Source / Sink – Relationships in Plants as Depending on Ammonium as „CULTAN“, Nitrate or Urea as Available Nitrogen Fertilizers

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Abstract

According to the common tenet in mineral N-fertilization as compared to ammonium nitrate is the more compatible and quicker effective N-form for plants. This common tenet was disproved by the development of the „CULTAN“-system. It was pointed out that the better compatibility and quicker effectiveness of nitrate as compared to ammonium are properties which depend on the kind of N-fertilization. Beyond this it was proved that in case of non-legumes depending on the kind of the available mineral N-fertilizer between the assimilates producing and the assimilates consuming organs of the plants (the sources and sinks), specific reciprocal actions are existing which may promote the storage of assimilates.

In case of nitrogen supply as nitrate broadcasted or urea in deposits there is a joint source within the plants for the synthesis of carbohydrates and organic N-compounds in the extended leaves with a joint sink incline to the growing parts of the shoots and to the roots.

In case of the supply of nitrogen according to the „CULTAN“-system there are separated sources for the assimilation of carbohydrates within the shoots and organic N-compounds in the tips of the roots, close to the surface of the „CULTAN“-deposits. Therefore countercurrent sink inclines for the carbohydrates from the shoots to the roots and for the organic N-compounds from the roots to the shoots are existing, which results in fundamental differences according the distribution of assimilates within plants and the intensity of growth of their different organs, i.e. shoots or roots, depending on the supply of nitrogen as nitrate in comparison to „CULTAN“ there are

These differences in the distribution of assimilates depending on the mineral N-fertilizer application have an impact on the synthesis of phytohormones and the specific equilibrium between phythohormones within the plants, and to a large extend regulate growth behavior as well as yield formation. Exceptions in source-/sink-relationships in dependence of the

nitrogen supply exist in legumes as compared to non-legumes.

1. Introduction

In crop production following N-forms may be applied as N-fertilizers:

(1) ammonium, (2) nitrate or (3) urea and their combinations, respectively as (4) ammonium x nitrate, (5) urea x ammonium or (6) urea x ammonium x nitrate.

In respect of the improvement of the N-supply of crops these N-forms according to the common tenet are discussed in respect of their compatibility as well as their quicker or delayed response. Since more than 50 years as compared to nitrate ammonium is classified to be less compatible and very slowly in its response to the plants, Kirkby and Mengel, 1967, Kafkafi, 1990, Lips et al., 1990, Wiesler, 1997, Brück and Guo, 2006, etc.

It should be pointed out, that these evaluations of the different N-forms are generally based on results from water and sand cultures or field experiments, which in respect to the kind of N-fertilization are limited to unbuffered systems and top-dressings. The results of these experiments are very subjective and cannot be transferred to practical conditions with an appropriate application of ammonium fertilizers according to the „CULTAN“-system. Under field conditions ammonium cannot be applied in a manner, where the whole root systems are surrounded by ammonium. On the basis of extensive results from pot and field experiments Sommer (2000 and 2005) referred to this recently.

Because of the nitrification in soils according to the common tenet it is suggested, that irrespectively of the applied N-form (ammonium, nitrate or urea), nitrogen will be available to the plants as nitrate. However, this is the case only after broadcasting mineral N-fertilizers. In the „CULTAN“-system, where ammonium is applied locally, ammonium is available to the plants and taken up and assimilated as a good compatible and quick responding N-form according to the intensity of plant growth, Sommer, 2000, Sommer, 2005. Urea or nitrate in mineral fertilizers as accompanying N-forms of ammonium after their application in combination with the „CULTAN“-system will be taken up and assimilated by the plants in the respective form. This may be connected with extensive disadvantages for the growth and yield formation as well as the enrichment of nitrate within cereals, grass or vegetables. As compared to broadcasted N-fertilizer application a N supply as nitrate by the „CULTAN“-system results in fundamental differences in the source/sink-relationships within the plants. This does not only hold true for the organic matter synthesizing and organic matter storing organs of the plants, but also for the behavior of the plant growths, its control by phytohormones as well as the yield formation and the resistance of plants against fungus diseases. These differences will be discussed.

2. Synthesis and transport of carbohydrates and organic N-compounds

2.1 Source / Sink-relationships according to the common tenet

The common tenet according to the metabolism of the assimilates in plants and the source/sink-relationships in between the organic matter synthesizing and the organic matter consuming organs of plants was extensively studied and in detail explained by Marschner, 1995. This tenet insinuates in case of the N-supply of the plants as nitrate, as usual with conventional techniques of the N-fertilization of agricultural crops, the assimilation of CO_2 as the beginning of the metabolism of carbohydrates and the reduction of nitrate as the beginning of the metabolism of the organic N-compounds predominately are located in the extended leaves of the plants. Marschner, 1995, reminds that essential amounts of nitrate taken up by plants already may be reduced in the roots. However, this holds true for plants with hidden N-deficiency, but not for agricultural crops. Therefore it has to be assumed that after common N-fertilization and N-supply as nitrate the extended leaves as the centre of the photosynthesis are the source of a plant, which is separated from the sinks, the assimilate consuming organs. Consuming organs are shoots and roots as well as the assimilates storing organs like grains, tubers, beets or fruits. According to the pressure-stream-theory of Münch, 1930 the transport of these assimilates takes place from the source to the different sinks, in case of the carbohydrates as sucrose and in case of the organic N-compounds as amino acids and amides in a parallel phloem-stream, fig.: 1.

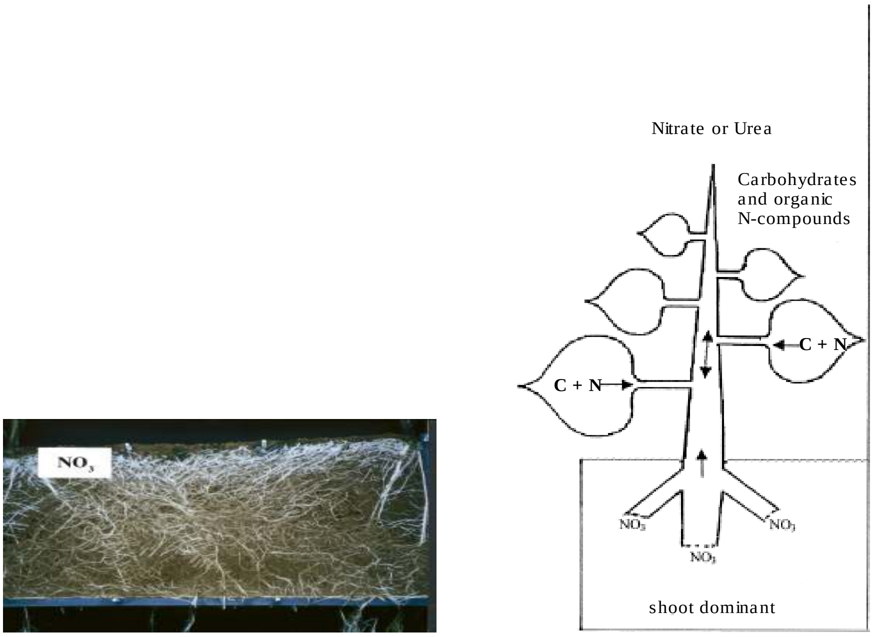


Fig.: 1 Root systems and source / sink-relationships in plants in presence of a N-supply as nitrate or urea in deposits in the soil or as foliar fertilization

Between the centers of the synthesis of carbohydrates and organic N-compounds within the extended leaves of the shoot, the source, and the carbohydrates and organic N-compounds consuming centers as the growth of the shoots and roots including the storage of assimilates in grains, tubers, beets or fruits as sinks there exists a orientated source/sink-incline and a hierarchy between these sinks according to their succession within the stream of assimilates and their intensity as a sink, fig.: 2.

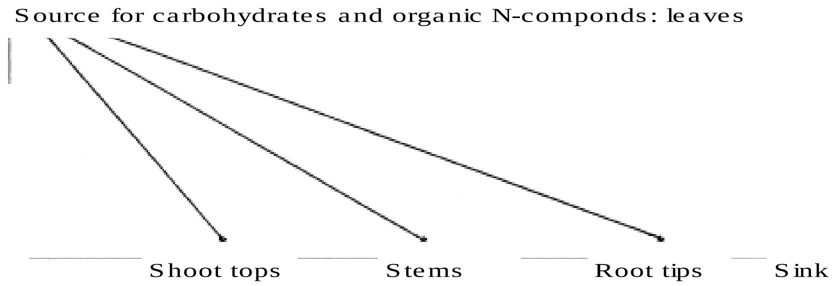


Fig.: 2 Source / sink-incline of the assimilates and the hierarchy of the sinks within plants in case of a N-supply as nitrate or urea in deposits in soils or as foliar fertilization

According to Marschner, 1995, the intensity of the transport of assimilates from the sources to the sinks within the plants considerably depends on the speed of the loading and unloading of assimilates into the phloem-stream, which is controlled by phytohormones. Deficits in the regulation of growth of the plants to a certain extend are based on inadequacies in the N-supply in respect to the amounts applied and the kind of their splitting, the course of their effectiveness and the height of their efficiency or in the not foreseeable course of the weather. These factors, which cannot be controlled are corrected by spraying appropriate active substances, for example CCC to control elongation of cereals and to stabilize their stalks against logging.

The hierarchy of the sinks in their relation to the source, as for example the supply of the shoot with assimilates as compared to the roots, accompanied by shifting in the equilibrium between the phytohormones in the plants according to the preferred synthesis of phytohormones in specific centre of growth of the plants, do not find resonance in discussions of the common tenet. This is based on the fact, that the existing hierarchy is considered as given by nature. The same holds trure for the alternate relationships between the source and the sinks. To exhaust the potential of yield formation of plants not only the capacities of the sinks of the plants but also the intensity of the attraction of assimilates at least must correspond to the potential of their source, when possible exceed this. Losses of assimilates by unproductive respiration or the restraint of the photosynthesis by the deceleration of assimilates in the leaves in dependence on the course of the weather are well known examples, Marschner, 1995.

2.2 Source / Sink-relationships within the „CULTAN“-system

The basis of the „CULTAN“-system is the change of the N-supply of the plants from the so-called well compatible nitrate to the so-called high phytotoxic ammonium. To overcome the phytotoxicity, ammonium is placed in the soil in wide-tracked line- or point-like-deposits in the root area of the plants. In these suppositions ammonium is an absolutely stable N-source without any losses of nitrogen by leaching or denitrification. At the same time ammonium is a well compatible nitrogen source to the plants, attracting very actively roots. Because of it's high phytotoxicity in deposits, ammonium by the plants is taken up controlled and assimilated according to the intensity of growth. The use efficiency is higher than 90%, fig.: 3.

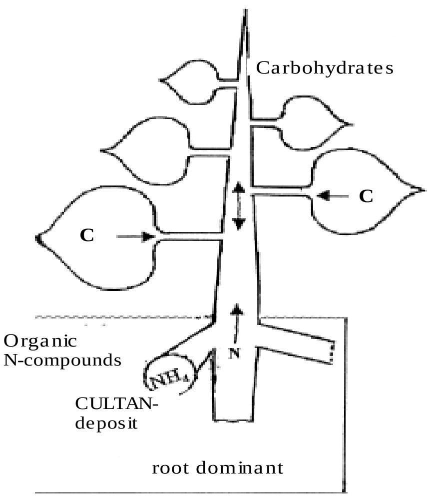


Fig.: 3 Root systems and source / sink-relationships in plants in presence of a N-supply as „CULTAN“

Although ammonium is phytotoxic according to the common tenet, the phytotoxicity is a prerequisite for the nitrogen nutrition of plants according to the „CULTAN"-system, where nitrogen is taken up by the roots according to the intensity of growth. This is the content of the term „CULTAN":

„Controlled **U**ptake **L**ong **T**erm **A**mmonium **N**utrition"

The intensive root growth on the surface of ammonium-deposits is based on the fact, that in these suppositions ammonium only can be taken up by the plants, when the respective tips of the roots as sinks are supplied sufficiently with carbohydrates by the shoot as the source, in order to assimilate the ammonium directly into the metabolism of the organic N-compounds. Root tips close to the surface of ammonium-deposits are earlier supplied with carbohydrates and organic N-compounds than any other plant organs to fulfill heterotrophic growth. For this reason, roots develop privileged as compared to the shoot.

Within the context of this essay it is important to realize, that plants supplied with N according to the conventional N-fertilization (top dressing; nitrogen available as nitrate) have the same source for carbohydrates and organic N-compounds in the extended leaves. However, in plants supplied with N according to the „CULTAN"-system the source is separated: 1.) the source of carbohydrates in the area of the extended leaves of the shoot and 2.) the source of the organic N-compounds in the tips of the roots on the surface of the „CULTAN"-deposits. Therefore, in these suppositions the streams of assimilates of carbohydrates and organic N-compounds are not flowing parallel like in plants with a conventional N-supply, fig.: 2, but in opposite directions to each other, fig.: 4. In which respect in these suppositions the transport of assimilates in the plants still at least can be explained by the pressure-theory of Münch, 1930, has to be proved. Furthermore it seems to be necessary to evaluate the hierarchy of the sinks in their relation to the sources and the reactions on the growth and the development of the plants in connection with a supply of nitrogen as ammonium by the „CULTAN"-system, fig.: 4, as compared to the supply of nitrogen as nitrate by conventional systems of fertilizer application, fig.: 2.

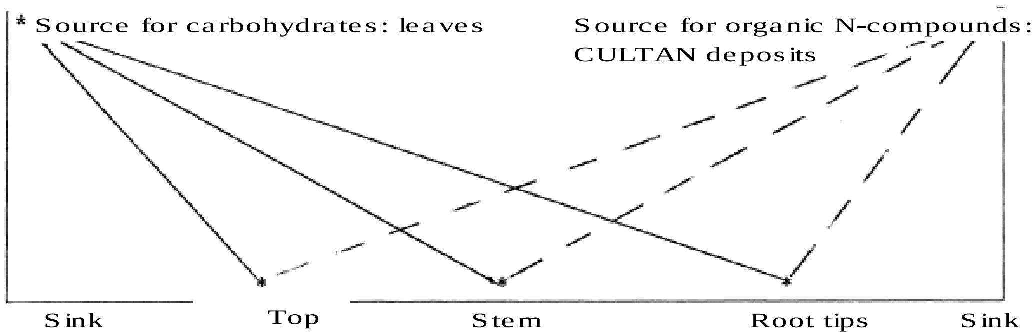


Fig.: 4 Source / sink-incline of the assimilates and the hierarchy of the sinks within plants in case of a N-supply as „CULTAN“

In case of the conventional N-supply as nitrate the hierarchy from the source to the sinks in the plants follows the scheme: top of the shoot > stem > roots. Because of the translocation of organic N-compounds into new growing organs of the shoot in cereals and grass this hierarchy is connected with a relative early physiological aging at the basis of the stems as well as of the roots and a short period of time of the maturing of the ears, fig.: 5.

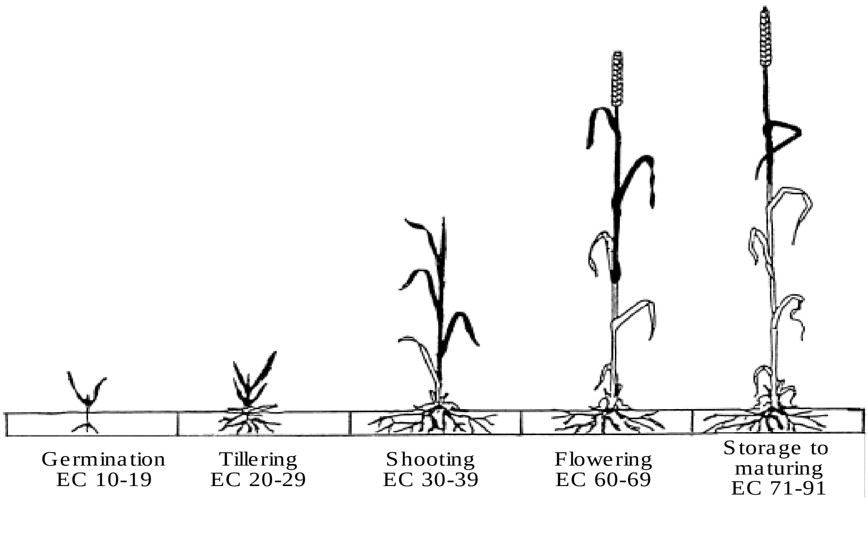


Fig.: 5 Storing and translocation of assimilates in the stalks of cereals during different stages of growth by a N-supply as nitrate, Bracht, 1998

In the „CULTAN“-system this hierarchy from the source to the sinks in plants supplied with nitrogen as nitrate only can be transferred to the metabolism of carbohydrates, but not to the metabolism of the organic N-compounds. In this case the hierarchy from the source to the sinks runs in the opposite direction of the flow of the carbohydrates from the tips of the roots close to the surface of the „CULTAN“-deposits > to the roots in general > to the stem > to the top of the shoot, sufficiently fig.: 4. In cereals this opposite run of the hierarchy from the sources to the sinks in case of the carbohydrates and the organic N-compounds as compared to a supply of nitrogen as nitrate is connected with a distinct delay in the secondary translocation of the organic N-compounds from older parts of the plants to growing organs of the shoot. This restrain is accompanied by a delay in the physiological aging of the basis of the stalks and the roots, resulting in a prolonged time of maturing of the ears, fig.: 6.

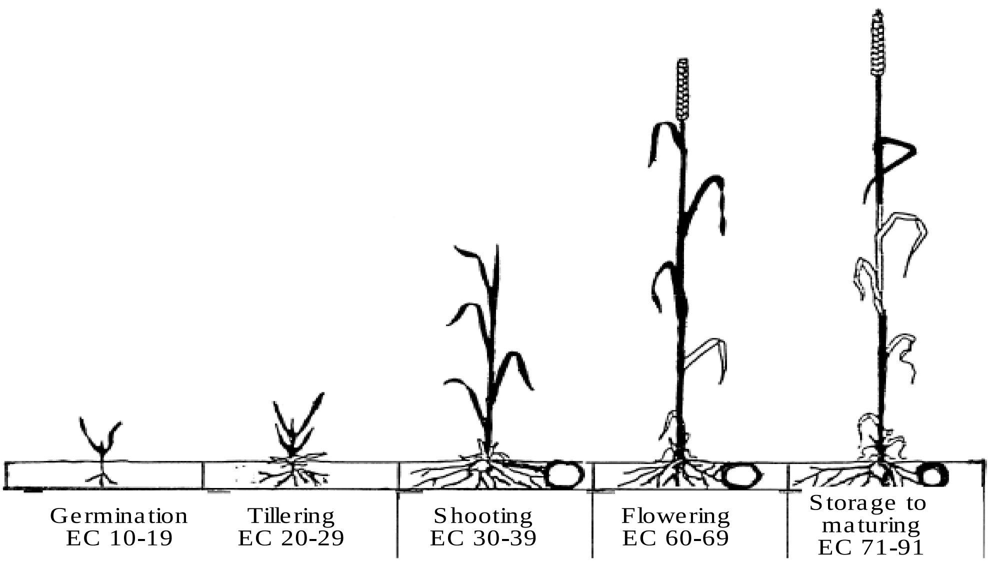


Fig.: 6 Storing and translocation of assimilates in the stalks of cereals during different stages of growth by a N-supply as „CULTAN“, Bracht, 1998

The reason for this reduced secondary translocation of organic N-compounds may be next based on the fact, that in the „CULTAN“-system the reduction of nitrate in the full extended leaves as a stimulating process for the secondary translocation of organic N-compounds is missing. Furthermore, because of the omission of the phloem by the continuous transport of organic N-compounds from the roots into the direction of the top of the shoot, the necessary incline to the sink is missing. Finally during the stage of the grain formation and their maturing there exists a separation in between the secondary translocation of the assimilates stored within the stalks during the period of vegetative growth, the upper part to the ears and the lower to the roots.

This altogether means that in case of a N-supply as „CULTAN“ the dominance of the shoot as sink as compared to the stem and the roots by a conventional N-supply as nitrate is broken and replaced by the dominance of the roots as compared to the stem and the top of the shoot. In these suppositions the course of transport of the assimilates as carbohydrates runs from the shoot to the roots in opposite direction of the transport of the assimilates of organic N-compounds from the roots to the shoots. Both, the carbohydrates and the organic N-compounds are essential for heterotrophic growth. They are not only the supposition for a development of the plants in harmony and the formation of high yields but in cereals also the basis of a distinct increase of the resistance against fungus diseases as „take all“ was observed. This shift in the source / sink-relationship in case of a N-supply as „CULTAN“ as compared to nitrate specially is confirmed by maize. In the case of a N-supply as „CULTAN“ root growth is improved distinctly and in presence of sufficient sun radiation quite easy a second cob per plant can be induced and even filled, fig.: 7.

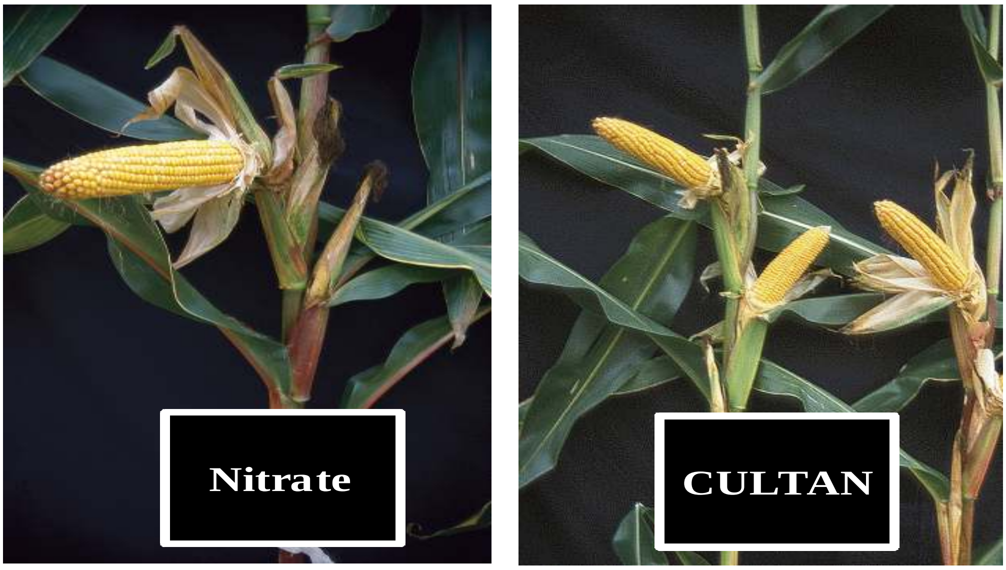


Fig.: 7 Inducing a second cob in maize as depending on the N-supply as nitrate or „CULTAN“

3. Phytohormones: synthesis, equilibria and regulator of actions

3.1 Phytohormons in regulation of growth and yield formation

According to the common tenet growth, development and the metabolism of plants is controlled by the signals of following phytohormones: Cytokinin (Cyt), Gibberellin (GA), Auxin (AUX; e.g. IAA) und Abszissin (ABA). The organs of the plants, where these phytohormones predominantly are synthesized, their transport within the plants as well as their kind of action are listed by Marschner, 1995, tab.: 1.

Cytokinins (CYT)

Bioynthesis: In root meristems

Prevailing long-distance transport: Via xylem from the roots to the shot

Effects: Cell division and expansion; stimulation of RNA and protein synthesis; delay in protein degradation and senescence; apical dominance

Substitutes: Benzyladenin

Gibberellins (GA)

Biosynthesis: Expanding leaves and shoot apex

Effects: Cell expansion; breaking of dormancy of buds; induction of flowers

Antagonistes / inhibitors: CCC, Triazoles and other synthetic compounds

Auxins (AUX; e.g. IAA)

Biosynthesis: Meristems or young expanding tissues

Prevailing transport: Basipetal from cell to cell

Effects: Cell expansion and division, apical dominance; induction and activation of enzymes

Antagonistes / inhibitors: ABA, TIBA, NAA and other synthetic compounds

Abscisic acid (ABA)

Biosynthesis: Fully differentiated tissues of shoots and roots

Effects: Inhibits cell extension in shoot tissue; induces stomatal closure; increases membrane permeability

Antagonistes / inhibitors: IAA; CYT; GA and other synthetic compounds

Tab.: 1 Main sites of biosynthesis and major effects of phytohormones, Marschner,

1995

The gibberellins and auxins, the phytohormones for the elongation of cells, predominantly are synthesized in the shoot and the cytokinins as phytohormones for cell division predominantly are synthesized in the meristemes of the roots, Marschner, 1995. Although the steering of growth and development of plants by phytohormones is manifested genetically, the equilibrium between phytohormones is depending on the growth promotion of the respective organs where they are synthesized. This process depends on the growth of the corresponding organs of the plants in which the phytohormones are synthesized predominantly. This means that the intensity of a signal of a phytohormone, finally its effect on the growth and development of plants depends on its concentration in relation to the other phytohormones present. For this reason finally the equilibrium of phytohormones is decisive for growth and development of plants. These on their part depend on the growth and development of the organs of their synthesis within the plants, which particularly is of importance for the relationship between the auxins and gibberellins as compared to the cytokinins. Therefore the effect of the steering of the growth and yield formation in plants by phytohormones substantially depends on the form of N-mineral-fertilizers and their kind of application. Within the plants the different N-forms influence the growth of the shoots or the roots specifically and because of this just as well the synthesis of phytohormones, tab.: 2.

1. In cereal plants nitrate in the soil or from top dressing specifically promotes the tillering of the plants and less intensive than urea the growth of the shoots as compared to the roots. Because of this the synthesis of auxins and gibberellins is promoted as compared to cytokinins, the so called „shoot dominating growth II. class“, fig.: 8.
2. In cereal plants urea in a deposit in soils or applied as foliar application promotes more intensively than nitrate specifically the growth of the shoots as compared to the roots. Because of this the synthesis of auxins and gibberellins is promoted as compared to cytokinins, the so called „shoot dominating growth I. Class“.
3. In cereal plants ammonium applied as „CULTAN“ in the soil specifically promotes the growth of the roots as compared to the shoots. Because of this the synthesis of cytokinins is promoted as compared to the auxins and gibberellins, the so called „root dominating growth“, fig.: 8, see also Knittl and Mannheim, 2002.

Tab.: 2 Synthesis of phytohormones in cereals as depending on the N-forms available in mineral fertilizers and the kind of their application

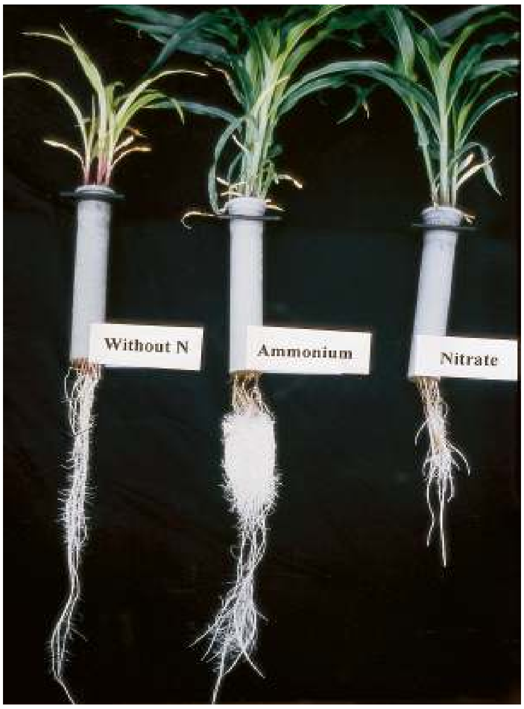


Fig.: 8 Promoting the growth of shoots and roots in maize as depending on the available N-form nitrate or ammonium as „CULTAN“

Between the auxins and gibberellins synthesized in the shoot and the cytokinins synthesized in the root tips of a cereal plant interrelationships are existing, which are changing from the period of the vegetative to the generative growth according to the stage of the development. Therefore a balanced steering of the growth of cereals by phytohormones cannot be reached by a N-supply as nitrate in splitted applications or urea in deposits or as foliar fertilization, because both N-forms cannot be taken up or assimilated in a controlled way. This is only possible by a controlled N uptake of plants fed according to the „CULTAN“-system, as system with an „ad libitum“ N-supply during the whole period of vegetative growth, but exhausting at the time of harvesting or maturing, guarantees a balanced N-supply of the whole plant. The same holds true for plant growth in total as well as for balanced phytohormone equilibrium in their metabolism, which during the time of growth corresponds to their actual stage of development fig.: 9.

Fig.: 9 Growth and development of winter-barley in pot experiments as depending on the available N-form nitrate or ammonium as „CULTAN“ and the time of N-fertilization, Sommer and Six, 1982

N-form	Date of fertili-zation	Yield in g/pot				Ears/pot	Grains in g per ear	Blade in cm
		Grains	s_x	Straw	s_x			
NO_3	04. 02. 75	89,9	2,6	105,9	3,0	80	1,12	95
NH_4 - C*		97,3	4,6	99,2	3,4	76	1,28	90
NO_3	03. 04. 75	93,3	1,0	98,1	3,8	72	1,30	90
NH_4 - C**		102,4	1,2	98,2	3,4	73	1,40	88

C* = „CULTAN“ at full growth / C** = „CULTAN“ at hidden N-deficiency

Tab.: 3 Influence of the available N-forms nitrate and ammonium at the time of N-fertilization an yield of winter-barley in pot experiments, Sommer and Six, 1982

Fig.: 10 Influence of the available N-forms nitrate and ammonium at the time of N-fertilization on growth and development of winterbarley in field experiments, Sommer and Six, 1982

In practice this opinion is certified by the conventional procedures of N-fertilization with the regulation of the growth of cereals by splitted N-applications. This splitting lately happens for to restrict the elongation of the stalks and by this to restrict the synthesis of auxins and gibberellins as compared to the synthesis of the cytokinins by periodic hidden N-deficiency. At the same time the growth of the roots as compared to the shoots is favored and because of this the synthesis of cytokinins as compared to auxins and gibberellins relatively increased. For this reason the growth of the stalks of cereals cannot be regulated sufficiently, so in addition to this growth regulators are sprayed for to shorten the stalks. However, the effectiveness of these sprays is time-limited and they are not necessary in case of a N-fertilization according to the „CULTAN"-system. In this system these sprays may be even wrong, because the shortenings of the stalks may be too strong and be accompanied by yield depression, Roperia, 1998.

Not only growth regulation by phytohormones and yield formation of cereals are very complex, but also growth itself, which is regulated by continuous changes in the hormone synthesis, depending on the right intensity at the right time according to the stage of the development of the plants and the climatic conditions. Such complex processes as the control of growth and development of cereals by phytohormones, influenced by the environment, the kind and variety of the cereal, the delivery of NO_3-N from the soil, the climatic conditions etc., cannot be optimized by periodic sprays on the leaves but only by the metabolism of the plant itself in presence of a nitrogen supply by the „CULTAN"-system, as the structures of yields in winter-wheat are showing, tab.: 4.

N-fertilization			Grains		Flag-leaves
N-form	kg N/ha	dates	dt/ha	tsw in g	length in cm
NH_4NO_3	150	3 x 50	85,7	47,6	17,1
NH_4NO_3	200	4 x 50	81,1	43,3	18,9
NH_4NO_3	250	5 x 50	75,6	41,3	19,0
NH_4-C*	150	22. 03. 1974	83,3	42,0	21,2
NH_4 -C*	200	22. 03. 1974	78,1	39,3	21,4
NH_4 -C*	250	22. 03. 1974	74,7	39,7	21,3
NH_4 -C**	150	11. 04. 1974	85,3	42,7	21,3
NH_4 -C**	200	11. 04. 1974	84,2	41,2	23,9
NH_4 -C**	250	11. 04. 1974	84,2	42,7	23,7
Urea-deposit	150	22. 03. 1974	80,0	41,7	19,7
Urea-deposit	200	22. 03. 1974	73,0	35,7	21,9
Urea-deposit	250	22. 03. 1974	67,4	36,4	20,4
GD = 5%			3,1	3,7	3,5

C* = „CULTAN“ at full growth / C** = „CULTAN“ at hidden N-deficiency

Tab.: 4 Size of flag-leaves and the stability of the yields in w-wheat influenced by the available N-forms, the height of the N-applications and the time of the N-fertilizer treatments in field experiments, Sommer and Rossig, 1978

3.2 Regularities of the phytohormonal regulation of plant growth

According to the literature the growth and development of plants is controlled by phytohormones. This statement as the tenet is completely accepted, Michael and Beringer, 1980, Davies, 1990. However, the reports about the regularity of these controls by phytohormones in dependence of the metabolism of assimilates in the plants and the mineral N-fertilization are very scarce. This may be contributed to the fact, that the metabolism of assimilates as well as mineral N-fertilization influence the behavior of cereales according to the growth of the shoots and roots or special organs like the ears or flag leaves. Also the specific extend of the synthesis of different phytohormones, connected by remarkable repercussions to the source-/sink-relationships of the metabolism of assimilates in dependence to the mineral N-fertilization is not realized. It seems to be that this behavior in research is based on the supposition, that because of nitrification processes in the soils finally nitrate is the N-form available to plants. In modern developments in the mineral N-fertilization techniques this not is the case.

Own investigations on the mineral N-fertilization with the most important N-forms: ammonium as „CULTAN", nitrate and urea as well as their mixtures have shown, that the growth of the shoots and roots of cereals and because of this also the control by phytohormones, by nitrate and urea as the available N-forms in the tendency is influenced negativly as compared to ammonium as „CULTAN" in the tendency positive in growth, yield formation and plant health. In general it was found, that nitrate and urea promote the growth of the shoots as compared to the roots specifically. Because of this the equilibrium of phytohormones are shifted to favor the auxins and gibberellins as compared to the cytokinins. The plants in their behavior of growth are impressed „shoot dominant". On the other hand by ammonium as „CULTAN" the growth of the root systems is promoted specifically as compared to the growth of the shoots. Because of this the equilibrium of phytohormones are shifted to favor the cytokinins as compared to the auxins and gibberellins. The plants in their behavior of growth are impressed „root dominant", Sommer, 2005.

Behind of these mineral N-fertilizers with single N-forms, ammonium, nitrate or urea there exist interrelationships in crops in between these N-forms, ammonium + nitrate, ammonium + urea, etc. and the growth of the plants. These interrelationships become relevant, when different forms of mineral N-fertilizers are applied simultaneously or one following the other and are taken up by the plants and metabolized in the concomitant form. In cereals for example, where these factors for their development are of special importance, these interrelationships are explained in tab.: 5.

1. According to their growth germinating cereals are so called „root dominant“, because the beginning of the growth of the shoots starts after the development of the primary roots. During further growth cereals remain „root dominant“ as long as its N-supply is covered by ammonium. In summer-cereals this holds true, when the „CULTAN“-fertilization is applied at sowing time. When young cereal crops cover their N-supply by the nitrate reserves of the soil, like winter-cereals sown in fall, then its habitus changes from „root dominant“ to „shoot dominant“ of growth.

2. So called „root dominant“ cereals will only be transformed to „shoot dominant“ growth by nitrate, when ammonium as N-source is exhausted. In the case that both N-forms are taken up by cereals at the same time, as compared to nitrate ammonium is privileged assimilated in the metabolism of the organic N-compounds and the growth of the cereals remains „root dominant“. In spite of this it has to be taken in account, that nitrate as osmotic regulator will be enriched in the plants. As such nitrate is a factor that reduces resistance against frost and dryness as well as increases susceptibility as compared to fungus diseases.

3. So called „root dominant“ cereals will be transformed to „shoot dominant“ growth by urea. This also is the case, when urea and ammonium are available to the plants at the same time and the concentration of ammonium is not high enough, to control the intensity of uptake of urea by its phytotoxicity. This behavior is based on the fact, that after uptake urea reaches the shoots of the plants by the transpiration stream, where it is converted into the metabolism of organic N-compounds. Because of exhausting the carbohydrates in the shoots by the assimilation of urea the uptake of ammonium is prevented and the growth of the roots as compared to the shoot is restricted.

Tab.: 5 Interactions between N-forms: ammonium as „CULTAN“, nitrate and urea as mineral fertilizers and „shoot-/root-dominanting“ character of the growth of cereal plants

4. „Shoot dominant“ stamped cereals by ammonium as „CULTAN“ only can be protected against the increase of „shoot dominant“ growth by nitrate. The transformation of „shoot dominant“ growth into „root dominant“ of cereals is possible, when the „shoot dominant“ N-supply by nitrate is exhausted and in the stadium of tillering until to the beginning of elongation because of hidden N-deficiency a shifting in the relationship of the shoot to the roots takes place in favor of the roots. This shifting in the relationship of the shoot to the roots at the beginning of elongation of cereals during full growth is attainable by cutting the plants above the primordia of the ears. In dicotyledones, for example winter-rape, these cuttings for the shifting in the relationship of the shoot to the roots can be compensated by the freezing of the leaves during winter time. In all of these situations plants fertilized after the „CULTAN „root dominant“ plants will develop. Plants will grow with high resistance against logging, frost, dryness and fungus diseases and very good dispositions for the development of ears or pods.

5. By a N-supply with nitrate or urea „shoot dominant“ stamped cereals are restricted in their „shoot dominant“ growth by splitted N-applications, because in periods of hidden N-deficiencies in between the N-applications the growth of the roots is relatively less restricted as compared to the growth of the shoots. Therefore the „shoot dominant“ growth of cereals is periodically changed to „root dominant“ growth, if the N-fertilization in splitted in several applications.

6. „Shoot dominant“ induced growth of cereals by nitrate nutrition will be strengthened by urea, because urea has to be assimilated by cereals in the metabolism of organic N-compounds in the shoot after its uptake by the stream of transpiration. Because of the metabolism of organic N-compounds will be exhausted at the same time the reduction of nitrate will be stopped and available nitrate be accumulated within the plants.

Tab.: 5a Interactions between N-forms: ammonium as „CULTAN“, nitrate and urea as mineral fertilizers and „shoot-/root-dominanting“ character of the growth of cereal plants

4. Regulation of source-/sink-relationships in crops by the „CULTAN“-System

The N-supply by the metabolism of carbohydrates and organic N-compounds as well as by the hormonal control of the growth and development interferes in the interrelationships between sources and sinks of plants. This especially is true in case of a N-supply by the

„CULTAN"-system, where the beginning of the synthesis of carbohydrates in the shoot is separated from the beginning of the synthesis of the organic N-compounds in the tips of the roots in the vicinity of the surface of „CULTAN"-deposits, fig.: 3. The aim in crop production should be, to take these interrelationships into account according to simple rules and direct these to optimize yields as well as quality. In the „CULTAN"-system this in general should be considered for a compact growth of the plants with relative high contents of dry matter, high density in the chlorophyll in the leaves and very good developed root-systems as compared to plants fertilized as common. In total in the „CULTAN"-system healthy and strong crops develop with high efficiency in assimilation, high stability in the stems and increased resistance against dryness and infections by fungus diseases. In spite of this also in the „CULTAN"-fertilization to the crops related rules have to be considered, when potentials of yields present shall be exhausted. In cereals this is the case as follows:

Because of the delivery of nitrate from the soil or a conventional N-fertilizer application by topdressing in fall the kind of growth shaped „shoot dominant" of winter-wheat cannot be changed to „root dominant" growth by „CULTAN"-fertilization alone. In these suppositions winter-wheat will continue with a „shoot dominant" growth. A change of the winter-wheat to „root dominant" growth is only possible, when winter-wheat grows into hidden N-deficiency at the stage of tillering, EC 29 to 31 before the „CULTAN"-fertilization, the, tab.: 3 and 4, fig.: 9 and 10, or in case of intensive growth at the beginning of shooting, stage EC 31, by cutting the plants above the primordia of the ears, resulting in a change of the shoot-/root-relation by favoring of the roots, Viehausen, 1983.

With summer-wheat, where the „CULTAN"-fertilization is applied at sawing, the „root dominant" development is guaranteed because of the priority of the N-assimilation of ammonium as compared to nitrate. This is of special interest for areas of cold climates, Sommer, 2005.

In the tab.: 6 and 6a typical examples for the correct application of the „CULTAN"-fertilization in important agricultural crops are summarized.

Cereals

1. **Application:** The „CULTAN"-fertilization follows as point injection depending on the humidity of the stand about 5.0 to 10.0 cm deep into the soil in summer-cereals at sawing and in winter-cereals in spring at hidden N-deficiency of the plants.
2. **Fixing of the aim:** By a relatively good developed root systems as compared to the shoot the synthesis of cytokinins shall be optimized and by this the development of the primordia of the ears. For the increase of the stability behind a shortening of the stalks a remarkable reduce of infections by take all is expected. The storing of assimilates in the whole stalk shall be reached until flowering. This for their direct translocation into the ears and for a longer preservation of the function of the roots.

Maize

1. **Application:** After a DAP-side root dressing at sowing the „CULTAN"-fertilization follows at the beginning of growth of the third leave between every second row.
2. **Fixing of the aim:** The dominance of storing assimilates in the upper cob shall be broken, resulting in the filling of a second cob. By a better efficiency in the use of the yield potential per plant high yields shall be obtained with less plants per area with less water consume.

Winter-rape

1. **Application:** To reach a good development from the beginning of growth already at sowing time in late summer a remarkable amount of mineral N fertilizer is applied. After intensive growth in fall during winter time the leaves shall freeze to death down to the top bud of the plant. In the case of a mild winter the leaves should be cut above the top bud, to get "root dominant" plants. Early in spring N according to the „CULTAN"-fertilization is applied between every second row in a depth of 5 to 10 cm.
2. **Fixing of the aim:** Compact and healthy plants shall develop with a high density of pods on relatively short branches.

Tab.: 6 Optimization of the „CULTAN"-fertilization of different crops and their aims

Potatoes

1. **Application:** The „CULTAN"-fertilizer is applied at planting time as depending on the kind of soil, loam or sand, 10 to 15 cm underneath the planted potatoes.
2. **Fixing of the aim:** For the optimization of the microclimate within the crop and the resistance against dryness the growth of the shoot shall be restrained and that of the roots be promoted. By separating the beginning of the synthesis of carbohydrates in the shoot and the beginning of the synthesis of the organic N-compounds in the tips of the roots on the surface of the „CULTAN"-deposits besides an equal development of the tubers an early storing of starch shall be gained.

Sugar beets

1. **Application:** After spraying a fertilizer band (10 cm wide with 40 kg N/ha as ammonium x nitrate x urea - solution) at sowing time, the „CULTAN"-fertilization is applied between every second row, about 15 cm deep into the soil at the development of the third leaf.
2. **Fixing of the aim:** For the optimization of the microclimate within the crop and the resistance of the beets against dryness the growth of the leaves shall be developed in upright standing position and that of the roots be promoted. By separating the beginning of the synthesis of carbohydrates in the shoot from the beginning of the synthesis of the organic N-compounds in the tips of the roots on the surface of the „CULTAN"-deposits besides an early development of the beets an early storing of sugar shall be gained.

Meadows and pastures

1. **Application:** The „CULTAN"-fertilization shall be applied by point injection 5 to 10 cm into the soil after every period of grazing or after every cutting of the grass.
2. **Fixing of the aim:** For to optimize the microclimate in the crop upright standing, sappy grass with very low nitrate contents, high energy contents and only small infections by fungi from the basis to the top shouldl be grown from early in the spring until late in fall. The portion of clover in the whole crop should be about 30%, to raise the flavor of the fodder and by a raised uptake of fodder to increase the result in animal husbandry.

Tab.: 6a Optimization of the „CULTAN"-fertilization of different crops and their aims

White cabbage

1. **Application:** After a DAP-side root dressing at planting the „CULTAN"-fertilization is applied in every second row in between, about 15 cm deep into the soil after the plants have started well to grow.
2. **Fixing of the aim:** Compact and strong heads of high quality shall be grown without browning spots inside. Furthermore the size of growth of the outside leaves shall be reduced remarkable to minimize the losses of water by transpiration and the plant residues in the field after harvest as well.

Fruit trees

1. **Application:** The „CULTAN"-fertilzation is applied directly after flowering into permanent deposits of a depth of 20 cm in the middle of every second interval between two trees.
2. **Fixing of the aim:** By the specific promotion of the development of the roots and stems healthy plantations with high resistance against dryness will be grown. In apples in combination with the application of gypsum the problems with bitter pit shall be solved. Furthermore it will be tried to overcome the changing of fruitening of trees in different years .

Tab.: 6 b Optimization of the „CULTAN"-fertilization of different crops and their aims

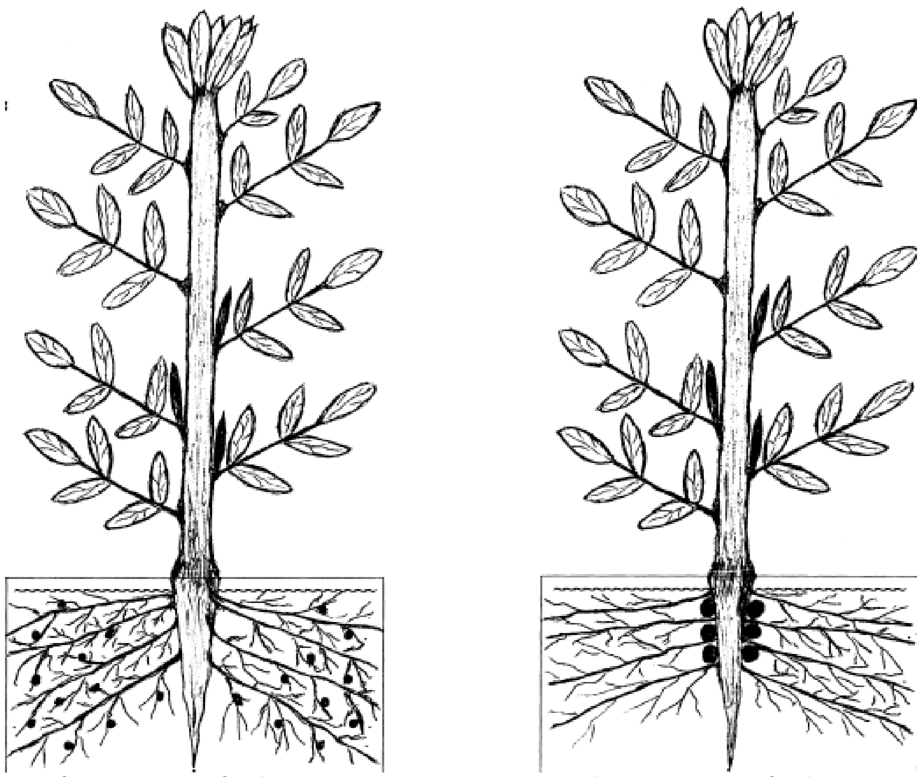
5. The enigma of legumes in „CULTAN"-systems

5.1 Source / Sink-relationships in legumes in „CULTAN"-Systems

Legumes as monocultures are important field crops and as mixed cultures with non-legumes like clover and grass in pastures and meadows.

N_2 fixation of legumes, which can cover their N demand by the symbiosis with rhizobia, is remarkably limited by the available nitrate in the soil, Münch, 1996. In case of sufficient N-supply as nitrate from N delivery of the soil or from N-fertilization the development of root nodules as shown with faba beans (*Vicia faba minor* L.) is reduced, accompanied by a lower N_2 fixation rate. It is assumed that nodules are not supplied sufficiently with carbohydrates because of the growing shoot is a dominating sink for carbohydrates.

In contradiction in the „CULTAN"-system legumes fix their nitrogen by themselves. Caused by the absence of nitrate, the dominance of growth of the shoot as compared to the supply of the roots with carbohydrates is broken. Because of the optimum supply with carbohydrates from the stem roots of faba beans are highly infected by rhizobia. In the presence of limited resources of nitrate in the soil or in case of a N-start-fertilization at sowing, nodule infections are observed on the fine roots. When carbohydrates are delivered by the shoot the rhizobia on the main roots as compared to those on the fine roots develop early as dominating sinks within the symbiosis. In these circumstances the fine roots are not sufficiently supplied with carbohydrates and therefore cannot take up ammonium from the surface of the „CULTAN“-deposits and assimilate it within the metabolism of the organic N-compounds, fig.: 11.



After an N-start-fertilisation or high NO_3 – delivery from soils by vicia faba small noduls are developed on the fine roots

Without an N-start-fertilisation and no NO_3 – delivery from soils by vicia faba big noduls are developed on the stem roots

Fig.: 11 Development of root nodules and N_2-fixation of Vicia faba minor L. dependent of the available N-forms as nitrate or ammonium as „CULTAN“

5.2 Balancing growth and yield formation by legumes in „CULTAN"-systems

The interrelationship between the nodulation for N_2-fixation and the „CULTAN"-fertilization of Vicia faba result in a stimulated growth of the shoot in comparison to the conventional cultivation. However, the intensive stimulation of growth may lead to a temporary crooking of the tops of the plants, a quite unnatural growth of branches and a tillering of shoots on the basis of the plants. This behavior is explained by the increased delivery of auxins by the rhizobia. Together with the cast off of flowers the potential of possible yields is reduced. fig.: 12.

Fig.: 12 The cast off of flowers and the development of branches and shoots by tillering by Vicia faba with high nodulation on stem roots for N_2-fixation

This explanation is certified by spraying Vicia faba with „Benzyladenin", a synthetic substitute of the phytohormone group of cytokinins. Spraying low concentrations of about

50 mg per liter at the time of the development of the first inflorescence can prevent such cast offs of inflorescences, fig.: 13.

Fig.: 13 Development of pods and the prevention of the cast off of inflorescences by Vicia faba with a high nodulation on the stem roots for N_2-fixation by a spray with Benzyladenin

This probably happens because of the retardation of carbohydrates in the leaves for a short period of time and the by this restricted activity of the rhizobia in the synthesis of auxin. It seems to be that by this the delivery of high concentrations of auxin to the host plant is restricted, Sommer, 2005.

In pastures favorable relationships between grass and clover can be adjusted by a N-fertilization according to „CULTAN“. A suppression of the clover by grass as common will not occur. As compared with grass monoculture high yields of better tasting fodder and richer in minerals can be grown in mixed stands. Furthermore N_2-fixation by clover results in remarkable savings of mineral N-fertilizer, Sommer, 2005.

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