or improved container types.

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