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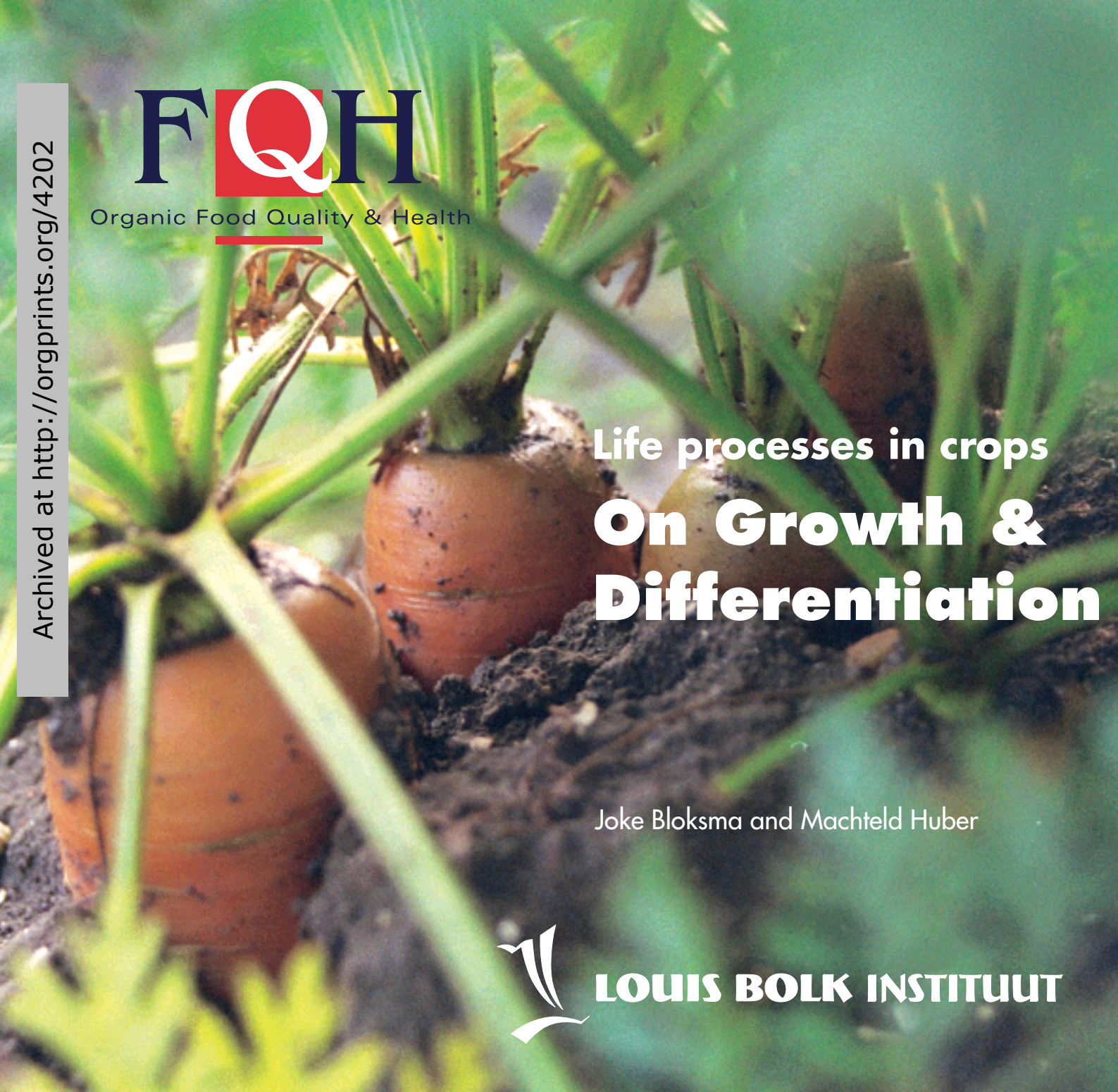


Life processes in crops

On Growth & Differentiation

Joke Bloksma and Machteld Huber

LOUIS BOLK INSTITUUT

About FQH

FQH - International Research Association for Organic Food Quality and Health - Association of research institutes and stakeholders, that aims to stimulate research in the field of organic food quality and health, present publications, organise scientific conferences and exhibitions.
Website: www.organicfqhresearch.org

About the Louis Bolk Instituut

The Louis Bolk Instituut has been a pioneer in innovative scientific research in organic farming, nutrition and healthcare since 1976. Broadening the basis of scientific research is the aim of the institute's work. Where conventional research methods do not suffice, new methods are looked for, such as: phenomenology, participatory research, pictomorphological investigations and conscious-intuitive methods, Rudolf Steiners philosophy being a source of inspiration.

About this publication

J. Bloksma, M. Huber, 2002
Editing: W. Beekman
Translation: J. Klerkx
Photography: unless mentionend otherwise,
from LBI-Anna de Weerd
Cover: Fingerprint Driebergen

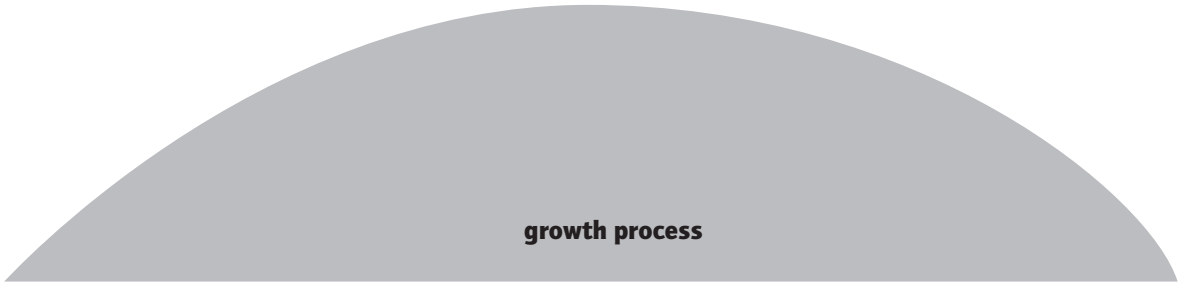
Growth and differentiation - Life processes in crops
Published in Dutch and in English
Louis Bolk Instituut
Hoofdstraat 24
3972 LA Driebergen
Tel: 0031-343523860
Web: www.louisbolk.nl

Louis Bolk Publication nr. GVV 02-Eng and/or
Food Quality & Health Publication nr. FQH 02-Eng
Price € 6,-, without postage

Growth & Differentiation

Joke Bloksma and Machteld Huber

This booklet discusses two basic life processes in nature: growth and differentiation. It uses the examples of apples, carrots and wheat to illustrate how growers can recognize these processes and can take practical measures to correct the balance between them in order to optimize the quality of their products. Thinking in growth and differentiation has proved valuable in the support, offered to growers by the Louis Bolk Instituut. It also speculates about the possible significance of these processes for human health.


growth process


differentiation process

Introduction

This booklet discusses two important life processes in plants: growth and differentiation. Since these two processes occur simultaneously in living organisms, they cannot be separated, but as agricultural practice shows, it is nevertheless useful to *distinguish* between them. Each of these processes has its own dynamics, and this booklet tries to help you understand them, for the following reasons:

- Growth and differentiation are two concepts that reflect the essence of crop plants and that play a major role in our ideas about the significance of nutrition for human health.
- It is important for growers to recognize these processes because this makes it easier for them to correct certain problems because they have a conceptual background for decisions in cultural practises.
- Merely emphasizing growth, as often happens in agricultural practice, results in problems of disease or poor quality. Problems that can be prevented by promoting a good balance between growth and differentiation.

This picture shows two principles of growth and differentiation as interlocking processes. The leaves of groundsel (Senecio vulgaris) have been lined up: from the first leaf grown on the stalk on the left to the latest on the right, which means that the line-up reflects the ages of the leaves. The first leaf is small and undifferentiated. This is followed by a stage of vigorous growth of both petiole and leaf blade. The leaves at the centre of the picture have attained their maximum size and the differentiation of their shape is becoming clear. Differentiation gradually takes over, and the leaves become smaller and more toothed. The growth stage has given way to the differentiation stage and the leaf 'ripens' into a narrow, pointed shape. It is time for flowering to start.

Growth

Growth can be defined as the process of filling space expansively with organic mass, by means of cell division and cell elongation. This process involves the uptake of water, warmth, carbon dioxide and minerals. Growth is made possible by the process of photosynthesis, which produces the sugars from which compounds such as starch, cellulose, amino acids and proteins are derived.

We use the concept of 'vitality' to refer to the final result of this growth process. A vital plant has many green leaves and produces a good yield. Its end product often has a high starch, sugar, amino acid and protein content. An actively growing plant contains relatively large quantities of free 'building blocks', such as free amino acids; however, as the plant completes its growth, these quantities start to decrease and the ratio of protein to free amino acids increases. Growth creates pressure in the cells (called turgor), resulting in a juicy and crisp final product.

After a product has been harvested, it gradually softens and loses its vitality. A vital plant, in the sense of an actively growing plant, does not necessarily have to be healthier, in the sense of supporting human vitality. Too much unbalanced vitality may be undesirable.

Growers try to stimulate plant growth by fertilizing the soil (especially with nitrogen), breaking it up to promote mineralization, watering it, adding extra carbon dioxide (in greenhouses) and selecting a warm site to grow their crops. Growers try to reduce growth by keeping the soil dry.

Characteristics of growth and differentiation for plants in general

Cultivation practices	Life processes in the crop	Properties of the final product
Promoting growth	**Growth**	**Vitality**
+ fertilization	• mass formation, spatial expansion	• many large, dark green leaves, large root system
+ watering	• germination, spreading leaves, production of flower, fruit and seed	• susceptible to leaf diseases
+ sheltered, warm location	• photosynthesis	• high yield
− drought	• production of primary compounds	• sugar, starch, cellulose, amino acids, protein
− shortage of certain nutrients		• high germinative capacity
Promoting differentiation	**Differentiation**	**Structure**
+ light	• orderly structure, specialisation	• differentiated, delicate shapes, multiformity
+ dry warmth	• ripening, refinement, multiformity	• orderly structure, robust crop
	• production of secondary compounds	• aroma, scent, colour, phenols
	• nutrients move to storage organ	
	• production of flower buds and pollen	

Differentiation

Differentiation is the process of specialization in terms of shape and function. An example is cell differentiation in plants, animals and humans: a young cell, which is initially multifunctional, gradually acquires one specific function and the corresponding shape. . The shape of a plant reflects this specialisation as refinement in terms of shapes, scents and colours: leaves turn their colours in autumn, the growth of shoots ends in a terminal bud, seeds enter dormancy and fruits ripen.

The process of differentiation can involve dispersion (in pollen or aromas being spread by the wind) or concentration and hardening (in the formation of rigid cell walls, the production of seeds and the storage of nutrients).

The process creates more orderly structures and more complex compounds, like the wax on an apple skin, pigments, phenols and bitter or aromatic substances. Growers try to stimulate differentiation by limiting growth and choosing a sunny, warm and dry place to grow their crops.

The balance between growth and differentiation

Although both of these processes always occur simultaneously, the balance between them can show considerable shifts. In certain seasons, the emphasis is on growth (for instance in young plants, in spring and early summer, when there is copious leaf production), while differentiation predominates at other times (in older plants, in late summer and autumn, in flowering and seed production). Distinguishing between the two processes may help the grower to select the right corrective growth measures.

Too much emphasis on the growth processes, providing insufficient opportunities for differentiation, leads to rampant growth, while overemphasising differentiation with too little growth leads to puny plants, as in 'emergency flowering'.

Industrialized agriculture, which prefers rapid and vigorous crop development, tends to focus on the process of growth (since high crop yields mean more money) at the cost of taste and storability (as consumers are often unwilling to pay for true quality). This has an adverse effect on all aspects of differentiation. Growers producing for bulk markets will tend to emphasize growth processes, while those producing for niche markets, where taste is all-important, will emphasize differentiation instead.

The three examples discussed below illustrate how growers can recognize and correct growth and differentiation processes as they try to improve crop plants and in the production of apples, carrots and wheat, in order to optimize the quality of their products. Extreme situations are discussed that allow growers to gain experience and gradually develop the necessary skills to strike the ideal balance between growth and differentiation for each developmental stage of the crop in their specific situation.

These processes can also be identified in so-called weeds, like the groundsel shown on page 4.

DEVELOPING
Cultivated plants from wild plants

The developmental process in wild plants shows clear transitions in time: young plants focus on growth, while older plants concentrate on differentiation. In 'domesticating' wild plants, growers alter two properties: firstly, they stimulate growth (swelling) and differentiation in a particular part of the plant. Secondly, they try to let growth and differentiation overlap and integrate at a certain moment and not take place after each other. The result is a large, juicy product with a good taste and storability. This means that the two processes are strengthened in the cultivated plant and are more simultaneous, relative to the wild plant. Thus, wild cabbage has been improved to produce various crops: the leaves have been adapted to produce leaf cabbage, the axillary buds have been adapted to produce Brussels sprouts, the stem has been adapted to produce kohlrabi and the flower bud has been adapted to produce cauliflower.

Reggy Waleson claims that his 'Demeter lettuce' is a 'mature' lettuce. He allows the head to grow fairly slowly and provides enough light to allow differentiation. He grows a lettuce that keeps well, with robust leaves and a sweet, aromatic taste. (Thanks to the Biodynamic Association)

In cultivated carrots (right) the growth and differentiation of the root have been emphasized relative to the wild carrot (left) (from Jochen Bockemühl, Lebenszusammenhänge, 1982).

Wild lettuce

Cultivated lettuce

Wild lettuce (Lactuca serriola) is a puny plant that first produces a rosette of leaves, from which a flower stalk arises, which then flowers and produces seed (with pappus). In cultivated lettuce, the rosette (a typical product of a growth process) has been greatly emphasized, leading to the well-known green head. If the formation of the head is not accompanied by differentiation, the sweet, nutty taste is poorly developed. Hence, rapidly grown lettuce from heated greenhouses consists of large heads that have little taste and cannot be stored for long. Such 'growth lettuce' is actually 'baby lettuce (from: Elemente der Naturwissenschaft, no 39, Ulrike Behrendt, Ein vergleich der Wild- und Kulturformen des Salates).

Growth & differentiations in APPLES

Growth

The growth process in an apple tree clearly reveals itself in the unfolding of young leaves, the emergence of the blossom, fruit production, shoot formation, increasing stem girth and root growth. A vital tree has large quantities of green leaves and produces many apples. The leaves are large and implanted far apart on the shoots. A vital apple is large, firm, crisp and juicy, and chemical analysis shows high levels of sugars and malic acid.

A vital apple is still engaged in growth processes, involving many transportable compounds like free amino acids and sugars. The pips have a high germinative capacity. As the apple ages, it loses its crispness and refreshing taste.

Fruit growers have many methods to influence growth. Growth can be stimulated by watering, fertilising, fruit thinning and using growth-promoting pruning strategies, and can be inhibited by root pruning, grooving the stem, watering sparingly in dry periods and using growth-inhibiting pruning strategies.

Differentiation

Differentiation processes in apple trees are clearly recognizable in the fine tooths along the leaf margins, the sheen on the leaves and fruits, the ripening of the fruit, the production of aroma, the leaf colours in autumn, and the formation of flower buds, pollen and seeds.

Differentiation processes create orderly structures and complex compounds, like the wax on the apple skins, phenols, vitamins, aromatic substances and tannin in the tree's bark. Well-differentiates fruits have many pips and a high calcium content.

Growth and differentiation can appear very close together: for example in the flower bud initiation for next years flowering. In spring small axillary buds above each apple leaf appear (*growth*) as multifunctional buds. In summer the cells *differentiate* into flower bud cells or into

Appletree on the left grows too vigorously, appletree on the right grows too weakly.

Appletree on the left grows too vigorously due to too few apples, appletree on the right grows too weakly due to too many apples.

leaf bud cells, depending on conditions. In late summer amino acids and carbohydrates are stored in those buds as reserve for *growth* in next spring.
Fruit growers promote differentiation for instance by limiting growth, by choosing a sunny location, by opening up the tree's crown by pruning, so that the apples get the sun, and by bending young shoots downwards, so that flower buds for the next year can form.

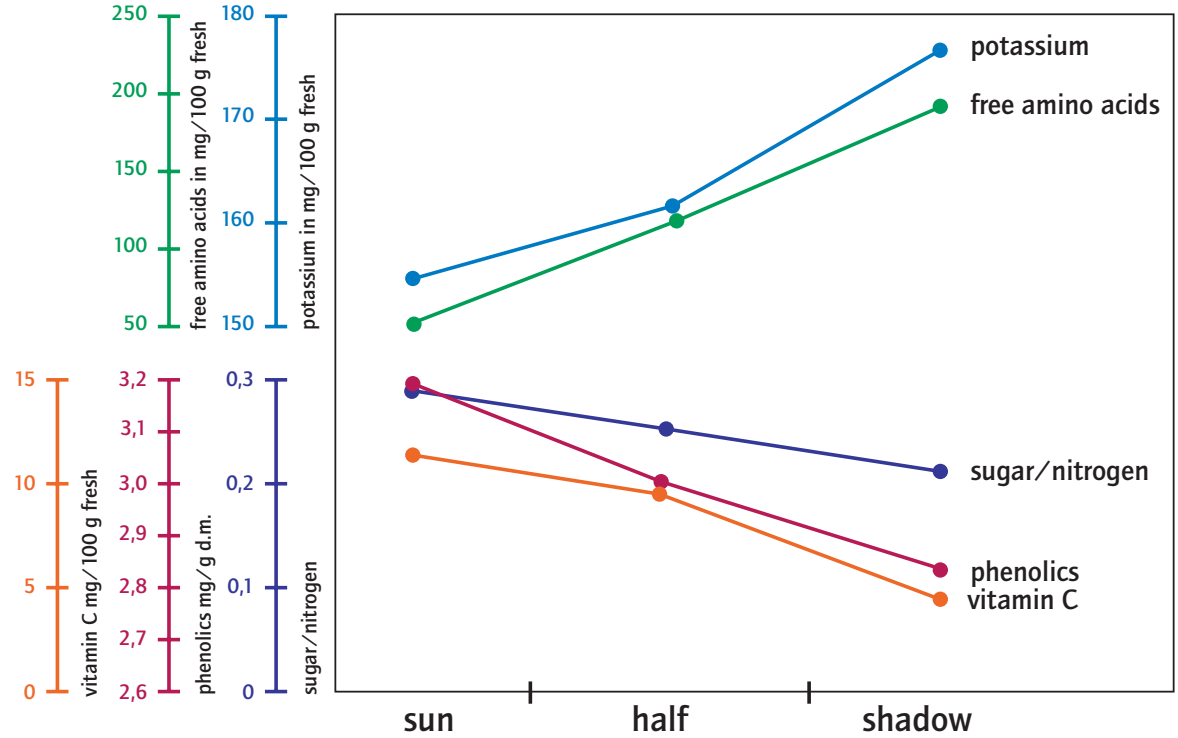
Optimizing the balance between growth and differentiation

Fruit growers aim at a combination of growth and differentiation. If growth predominates, trees grow very tall, fail to shed their leaves in time in autumn and are ill-prepared for frost. The great mass of leaves prevents the fruits from getting enough light, so that they ripen poorly and late. If there is not enough growth, for instance because lice sap the tree's nutrients, differentiation leads to hardening instead of refinement, producing small, dry, hard apples. The ideal balance between growth and differentiation processes depends on the age of the orchard: in its early years, growers focus on growth by providing fertiliser and water and removing the fruits. After that, branches are bent downwards to stimulate differentiation. As the trees grow larger and denser, they need to be pruned to allow the fruits enough light to ripen. In old orchards, which by nature tend to produce many small fruits, growth-stimulating pruning strategies are used to re-stimulate growth.

Big photo: the rosy apple aphid takes away so many nutrients that small, hard, dry apples result.

The gleaming Elstar apple with its red blush, which grows on the sunny side of the tree, contains more sugars, phenols and vitamin C and less free amino acids than the dull, yellowish apple growing in the shade among the leaves. Sunlight has induced more differentiation in the former than in the latter.

Elstar apples from different positions in the tree



This Elstar mutant, which is always red, does not show whether the apple inside its skin is sweet or ripe.

Various compounds can be used to assess the levels of growth and differentiation during the development of the product. In apples, high levels of free amino acids can be regarded as a sign of growth, while high levels of phenols and vitamin C and high levels of sugar relative to nitrogen indicate strong differentiation.

Growth & differentiations in CARROTS

Growth

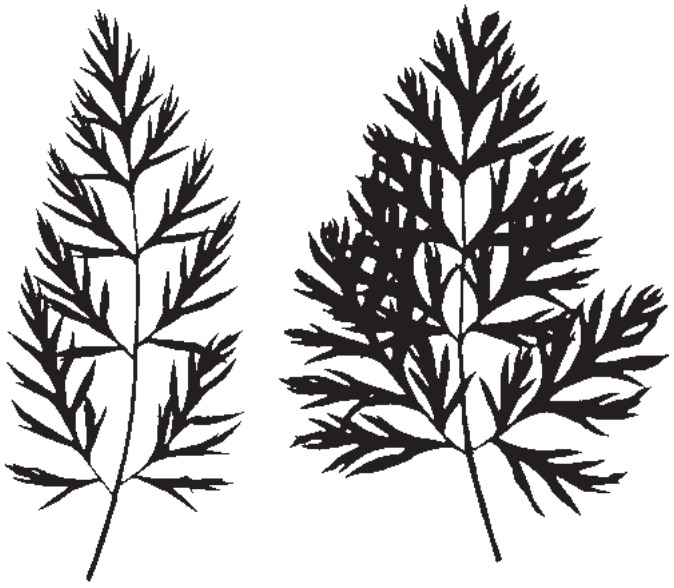
Growth processes in carrots can be seen in the germination of the seeds, followed by the leaves unfolding one by one, making the plants expand in space. The field grows greener and the soil gradually disappears. The plants take up water and nutrients from the soil, and their leaves take up carbon dioxide and light for photosynthesis, producing materials for further growth and for storage in the carrot.
A highly vital carrot is one in which the growth processes predominate. This can be seen in the field as large quantities of tall, dark green and coarse foliage, which is still growing when the carrots are harvested. Yields are high and the carrots are thick and long. If they are cut across, they show a wide core (stele) surrounded by a narrow cortex. The carrot is juicy and crisp, and analyses show relatively high levels of free building blocks like nitrate and free amino acids.
Carrot growers who want to promote growth have to provide enough fertiliser and water and a warm location; they grow their plants on ridges, where the soil is warmer and more nitrogen is released.

Differentiation

Differentiation processes in the carrot reveal themselves in the production of more finely divided leaves. In addition to scents and pigments, the plant produces substances like phenols, which give the carrot its characteristic taste and protect the plant against diseases. Well-differentiated carrots have a stronger scent and more intense colour than rapidly growing and hence less differentiated carrots that grow on very fertile soil. A field of carrots growing at a quiet pace, with

As long as new leaves are being produced at the plant's core, growth processes are still active.

Carrot from sandy soil (upper) and from loamy soil (lower) (from: Jochen Bockemühl, Lebenszusammenhänge, 1982).



On sandy soil (left) carrot leaves are often more finely divided than on loamy soil (right).

enough sunshine, shows regular and firm foliage, remaining fairly low and showing the first autumn colouring before the carrots are harvested. The plants as well as the carrots themselves have a good structure, as shown by their regularity and firmness, multiformity and variegated colour. If you cut across the carrot, it shows a wide cortex. Its taste is sweet, with touches of spicy bitterness, and analyses show relatively high levels of phenols and sugars.
Light is an important factor in differentiation. This is evident from the leaves of carrot plants grown under insect netting, which tend to be long, limp and coarsely shaped. While the netting helps to protect the carrots from carrot fly, their taste is less sweet.

Optimizing the balance between growth and differentiation

Growers try to produce juicy and aromatic carrots with a good yield and storability by striking a balance between the processes of growth and differentiation. Carrots with a high rate of growth, for instance on too heavily fertilized soil, fail to ripen adequately. Thus, carrots should receive moderate levels of fertiliser.
At the same time, growth should not be too slow either. If the soil houses many parasitical nematodes, these sap the plants' nutrients, which inhibits growth to such an extent that differentiation leads to 'premature ripening'. The carrots remain small, short and stocky, are forked and have a dry and sour taste. Market gardeners can keep the numbers of nematodes in the soil down by means of crop rotation.

Finely divided carrot leaves in a well-lit location.

Crisp, juicy as well as sweet and aromatic carrots are obtained if both growth and differentiation processes are allowed to contribute.

A sliced carrot tells about growing conditions: a narrow cortex indicates heavy growth...

... and a wide cortex indicates differentiating conditions.

Under dense insect netting, the carrot tops remain long, limp and coarsely shaped. This picture clearly shows the effects of too little light. While the netting protects the carrots from carrot fly, their taste becomes less sweet.

WHEAT

Growth

Growth processes in wheat reveal themselves clearly in that the plant gradually takes up more and more space, as it germinates and forms tillers, its stalks grows taller, new leaves form and the ears fill up. Photosynthesis produces sugars, starch and secondary products like amino acids and proteins.

A wheat plant with vigorous growth processes is a vital crop, showing extensive tillering, many tall stalks and much dark green foliage. The ears contain many large grains and grain yields are high. Analysis of the gains shows relatively high levels of amino acids. Wheat growers can promote growth by providing enough fertiliser and water, stimulating tillering by means of weed harrowing and selecting a warm location.

Germination and expansion are clear examples of growth processes.

The flowers in wild oats (upper) have more differentiated shapes than those of cultivated oats (lower).

As the wheat crop ripens, the green colours are gradually replaced by light brown to golden yellow. Dry, warm weather is essential for this differentiation process.

Differentiation

Differentiation processes in wheat reveal themselves not only in the ripening ears, but wherever there is refinement and specialisation, such as the formation of stamens with pollen, awns and hairs. Materials are taken from the leaves and end up stored as nutrients in the seeds. The crop starts to show more structure and colour, as the flexible green stalk develops into brittle yellow straw. Analysis now shows more storage proteins, like gliadins and glutenins, which contribute to the flour's baking characteristics.

Wheat growers stimulate seed ripening by using moderate amounts of fertiliser and not sowing the plants too close together, allowing light to reach the foot of the plant. Warm, dry summer weather is another crucial factor for differentiation and the eventual quality of the wheat produced.

Optimizing the balance between growth and differentiation

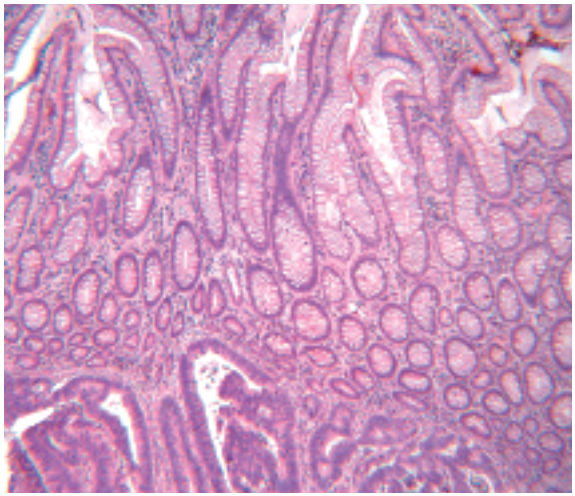
Once again, the balance between growth and differentiation is the key factor. A good balance ensures the best quality of crop and product.

Too much growth and too little differentiation make the plants' leaves susceptible to fungal diseases. Plants are flattened by the first thunderstorm to come along, and if the weather is humid, the grains start to germinate within the ears.

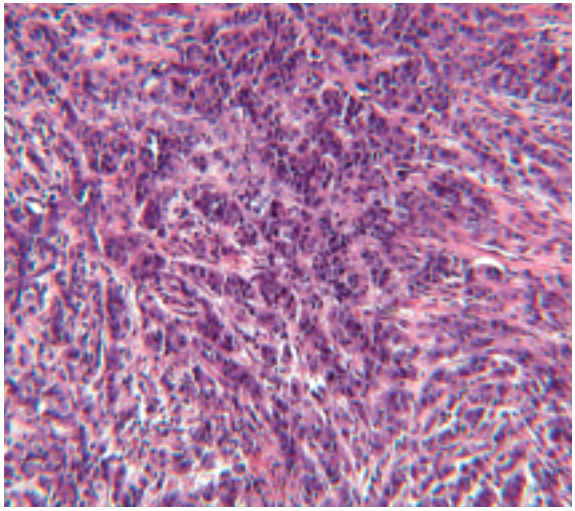
Too little growth, for instance because of drought, causes premature ripening, producing grains with a low protein content. Wheat growers are therefore trying to achieve both growth and differentiation, resulting in sturdy plants with good yields, few diseases and high quality wheat for baking.

Wheat in bloom.

Wheat growing too vigorously is subject to many fungal diseases of the leaves.



Above normal mucosa of the colon including regular, straight (glandular) tubules, while below transition to a well-differentiated colon cancer with irregular (glandular) tubules (enlarged 100x).



Poorly differentiated colon cancer lacking recognizable tissue structures (enlarged 200x).

(With thanks to Dr. F. Bot en Prof.Dr. F. Ramaekers, Universiteit Maastricht)

Perspective for growth and differentiation in

HUMANS

Although human beings are far more complicated creatures than plants, growth and differentiation are also regarded as basic life processes contributing to human health.

This is most obvious at the cellular level. Growth takes place by the formation of new cells, especially during the embryonic development but also in later life, and these cells then specialise (differentiate) in a specific function in a particular organ. This is the principle underlying the current attempts to collect 'stem cells' from embryos and use them to cure certain brain diseases in adults. Once the stem cells are placed in a particular organ, they are expected to specialise under the influence of their environment, and it is then hoped that they will help the organ resume the functions it had lost.

An example of a disturbed balance between growth and differentiation is cancer, a disease characterized by excessive cell growth. At the same time, cancer cells are less differentiated than 'healthy' body cells.

A recent trend in cancer research is therefore to look for factors that could restore the differentiation in cancer cells, forcing them to rejoin the orderly structure of the body. This therapy does not involve destroying cells, but tries to adjust the life processes towards a healthy balance between growth and differentiation (De Luca et al: Retinoids in differentiation and neoplasia, Science and Medicine 1995).

Just as in plants, the balance between growth and differentiation processes in human beings changes in the course of life. Youth is dominated by growth, and as life passes, this growth gradually decreases, while differentiation increases. With decreasing vitality, differentiation leads to hardening in the form of things like sclerosis.

Since these processes are so universal and susceptible to various influences, it is a challenging idea that human health might be favourably influenced by the use of food with an ideal balance between growth and differentiation. This connects to the growing acknowledgement that chemical compounds, generated in the differentiation phase (phenolic compounds, vitamins etc.), have a strong health promoting impact.

This idea must of course be further confirmed by research. Such research can only be done if foodstuffs are available which, in the sense described above, have been grown in perfectly balanced processes and have hence acquired perfect quality.

Life processes in crops: on growth & differentiation

This booklet discusses two basic life processes in living nature: growth and differentiation. It uses the examples of apples, carrots and wheat to illustrate how growers can recognize these processes and take practical measures to correct the balance between them in order to optimize the quality of their products. Thinking in growth and differentiation has also proved valuable in the support offered to growers by the Louis Bolk Instituut. It also speculates about the possible significance of these processes for human health.

Industrialized agriculture, which prefers rapid and vigorous crop development, tends to emphasize the process of growth, at the cost of taste and storability. This has an adverse effect on all aspects of differentiation. Growers focusing on quality need to be able to distinguish between these two processes, as this will allow them to emphasize differentiation processes.

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