SEGES

CULTAN FERTILIZATION METHOD

STØTTET AF
Promilleafgiftsfonden for landbrug

Der er gennemført et studium af udenlandsk litteratur af virkning og effekt af CULTAN-gødskning (controlled uptake long-term ammonia nutrition).

DANSK SAMMENDRAG

Der er gennemført et studium af udenlandsk litteratur af virkning og effekt af CULTAN-gødskning (controlled uptake long-term ammonia nutrition). Ved CULTAN punktplaceres ammoniumgødning i depoter i 5-8 cm dybde i jorden med en specialnedfælder. Med CULTAN-systemet forsynes planterne med kvælstof i hele den vegetative vækstperiode, og det giver en afbalanceret N-forsyning. Omdannelsen af ammonium til nitrat sker kun ved grænserne af depoterne, fordi ammoniakkoncentrationen inde i depoterne er for høj til aktivitet af nitrificerende bakterier.

CULTAN gødskning nedsætter nitrificeringen, hvilket reducerer risikoen for kvæl-stoftab som følge af nitratudvaskning. Mange undersøgelser har fundet øget kornudbytte af CULTAN gødskede afgrøder i forhold til traditionel nitratgødskning. Det kan forklares ved et højere antal aks og større antal kerner pr. aks sammenlignet med konventionel gødskning. Der blev ikke fundet litteratur, som tyder på, at CULTAN har en positiv effekt på kornets proteinindhold.

THE CULTAN FERTILIZATION METHOD

In Germany, Sommer (2000) introduced the controlled uptake long-term ammonia nutrition (CULTAN) fertilization method for agriculture and horticulture. The term “CULTAN” is used because nitrogen (N) is taken up by the roots according to intensity of growth (Sommer and Scherer, 2009). The intension of CULTAN is to obtain a better N use efficiency and less N leaching by placing ammonium-based N fertilizer in highly concentrated depots in the soil, instead of using nitrate (Deppe et al., 2016).

In practice, CULTAN fertilization consists of injecting N in ammonium form into the root space of the plant, usually injected 7 to 20 cm deep in the soil near the crops to the seed or plant rows Kücke (2001), which results in higher stability of fertilizer in the soil due to the positive charge of ammonium and a high concentration of fertilizer in the root space of the plant Sommer and Scherer (2009). Once the ammonium-rich fertilizer is injected, it is retained in spots with high concentration of ammonium, referred to as depots (Kücke, 2001). These highly concentrated ammonium depots are stable against nitrification due to the toxicity of ammonium.

Ammonium is taken up by mesophyll cells evenly vs. a concentration gradient, where it then occurs in the millimolar range in the cytosol of healthy plant tissue (Schittenhelm and Menge-Hartmann, 2006). Overall, CULTAN-fertilized crops are healthy, strong and developing with high efficiency in assimilation, high stem stability and improved resistance against dryness and infections by fungus diseases Sommer and Scherer (2009).

CULTAN VS. CONVENTIONAL N-FERTILIZATION

Sommer and Scherer (2009) evaluated the storage and translocation of assimilates in the stalks of cereals during different growth stages within the CULTAN-system and how they differ from conventional N-fertilization. Compared to broadcasted N-fertilizer application, N-supply as nitrate by CULTAN fertilization results in fundamental differences in the storage and translocation of assimilations within the plants. These differences include the behavior of the plant growths, the plant's control by phytohormones, yield formation and resistance against fungus diseases (Sommer and Scherer, 2009).

In conventional N-fertilization, the translocation of organic N-compounds into new growing organs of the shoot in cereals causes relatively early physiological aging at the basis of the stems as well as the roots and a short period of time of the maturing of the ears (Figure 1). The ammonium-rich fertilizer of CULTAN causes high phytotoxicity in deposits that plants can take up, control and assimilate according to the intensity of plant growth. In CULTAN fertilized cereals, there is 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 (Figure 2). Therefore, the use efficiency of ammonium taken up by plants in a CULTAN-system is higher than 90% (Sommer and Scherer, 2009).

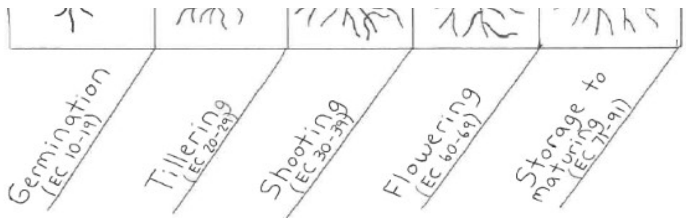

Figure 1. Storing and translocation of assimilates (highlighted in green) in the stalks of cereals during different stages of growth by an N-supply as nitrate.

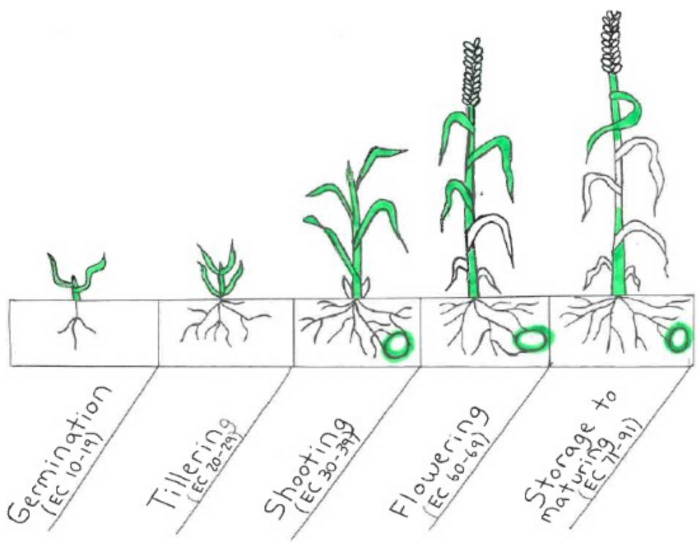

Figure 2. Storing and translocation of assimilates (highlighted in green) in the stalks of cereals during different stages of growth by a N-supply as “CULTAN”.

CULTAN-fertilized wheat plants take up most N in the ammonium form and can thus self-adjust its amount by spreading roots into the diffuse zones left after N was drawn from around the surface of depots (Kücke and Scherer, 2006). CULTAN fertilization is usually applied to winter wheat at the end of tillering, which is when the first symptoms of acute N deficiency are prevalent.

The application of CULTAN causes a shift of the ratio of roots and aboveground mass in benefit of roots, resulting in changes of hormonal balance in wheat plants (Kozlovsky et al., 2009). Sommer (2005) explains that this results in a slower growth of aboveground mass in the first half of the vegetation period. This is compatible with observations by Schittenhelm and Menge-Hartmann (2006) that slower early growth in the CULTAN treatment in spring barley, which they attribute to the increased time roots of distant plants to reach the soil zones containing the injected ammonium and start taking up the large amount of N necessary for rapid plant growth. Figure 3 demonstrates the growth of the shoots and roots depending on the different N-forms supplied to maize.

Figure 3. Growth of shoot and roots in maize depending on the available N-form nitrate or ammonium as CULTAN (Kücke M., 2001 and Sommer and Scherer, 2009).

In cereals, carbohydrates and organic N-compounds are not only essential for heterotrophic growth, but also known to increase resistance against fungus diseases. The shift in sink/source-relationship in CULTAN-fertilized plants, compared to nitrate, is confirmed in maize by Sommer and Scherer (2009). In the CULTAN-fertilized maize root growth is noticeably improved and, with plenty of sun radiation, the plant can easily grow a second filled cob (Figure 4) (Sommer and Scherer, 2009).

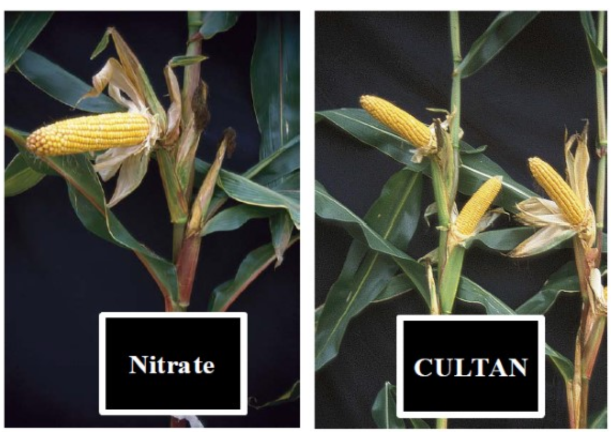

Figure 4. Induction of a second cob in maize depending on N-supply as nitrate or CULTAN (Sommer and Scherer, 2009).

NITROGEN UPTAKE, GRAIN YIELD AND NITROGEN USE EFFICIENCY RESPONSE TO CULTAN FERTILIZATION

In an article by Schittenhelm and Menge-Hartmann (2006), they discuss that the switch from nitrate to ammonium-dominated plant nutrition causes changes at the physiological and morphological level. Crop growth is affected by CULTAN fertilization due to the detoxification of absorbed ammonium in the roots by a downward directed flow of C-skeletons, which delays senescence of the lower leaves caused by the improved supply of chemical energy.

According to German farmers, CULTAN treatment to cereal crops cause smaller leaf blades and reduced stem length is reduced, compared with broadcasting N fertilizers, which may affect crop yield by modifying light absorption, leaf photosynthesis and harvest index (Schittenhelm and Menge-Hartmann, 2006).

In the study by Schittenhelm and Menge-Hartmann (2006), they evaluated the effect of N-fertilizer regime on yield and yield components by growing barley in a vegetation hall, at the Institute of Crop and Grassland Science in Braunschweig, Germany, in sandy loam topsoil, sub-soil loam and sand in three different treatments: (1) a control without N-fertilizer '-N' (2) 3 g NO_3-N per container as calcium nitrate incorporated into the soil as a shallow depth before sowing and (3) 3 g NH_4-N per container as diammonium phosphate (DAP) injected 7-cm depth when the barley plants were in the two-leaf stage.

They observed a 20% higher grain yield than in the NO_3-N treatment as well as greater grain dry weight, more ears per plant and more grains per ear (Table 1). The NH_4-N treatment had a significantly higher N harvest index, however, the plants in the NO_3-N treatment had significantly higher straw N-concentration than the other treatments (Table 1).

Table 1. Effect of N-fertilizer regime on yield and yield components of Maresi spring barley grown in containers[1].

	N treatment					
Parameter	**-N**	**SD3**	**NO3-N**	**SD3**	**NH4-N**	**SD3**
Grain DW (g per plant)	1,31	a	2,35	b	2,83	c
Straw DW (g per plant)	1,51	a	2,35	b	2,49	b
Harvest index (%)	46,4	a	50,1	b	53,1	c
Ears per plant (n)	1,84	a	2,96	b	3,33	c
Grains per ear (n)	17,4	a	18,1	b	19,2	c
DW per grain (mg)	41	a	44	a	44,4	a
Grain Nconcentration (mg g^{-1} DW)	11,6	a	15,7	b	15,9	b
Straw N concentration (mg g^{-1} DW)	3	a	4,5	c	3,9	b
N harvest index (%)	77	a	77,9	a	82	b
N uptake (mg N per plant)	19,7	a	47,2	b	54,9	b
N utilization efficiency (g g^{-1})	66,5	b	49,9	a	51,8	a

[1] Reproduced from Schittenhelm and Menge-Hartmann (2006)

[2] Data is based on 40 plants sampled in the harvest ripe stage

[3] Significant difference

Since this study, there have been numerous studies focusing on the N uptake, grain yield and N use efficiency response to CULTAN fertilization. Deppe et al (2016) performed a two-year field study, in Germany, where they analyzed the dynamics of mineral N in soils after injection of ammonium sulfate solution (CULTAN) compared to conventional surface application of the same fertilizer type (ammonium sulfate at a rate of 130 kg N ha^{-1}) to winter wheat in loam and sandy loam soils. They found higher yields and a greater N uptake in the CULTAN plots, compared to surface application (Table 2). Grain yields in the loam site in 2011 and at the sandy loam site in 2012 were significantly higher in the CULTAN plots.

Table 2. Grain yields, N use efficiency and N content in aboveground biomass[1].

Treatment	Grain yield				N uptake3			
	(t d.w. ha-1)				(kg N ha-1)			
	2011	SD[2]	2012	SD[2]	2011	SD[2]	2012	SD2
Loam site								
Unfertilized	3,47 ± 0,34	bc	4,21 ± 0,55	bc	54,1 ± 5,3	ab	55,3 ± 6,5	ab
Surface application	4,43 ± 1,06	bc	7,06 ± 0,49	de	87,3 ± 23,1	bc	170,5 ± 22,7	e
CULTAN	6,12 ± 0,83	d	7,32 ± 0,25	e	120,9 ± 26,6	cd	145,7 ± 30,2	de
Sandy loam site								
Unfertilized	1,38 ± 0,63	a	1,17 ± 0,11	a	31,3 ± 6,2	a	24,8 ± 2,8	a
Surface application	3,39 ± 0,64	b	4,86 ± 0,56	c	110,6 ± 17,8	cd	98,3 ± 8,5	bc
CULTAN	4,20 ± 0,38	bc	6,34 ± 0,34	de	116,9 ± 15,4	cd	122,5 ± 8,5	cd

[1] Reproduced from Deppe et al (2016)

[2] Significant difference

[3] N uptake is the amount of N in aboveground plant biomass (grains and straw) at harvest

Deppe et al (2016)'s observations are consistent with Sedlář et al (2011) in spring barley and Weber et al (2008) in winter wheat (Table 6). Controversially, Kozlovsky et al (2009) found that the average grain yield of winter wheat was lower in the urea ammonium sulphate (UAS) CULTAN treatment (8.78 t ha^{-1} in 2007 and 9.63 t ha^{-1} in 2008), compared to the calcium ammonium nitrate (CAN) control treatment (9.56 t ha^{-1} in 2007 and 9.91 t ha^{-1} in 2008). Kozlovsky et al (2009) contributes this significantly lower grain yield in 2007 to a negative influence due to drought. In the same experiments, they also observed a higher N content in grains of the control treatment, with the average N uptake at 183 kg N ha^{-1} at the control and 159 kg N ha^{-1} at CULTAN treatment.

Sedlář et al., 2013 found that N uptake in the plots with CULTAN-fertilized spring barley was more even during vegetation period, which they attribute to the delayed term of fertilizer application. However, contrary to the findings of Deppe et al (2016), Sedlář et al (2013) found no effect on grain yield, including no significant differences in N lost or gained at heading between conventional and CULTAN treatments in spring barley. Observations on the N use efficiency in studies consistently find no significant effect of CULTAN treatment on N use efficiency (Deppe et al., 2016 and Sedlář, et al., 2013).

PROTEIN CONTENT IN GRAIN OF CULTAN-FERTILIZED

PLANTS

In a study by Sedlář et al (2011), completed in the Czech Republic, they observed a lower protein content in grain of CULTAN-fertilized spring barley and Sedlář et al (2013) attributes this to a tendency to lower total N concentration in aboveground biomass at the beginning of heading. This is consistent with conclusions by Weber et al (2008), who also found that CULTAN-fertilized winter wheat, (CULTAN 180 kg N ha^{-1}), resulted to a significantly lower percentage of crude protein in grain compared to different conventional N fertilizer treatments, though grain yield was greater than in all other treatments, in both years (Table 6). Weber et al (2008)'s study was conducted at the University of Hohenheim, in Stuttgart, Germany, on a loess-derived soil with sugar beet as the previous crop.

Table 6. Grain yield and percentage of crude protein in grain and flour dependent on fertilization of winter wheat in the years 2004 and 2005[1].

Treatment	**Crude protein grain**		**Crude protein flour**		**Grain yield**	
kg N ha-1	%		%		**dt ha-1 DM**	
	2004	2005	2004	2005	2004	2005
Control 0	9,03	9,6	7,03	7,19	45,9	41,6
CAN 180[2]	14,6	14,71	15,39	15,47	73,9	75,9
CAN 180 + S[3]	15,02	15,45	16,07	15,75	74,5	76,4
CULTAN 180	12,55	13,27	11,78	11,67	85,8	82,5
Urea 180	13,74	15,25	14,03	14,76	77,1	72,0
UAN[4]	11,03	19,06	9,2	11,24	66,8	69,5
Entec 26 180[5]	10,28	12,48	8,16	10,7	68,8	80,4
Liq. man. + CAN 180[6]	14,14	15,64	14,15	15,5	60,5	62,5

[1] Reproduced from Weber et al (2008)

[2] Calcium ammonium nitrate, broadcast application

[3] Calcium ammonium nitrate with sulfur applied as Kieserite: 25% MgO; 20% S

[4] Urea ammonium nitrate, first rate applied with ID-(Injector) nozzles, following rates as guided applications *via* drag hose

[5] Ammonium sulfate nitrate with supplemental nitrification inhibitor (3, 4 dimethylpyrazole phosphate, DMPP), broadly applied

[6] Liquid manure with calcium ammonium nitrate, application of liquid manure *via* splash plate

NITROGEN LOSSES FROM CULTAN-SYSTEM

Sommer 2009 claims that, in the CULTAN-system, ammonium placed in the root area of the soil in wide-tracked line or point-like-deposits is a completely stable N-source without any losses of N by leaching or denitrification. However, in a study by Deppe et al (2016) where they evaluated the impact of CULTAN fertilization with ammonium sulfate on field emissions of nitrous oxide (N_2O), they concluded that inhibition of nitrification in fertilizer depots after CULTAN fertilization was not strong enough to prevent nitrate accumulation in both loam and sandy loam soil.

The higher N_2O emission from the loam site was attributed to N_2O hotspots due to higher soil moisture, the tendency to establish denitrifying microsites in finer soil textures, along with patchy distribution of N_{min}, resulting in transient local N_{min} surplus. Schittenhelm and Menge-Hartmann (2006) emphasizes that the combination of a dense root network around the depots and adsorption of ammonium to the cation exchange sites, reduce the risk of N losses.

However, even when ammonium is injected in high concentration in soil, it is supposed that a certain proportion of ammonium is oxidized to nitrate in the border zones of the depots. This occurs because the concentration of the ammonium solution towards the border zones of the depots rapidly decrease that an inhibition of the nitrification does not begin. Furthermore, Kozlovsky et al (2009) concluded that by injecting ammonium solutions into soil to the depth of 3 cm, nitrogen losses by ammonia volatilization are reduced by 30% compared to surface application. It is thought that CULTAN fertilization may change nitrate leaching, which would then affect indirect N_2O emission, however insufficient literature was found regarding CULTAN fertilization's affect on nitrate leaching.

OPTIMIZATION OF CULTAN FERTILIZATION OF DIFFERENT CROPS

Table 7 is a summary of examples for the correct application of the CULTAN fertilization in common agricultural crops according to Sommer and Scherer (2009).

Table 7. Optimization different CULTAN-fertilized crops and their aims (Sommer and Scherer, 2009).

Crop Type	**Application**
Cereals	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.
Maize	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.
Winter-rape	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.
Potatoes	The "CULTAN"-fertilizer is applied at planting time depending on the kind of soil, loam or sand, 10 to 15 cm underneath the planted potatoes.

Sugar beets	After spraying a fertilizer band (10 cm wide with 40 kg N/ha as ammonium × nitrate × 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.
White cabbage	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.

CONCLUSION

In the CULTAN-system, N is supplied to the plants throughout the vegetative growth period, which guarantees a balanced N-supply of the entire plant. The change of ammonium to nitrate only occurs in the borders of depots because inside depots the ammonia concentration is too high for the activity of nitrifying bacteria. CULTAN treatments greatly decrease nitrification, which reduces the risk of N loss due to leaching. Many studies have found increased grain yield of CULTAN fertilized plants, which can be explained by higher number of spikes and greater number of grains per spike compared to conventional fertilization. Partial nitrification of the ammonium N in the depots appears to be required to obtain high crop yields. No literature was found regarding CULTAN having a positive effect on the protein content of plants. Literature suggests controversial results regarding detailed examination of the CULTAN method and, therefore, further analysis is required before specific usage in agricultural practice is recommended.

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