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Effects of precise fertilizer placement in corn

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Improving fertilizer efficiency requires revising established procedures and using new methods and procedures. Therefore, a system for the precise application of fertilizer in maize cultivation was developed and tested in the laboratory and in the field. This technical development was accompanied by manual field trials to test the relevance of this novel application method for crop production. Yield-neutral savings potential of up to 50% of the current starter fertilizer application by the more precise fertilizer application was shown. A significant yield increase (α < 0.05) of 6 to 7% was documented with the same fertilizer input. Based on the results of the agronomic field trials, a method for mechanically applying this precise fertilizer placement method was developed and validated.

Keywords
Maize sowing, starter fertiliser, fertilizer efficiency, field trials

The importance of nutrient efficiency in using fertilizers has increased significantly in recent years, and not only because of the reformed fertilizer ordinance. Despite reduced fertilizer application quantities, it is important to achieve or even increase yield levels. Furthermore, the use of plant protection products and fertilisers in modern agriculture is increasingly being discussed in society. The loss of acceptance among the population that this frequently entails can and will also have an impact on political conditions and the development of agricultural enterprises in the future. It is, therefore, necessary to analyze and optimize existing processes and, if necessary, replace them with more efficient processes and techniques.

Funded by the Federal Ministry of Food and Agriculture (BMEL), a system for the precise application of fertilizers in maize cultivation was developed within the framework of the PUDAMA research project, which was carried out by the TH Köln and the Kverneland Group Soest. In addition to the technical development, the aim was to investigate the effects of precise fertilizer placement, which is synchronized to the seed, in comparison to conventional, band application.

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Fundamentals of Nutrient Supply in Maize

Plant growth is generally influenced by numerous parameters. For example, Poorter et al. (2010) describe total plant growth in four categories (species traits, growth environment, environmental niche, environmental stress factors). Nutrient availability is only one of the twelve environmental stress factors. In the context of this research, nutrient availability was investigated with a special focus on the nutrient requirements during early growth in which maize only absorbs a small part of the total nutrient requirement. For example, only about 10 to 20% of the total phosphate requirement is absorbed during early growth. Nevertheless, especially in these early stages of development, nutrient deficiencies may occur (Zscheischler 1984). With regard to availability, a distinction must be made between low, such as phosphorus (P) or potassium (K), and high nutrient mobility in the soil, such as nitrogen in nitrate form. Due to the high mobility of nitrate in the soil, nutrient uptake is possible to a sufficient extent, even with a weakly developed root system, if the supply in the soil is sufficient (Behrens 2002). In contrast, Barber and Mackay (1986) documented a direct correlation between root density and phosphorus and potassium uptake in maize. Furthermore, the authors were previously able to demonstrate a direct relationship between soil temperature and phosphorus uptake (Mackay and Barber 1984). An influence of fertilizer placement on the root development of maize was demonstrated by Chassot et al. (2001), although the experiments conducted did not allow quantification of the effect on yield.

Fernandez and Rubio (2015) were able to prove in their experiments that excessive phosphorus fertilization of the young plant is not desirable. They showed a strengthening of the root development due to a slight P deficiency of the plant. However, the authors point out that an increased P deficiency of the plant, which is usually visible as a purple-red discoloration of the leaves, can cancel out the advantage of the stronger root development. In addition to the limited, especially at low temperatures, nutrient uptake ability of the maize plant depending on root development and soil temperature, the placement of nutrients should also be considered. Anghinoni and Barber (1980) determined a more efficient nutrient uptake when the P-fertilizer was deposited in the soil as bands instead of homogeneously mixing the same amount into the soil. The authors attributed this to a lower binding of the phosphorus fertilizer in the soil that was not available to the plants.

The agronomical knowledge known so far has contributed to the establishment of starter fertilization applied as bands in maize in many regions with low temperatures during early growth and low nutrient contents in the soil. Positive influence on the root system and an increase in nutrient efficiency could be proven. The negative influence of a too high central phosphorus supply of the maize plant has also been documented. Therefore, the approach of a reduced but locally more concentrated and precise fertilizer application at the beginning of the early growth phase can be considered as a further development of the established method. In practical field trials, the effect of precise fertilizer application upon maize growth was investigated.

Material and Methods

To investigate the effects of precise fertilizer application on maize plants, three-year agronomical trials were carried out and analyzed with conventional fertilizer bands and precisely applied manual starter fertilizer applications. For the investigation under practical experimental conditions, plot trials were set up at three locations in the first and third trial years (2017/2019) and at four locations in two regions in the second trial year (2018).

Locations in the Rhineland and in South Westphalia were selected as test sites in the first year of the field trials and also in the Lower Rhine region from the second year onwards. Due to the spatial distance between the selected locations, the risk of severe weather events could be reduced and a broader spectrum of conditions common in practice could be represented. An overview of the characteristics of the test sites is shown in Table 1. The trial plots differ not only in the soil types and textures, but also in the degree of nutrient supply, which was determined annually before the start of vegetation on the basis of soil analyses. The rotation of the trial plots due to crop rotation results in different degrees of nutrient supply depending on location and test year. In addition to the different soil types, the trial plots also represent different sowing procedures and methods of seed bed preparation. More intensive cultivation methods with conventional tillage were considered as well as reduced conservational tillage without deep loosening at the Rheinbach site after sugar beets. Soil cultivation, seed bed preparation and crop protection were carried out in accordance with standard business practice.

Table 1: Characterization of the trial plots with type of soil preparation, maximal working depth (ABT = Arbeitstiefe) and nutrient-supply according to soil analysis

Trial plot	**Weilerswist**	**Rheinbach**	**Lippstadt**	**Hamminkeln**	**Bislich**
Region	Rhineland		South Westphalia	Lower Rhine	
Year	2017–2019	2017–2018	2017	2018–2019	2018–2019
Soil texture	loamy silt (lU)	silty loam (uL)	loamy sand (lS)	loamy sand (lS)	sandy loam (sL)
Soil type	Pseudogley-Vega	Luvisol	Gley	Gley	Gley
Soil tillage	plow 25 cm ABT	short disc harrow 10 cm ABT	plow 20 cm ABT	plow 25 cm ABT	plow 20 cm ABT
Seed bed preparation	rotary harrow	short disc harrow	cultivator	rotary harrow	rotary harrow
Previous crop	WG/KM/KM	ZR/ZR/-	SM	WG/AG	SM/ZR
Nutrient-supply according to soil analysis (2017/2018/2019)					
Phosphorus (P)	C/C/C	B/B/-	B/-/-	-/C/C	-/C/E
Potassium (K)	C/D/D	A/C/-	C/-/-	-/C/C	-/B/B
Magnesium (Mg)	C/C/D	C/D/-	B/-/-	-/C/D	-/D/D
Copper (Cu)	C/C/C	C/C/-	C/-/-	-/E/E	-/E/E
Manganese (Mn)	E/E/E	E/E/-	E/-/-	-/E/E	-/E/E
Boron (B)	C/C/C	C/C/-	C/-/-	-/C/A	-/C/C
Zinc (Zn)	E/E/E	E/E/-	E/-/-	-/E/E	-/E/E
pH-value	B/B/B	B/C/-	B/-/-	-/B/B	-/C/C

Classes according to LUFA:
A = very low; B = low; C = optimal; D = high; E = very high
Previous crop: WG = winter barley; AG = annual grass; ZR = sugar beet; SM = silage maize; KM = kernel maize

To test the hypothesis, a total of five fertilization variants with diammonium phosphate (DAP 18+46) and a control with four repetitions each were applied per test area:

- 100% variant, conventional banded and precise starter fertilizer placement (2017–2019)
- 75% variant conventional banded and precise starter fertilizer placement (2017–2019)
- 50% variant, precise starter fertilizer placement (2018–2019)
- Control variant without starter fertilization (2017–2019)

Table 2 lists the applied fertilizer amounts according to site and year. A second nitrogen fertilizer was applied after sowing at the Rheinbach site. No further fertilizer was applied after the starter fertilization at the other sites. Each variant was sown both in normal sowing at 75 cm row width and in narrow sowing at 37.5 cm row width. The combinations of application rate, placement type and repetition result in a total of 48 trial plots (40 in 2017) per site.

Table 2: Overview of the specific fertilizer amounts according to variant, trial site, and year

Trial site		**Weilerswist**	**Rheinbach***	**Lippstadt**	**Hamminkeln**	**Bislich**
Year	**Variant**	**Applied fertilizer amount of diammonium phosphate (DAP) and total nutrient amount (total-N / P2O5) in kg ha^{-1}**				
2017	100%	100 (18 / 46)	120 (122* / 55)	150 (27 / 69)	-	-
	75%	75 (14 / 35)	90 (116* / 41)	110 (20 / 51)	-	-
2018	100%	120 (22 / 55)	150 (127* / 69)	-	100 (18 / 46)	100 (18 / 46)
	75%	90 (16 / 41)	110 (120* / 51)	-	75 (14 / 35)	75 (14 / 35)
	50%	60 (11/28)	75 (114* / 35)	-	50 (9 / 23)	50 (9 / 23)
2019	100%	120 (22 / 55)	-	-	120 (22 / 55)	100 (18 / 46)
	75%	90 (16 / 41)	-	-	90 (16 / 41)	75 (14 / 35)
	50%	60 (11/28)	-	-	60 (11/28)	50 (9 / 23)
Control		0 (0 / 0)	0 (100* / 0)	0 (0 / 0)	0 (0 / 0)	0 (0 / 0)

*Second fertilizer application after sowing (100 kg ha^{-1} total-N)

The trials plots of each row were set up randomly. The 100% fertilizer application rate was determined based on the existing nutrient supply level for phosphorus in the test area. This rate was used to determine the site-specific application rates of 75% and 50%, whereas the 50% reduced application rate was exclusively applied as precisely applied starter fertilizer. In addition to the starter fertilization, a second nitrogen fertilization was applied at the Rheinbach site after sowing, as customary. At all locations, maize of the Ricardinio variety (seed coating: Mesurol) from the seed manufacturer KWS Saat was sown at a sowing rate of 8.9 seeds per m^2, which corresponds to a seed spacing of 15 cm at a row width of 75 cm. Sowing of all test variants was carried out with a four-row precision drill (Kverneland, Optima HD, Soest, Germany). Likewise, the starter fertilization of the conventional variants was also carried out with a seed drill, whereby the fertilizer coulters were also in contact with the soil when sowing the control and the precisely placed variants without mechanical fertilizer application in order to avoid influences due to soil displacement.

Since the technology for precise starter fertilizer placement was not available at the beginning of the trials, the discontinuous variant was precisely applied manually over all four rows. The seed drill used (GEO-Seed Level I) enabled synchronized seed placement (parallel sowing) to allow determining the seed position without manually exposing the seeds in the two central rows relevant for assessing later. This facilitated a time-synchronized placement of the seeds over all four rows, allowing indirect detection of the seeds in rows 2 and 3 by exposing the seeds in rows 1 and 4. When manually applying starter fertilizer precisely, special attention must be paid to a coordinated chronological sequence of the work steps, as there is a risk that the seed furrow will dry out considerably and the field emergence will be poorer as a result. Likewise, the manual placement of each fertilizer portion requires a high degree of accuracy in order to maintain the desired horizontal distance of 5 cm to the seed, whereby small deviations cannot be avoided. Regular checks of the placement accuracy ensure that the requirements are met. An example of such a check is shown in Figure 1. The tool for manual fertilizer application places a portion of fertilizer about 50 mm long and 10 mm wide parallel to the seed row. The horizontal and vertical distance between seed and fertilizer placement is identical to conventional band starter fertilizer placement.

Figure 1: Representation of a randomized check of the manual fertilizer application by exposing the seeds and measuring the horizontal distance between fertilizer and seed (right) (© M. Bouten)

Each trial plot was three meters wide and ten meters long, whereby only the middle two rows respectively the middle four for the plots with narrow rows were used for the plant ratings. Moreover, the two meters at the start and end areas were not considered in the ratings. This resulted in an effective plot length of at least six meters for each variant and repetition. The influence the fertilizer variants had upon plant growth in the test area was evaluated and documented over the growing period according to the following parameters:

- Field emergence
- Early growth
  - BBCH development stage
  - Plant height
  - Nutrient deficiency symptoms
- Harvest
  - Silage maize yield (37.5 cm row width)
  - Kernel yield (75 cm row width)

This investigation focused on determining the early growth and the yield results from the different test variants. Weekly ratings were carried out from field emergence to the transition to main crop development (BBCH 30, Federal Biological Research Centre for Agriculture and Forestry 2001) on development stage and plant height. Moreover, any signs of nutrient deficiency were also rated and documented. Ten randomly selected plants were used for this in each plot; thus, a total of 480 individual plants (400 in the first year) were rated and documented.

To determine the yield, at least 20 individual plants were manually harvested in the core area of each trial plot. The maize was harvested as whole plant maize silage from the trial plots with narrow rows and only the ears as kernel maize from the trial plots with the normal rows. The plants were comminuted immediately after being cut on the field, whereby a mixed sample was formed out of four repetitions to determine the contents. The ears were threshed and kernel moisture determined within 24 hours at the Cologne Institute of Construction Machinery and Agricultural Engineering. Kernel moisture was determined with a hand unit (Pfeuffer, HE50, Kitzingen, Germany) with three repetitions. In addition, the moisture content was verified by drying in a sample dryer.

Results and Discussion

The mean field emergence of the three-year trials is over 90% across all trial variants and locations. The maximum difference between the mean values is 1.6%; differences between the test variants are not significant (α=0.05). Thus, the homogenous field emergence confirms the field trial set up with respect to manual starter fertilizer placement and forms the basis for further investigations of the early growth development and the yield.

Early growth

The comparison of the trial variants during early growth is based on the developmental stage, plant height and visually visible nutrient deficiency symptoms. The trial plots were assessed weekly and no significant differences in the developmental stage were determined between the variants in the different plot trials.

During the field trials, only one test area (Rheinbach - Rhineland) showed increased nutrient deficiency symptoms in 2017. The purplish leaves indicated a P-deficiency. In spite of having a starter fertilizer amount of 100%, 89% of the plants with conventional starter fertilizer showed low to medium deficiency symptoms. In contrast, only 20% of the plants with 100% precise starter fertilizer placement showed such deficiency symptoms. Moreover, with a reduced starter fertilizer amount of 75%, only 28% of the plants with precise starter fertilizer placement showed low deficiency symptoms. However, since there were no deficiencies at the other trial plots in the following test years, the data basis on this topic is still small.

The results on plant height show a significant differentiation between the variants. Figure 2 shows the mean relative plant height at the transition from early growth to crop growth (BBCH 19/30). All results are referenced to the 100% conventional variant of the respective row width for comparability.

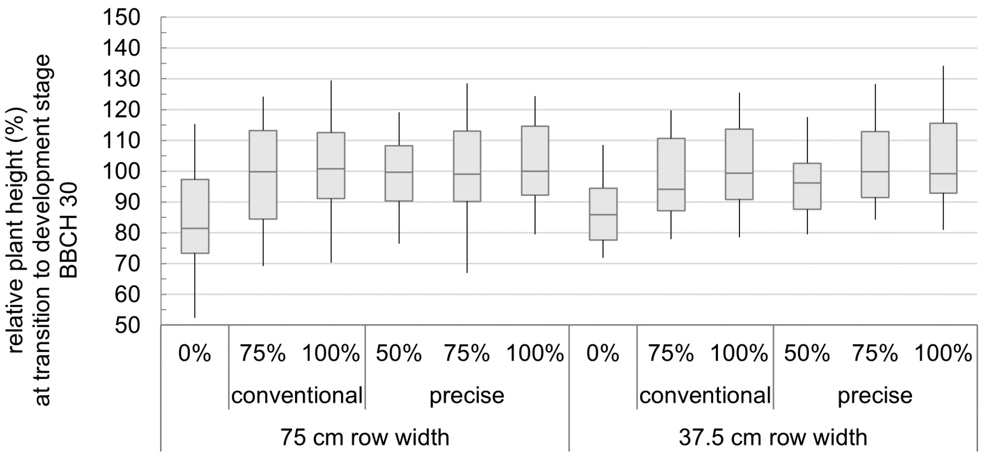

Figure 2: Boxplot of relative plant height of the trial variants at the transition to crop development in standard and narrow row width trials for all trial plots and test years (n = 412) (The individual results were standardized to the 100% conventional variant of the respective row width)

Table 3 displays a comparison between the control and the fertilized variants and shows the positive influence that precise starter fertilizer placement has upon early growth development. Furthermore, it also shows how this connection is independent of the row width and application method of the starter fertilizer. There are only small differences between the fertilized variants over the entire test period and all locations, whereby especially in 2017 differences of over 20% between both 100% fertilized variants were determined (Bouten et al. (2019a). All in all, the row width only has a small influence on the qualitative result of the plant height among the fertilized variants. The 50% variants with precise starter fertilizer placement are significantly smaller than the 100% conventional variant in both row widths (t-Test, $\alpha = 0.05$). Furthermore, the 75% conventional variant is slightly smaller than the 100% variant; however, it is not significant. In contrast, the variant with precise starter fertilizer placement that had the same amount of fertilizer had a positive, but not significant effect upon the plant height.

Table 3: Relative mean plant height at the end of the early growth development (BBCH 19/30) for all trial plots and test years, standardized to the reference 100% conventional variant

Amount of DAP	Type of placement	Relative plant height in % 75 cm Row width	Relative plant height in % 37.5 cm Row width
0%	-	83 a*	87 a
50%	precise	97 b	96 b
75%	conventional	98 bc	98 bc
	precise	101 cd	103 d
100%	conventional (reference)	100 cd	100 cd
	precise	103 d	104 d

* The letters identify the class of significance (t-Test, α = 0.05), comparisons are only possible within each column.

A comparison of the 100% variants shows a positive trend in favor of precise starter fertilizer placement. Due to the different characteristics of this positive effect over the trial plots and years, the differences of three and four percent are not significant. In summary, at the end of early growth development, all variants with the same amount of fertilizer show a potential in favor of precise starter fertilizer placement. Furthermore, a 25% reduction in fertilizer does not have any negative effects on early growth development. Due to the various influencing parameters that contribute to yield, the influence that precise starter fertilizer placement has upon the yield was also examined.

Yield Results

Analog to the early growth results, the yield results were standardized to the variant 100% conventional. Figure 3 shows the boxplot of the relative yield results of the three-year field trials.

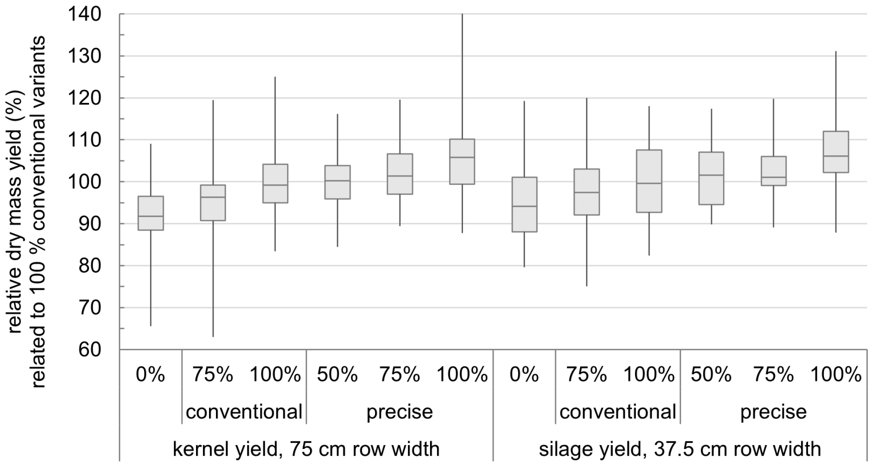

Figure 3: Boxplot of the relative dry mass yield of the test variants (n = 397) as kernel and silage maize over all trial plots and test years (The individual results are standardized to the variant 100% conventional of the respective row width. 100% correspond to 90 dt DM ha^{-1} for kernel maize and 149 dt DM ha^{-1} for silage maize)

A direct comparison of the 100% variants shows that the kernel yield shows an increase of 6% and that the silage maize has an increase of 7% with precise starter fertilizer placement. These differences are significant (α = 0.05) so that an increase in yield - with the same amount of fertilizer - due to precise starter fertilizer placement could be verified in the field trials. The quantitative yield results in relation to the reference variant are listed in Table 4.

Table 4: Mean dry mass yield over all trial plots and test years standardized to the respective reference variant 100% conventional

		Relative DM-yield in%	
Amount of DAP	**Type of placement**	**Kernel maize***	**Silage maize**
0%	-	92 ^{a**}	94 ^{a}
50%	precise	100 ^{b}	102 ^{bc}
75%	conventional	96 ^{a}	98 ^{ab}
	precise	102 ^{b}	103 ^{bc}
100%	conventional (reference)	100 ^{b}	100 ^{b}
	precise	106 ^{c}	107 ^{c}

* Kernel maize had row widths of 75 cm and silage maize had row widths of 37.5 cm.
** The letters identify the class of significance (t-Test, α = 0.05), comparisons are only possible within each column.

Discussion

The results of the yield assessment of the three-year agronomic field trials showed that applying conventional starter fertilizer provides a significant yield advantage as compared to no fertilizer. Moreover, the results showed that there is also potential for increases in efficiency with precise starter fertilizer placement. The three-year field trials verified that – using customary amounts of fertilizer – a significant yield advantage was possible through precise starter fertilizer placement. Moreover, using precise starter fertilizer placement and reducing the fertilizer amount by 25% had no negative effects upon early growth or the yield. Furthermore, the two-year field trials showed that reducing the fertilizer by 50% with precise starter fertilizer placement did not lower the yield.

All in all, the agronomic field trials verified the initial hypothesis that precise starter fertilizer placement increases fertilizer efficiency during maize sowing. This increase in efficiency is due to several different contexts. Due to the spatial delimitation of the fertilizer, there is a lower fixation of the easily soluble phosphates in the soil, which is of increasing importance at lower degrees of soil supply. This could be seen especially well in the trial plots in Rheinbach, which tended to have lower P-supplies and reduced soil tillage, yet had significant increases in early growth as well as yield. However, based on the available research data from the field trials, a statement as to what impact soil texture has upon the selection of the fertilizer application type cannot be made.

Anghinoni and Barber (1980) already determined that banded fertilizer placement provides an advantage as compared to mixing it into the soil; thus, precise starter fertilizer placement can be seen as a further development step here. Moreover, through the targeted placement of a lower amount of fertilizer, less fertilizer can be used without risking an undersupply. With respect to the investigation by Fernandez and Rubio (2015) on the favor effect that a minor P-deficiency has upon the development of maize, a more targeted control of plant development can be achieved. With regard to root development, the question arises as to the influence of highly concentrated fertilizer application on root distribution.

The positive yield results achieved by the control variant in these tests can have various causes. On the one hand, the soils in the trial plots had a good to very good supply of nutrients, which means that even without starter fertilizer in the spring, the plant were well supplied, assuming suitable weather conditions. On the other hand, maize is, as already described, able to completely compensate for short-term nutrient deficiencies under good conditions. Since, with the exception of the Rheinbach site, no additional fertilization was applied, the total nutrient supply was basically reduced, which can also have limiting effect on the yield.

Outlook

The results confirm the hypothesis of an increase in fertilizer efficiency through precise fertilizer placement 5 cm next to and below the seed. To quantify the individual influencing factors such as soil texture and supply, type of fertilizer or the influence of the maize variety, further investigations will be necessary in the coming years. Especially the importance of fertilizer application for root growth and the holistic nutrient uptake are of great interest for a targeted further development of fertilizer application technology towards maximizing fertilization efficiency

In the context of a possible reduction of the desired soil nutrient contents and the reduction of the permissible nutrient quantities, new approaches and procedures for fertilization are necessary. Bouten et al. (2019b) presented a technical procedure for the mechanical application of the precise fertilizer placement method investigated here, which is now being further developed to series production readiness by the project partner Kverneland. This will allow large-scale trials to be conducted in the future to further optimize the process.

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