LANDTECHNIK 74(2), 2019, 25–34
DOI:10.15150/lt.2019.3202
LANDTECHNIK AGRICULTURAL ENGINEERING

Investigating the influence of precisely applied starter P-fertilizer in maize – initial field trial results

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To ensure quick early growth, maize requires the immediate accessibility of essential nutrients, especially since the seedlings only have a limited nutrient uptake ability. The P-supply is frequently ensured through starter fertilizer. In general, fertilizer mixes with phosphorus (P) and nitrogen (N), sulfur (S) or additional nutrients are used. Traditionally, granular fertilizer is continually applied as a fertilizer band parallel to the seed row, also between the seeds. Up to 25 % can be saved by using precisely the right amount of the fertilizer and concentrating it in the area of the single seeds. This environmentally friendly practice also saves costs. In the course of this research project, which was funded by the Federal Ministry of Food and Agriculture (BMEL), possibilities for precision fertilizer application were investigated and a technical solution sought for realizing precise sowing. This research project was carried out in cooperation with the Kverneland Group Soest. The initial field tests with diammonium phosphate verified the hypothesis of improved early growth at different sites. The field tests also verified significant growth advantages during early growth in variants treated with precisely placed starter fertilizer.

Key words
maize sowing, crop development, starter P-fertilizer, fertilizer efficiency, field trials

Using starter P-fertilizer for sowing maize has established itself in practice. In general, a granular fertilizer containing phosphorus is used, since is especially suited to supporting nutrient uptake in the maize plant during early growth (Heinitz et al. 2013). Precision drills sow using the exact amount of fertilizer that is required for each location in the field and sowing time continuously, whereby the banded starter fertilizer is applied in front of the seed (Figure 1). Thus, the banded starter fertilizer is continuously applied approximately 5 cm below and 5 cm next to the seed, which enables the seeding roots to have direct access to the nutrients.

received 22 October 2018 | accepted 6 December 2018| published 5 March 2019

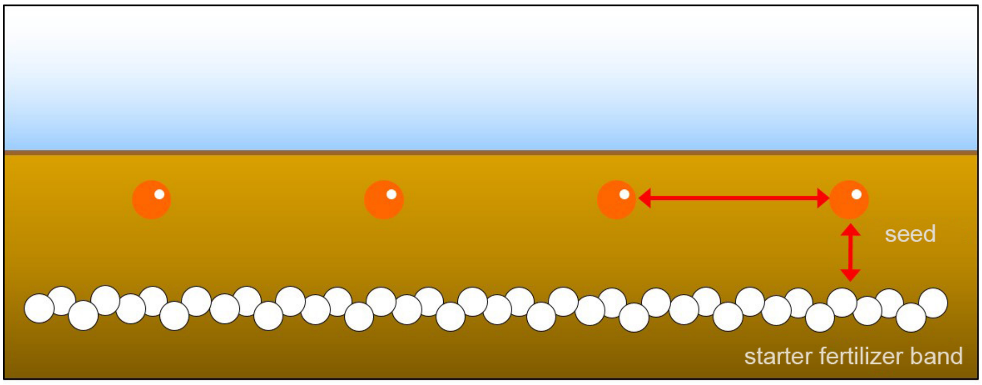

Figure 1: Schematic illustration of continuous placement of the starter fertilizer band

During maize sowing with a seed density of ca. 90,000 seeds/ha and a row width of 75 cm, the maize seeds are planted approximately 15 cm apart in the rows. However, since root development is limited especially during early growth, nutrient uptake is also limited. Thus, some of the fertilizer band could remain unused. It is hypothesized that up to 25 % of the fertilizer used can be saved through optimized placement of the starter fertilizer (Figure 2). This would have positive environmental and economic impacts in maize cultivation: sowing capacity is increased, fertilizer logistics are simplified, and the nutrient balance of the field is improved.

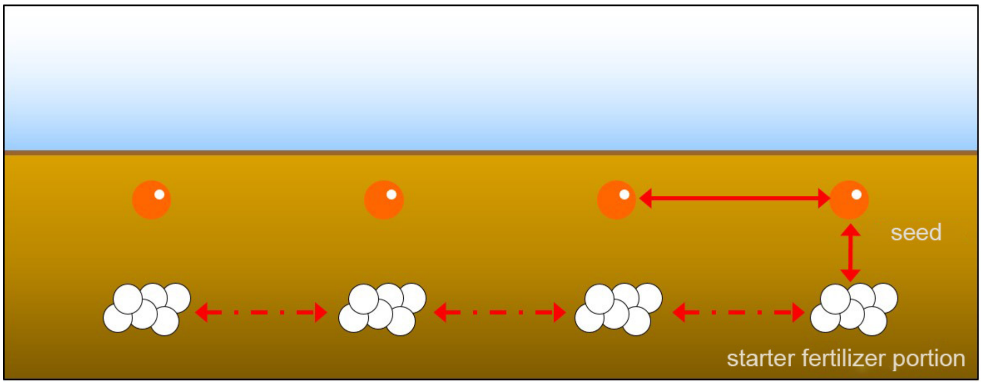

Figure 2: Schematic illustration of the precise placement of the starter fertilizer

This is being investigated in a research project, which is funded by the Federal Ministry of Food and Agriculture (BMEL), and is initially focusing on agronomic issues. However, if it is shown that the changed P fertilization distribution has no negative impacts, the research project will investigate technical possibilities.

The research project investigates the following agronomic hypotheses:

- Quick and secure early growth through precisely applied starter P fertilizer
- Potential savings that do not affect yield through precise P fertilizer application
- Increased yield without increased P fertilizer application
- Increased savings through narrow row widths and precisely applied starter P fertilizer

Material and Methods

The first field trials were carried out in the 2017 vegetation period. Since the technology for precisely applying fertilizer is not available, the discontinuous variant was precisely applied manually.

Three areas were selected for the field trials (Table 1). Differences in climate and changing soil conditions were taken into consideration in selecting the fields as well as the capability of timely and economical monitoring, since weekly ratings needed to be completed during the early growth season. Two areas, which essentially only differed in their soil quality, were selected in the Rhineland and the third area (South Westphalia) was selected to minimize the risk due to climatic events (e. g. storms) and also due to its typical soil for growing maize.

The test areas differ with respect to their nutrient supply in the soil and their typical crop rotation management (Table 1).

Table 1: Characterization of the test areas: crop rotation, tillage type, and nutrient-supply classes (Federal Institute for Geosciences and Natural Resources 2017; LUFA Nord-West 2017)

Test area	**Rheinbach**	**Weilerswist**	**Lippstadt**
Region	Rheinland		Südwestfalen
Previous crop	Sugar beets	Winter barley	Maize
Soil texture	Sandy loam (sL)	Sandy loam (sL)	Loamy sand (lS)
Soil type	Pseudogley-Vega	Luvisol	Gley
Soil tillage	-	Plow	Plow + Packer
Seed bed preparation	Compact disc harrow	Power Harrow	Cultivator
Nutrient-supply class according to soil analysis			
N_{min} (0–30 cm)	45 kg/ha	24 kg/ha	18 kg/ha
Phosphorus (P)	B	C	B
Potassium (K)	A	C	C
Magnesium (Mg)	C	C	B
Copper (Cu)	C	C	C
Manganese (Mn)	E	E	E
Boron (B)	C	C	C
Zinc (Zn)	E	E	E
pH-value	B	B	B

Classes after LUFA Nord-West (2017):
A = very low; B = low; C = target; D = high; E = very high

Two of the test areas (Rheinbach and Lippstadt) have a slight nutrient deficiency (class B) for phosphorus. Thus, it can be expected that different effects can be seen due to the application of the starter fertilizer as described above (Figure 1 and 2).

To verify the stated hypotheses, trials with five different fertilizer variants were repeated four times in each test area. The trials were carried out in the test areas in a completely randomized design (Figure 3). Sowing was carried out in all test areas in rows with widths of 75 cm and in the two test areas in Rhineland additionally in narrow rows with widths of 37.5 cm.

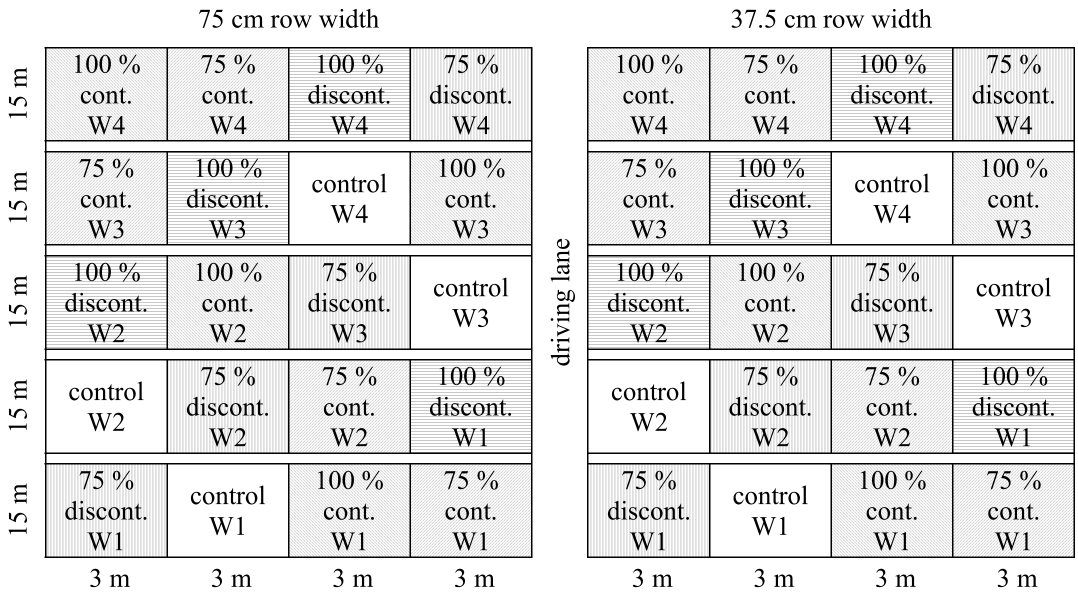

Figure 3: Area plan of the test areas (cont.: banded starter P fertilizer; discont.: precisely applied starter P fertilizer; W1-W4: repeats 1-4; fertilizer type: DAP; control without DAP)

In addition to the continuous and discontinuous variants with 100 % of the standard P fertilizer amount, sowing with 75 % of the standard P fertilizer amount was also carried out. Diammonium phosphate (DAP) with 46 % phosphate (P_2O_5) and 18 % ammonium nitrogen (NH_4-N) was applied (Table 2).

The specific fertilizer amounts of the 100 %-variants were determined according to the nutrient supply class and soil quality of the test area (see Table 1).

Table 2: Overview of the applied sowing density and amount of fertilizer in the trials

Trial variant	**Unit**	**Rheinbach**	**Weilerswist**	**Lippstadt**
			Soil texture	
		sL	**sL**	**lS**
100 % continuous	kg DAP ha^{-1}	120	100	150
100 % discontinuous				
75 % continuous	kg DAP ha^{-1}	90	75	110
75 % discontinuous				
Control	kg DAP ha^{-1}	0	0	0
Fertilizer type		Diammonium phosphate (DAP; 46 % P_2O_5, 18 % NH_4-N)		
Maize sowing density		8.9 seeds/m² (type : KWS Ricardinio)		

Sowing was carried out with a commercially available precision drill (model Optima from the company Kverneland). Optima has GEO-seed – an electronic control and synchronization unit – that enables synchronized seed placement (parallel sowing). This facilitates a precise manual placement of the fertilizer with a specially adapted planter tool. Random checks verified the exact work of the electronics and the corresponding manual fertilization. Each outer maize row (1 and 4) was used to check the sowing accuracy; both middle maize rows were used for the following ratings. After sowing, the discontinuous starter fertilization was applied manually, since the machine used could not apply the fertilizer discontinuously. The granular fertilizer was manually placed near the seed, and then the control rows closed again and pressed down with the hand-held V-pressing roller. These work steps were carried out quickly so that the seed did not dry out.

The sowing dates were customary – in accordance to the locations – and from the beginning to the end of April 2017. A subsequent cold spell delayed the field emergence of the early sowing (Table 3). There were no statistically significant differences between the manually fertilized and the mechanically fertilized maize crops. Thus, all variants had homogenous field emergence.

Table 3: Sowing dates and mean field emergence in the plots of the test areas

	Rheinbach	**Weilerswist**	**Lippstadt**
Soil texture	sL	sL	lS
Sowing date	07.–08.04.2017	10.–11.04.2017	27.–28.04.2017
Field emergence (value range of all variants according to site)	86–91	86–89	91–96

DLG Field emergence evaluation: good (85–89 %); very good (> = 90 %)

2017 was characterized by an exceptionally warm and dry first six months (Table 4) as well as unusually high precipitation amounts in July and August in both test regions. Moreover, the cold weather conditions in April 2017 with low temperatures delayed the development of the maize crops.

Table 4: Weather and climate data of the test areas Rhineland and South Westphalia and monthly deviations from the mean from the years 1981 to 2010 (Wetterkontor GmbH 2017)

Month	**Rhineland (Rheinbach, Weilerswist) (Station: Euskirchen-Lommersum)**				**South Westphalia (Lippstadt) (Station: Lippstadt-Borkenförde)**			
	Temperature (in °C)		**Precipitation (in mm)**		**Temperature (in °C)**		**Precipitation (in mm)**	
	Monthly average	**Deviation from longterm mean**	**Monthly average**	**Deviation from longterm mean (in %)**	**Monthly average**	**Deviation from longterm mean**	**Monthly average**	**Deviation from longterm mean (in %)**
Jan. 2017	0.0	-2.6	22.7	-40	0.1	-2.3	36.8	-43
Feb. 2017	5.6	+2.8	26.8	-65	4.9	+2.3	49.1	-6
Mar. 2017	9.2	+3.0	47.3	-1	8.7	+2.9	33.7	-52
Apr. 2017	8.2	-1.2	17.3	-64	8.0	-1.1	23.4	-55
May 2017	15.5	+1.7	36.5	-43	14.8	+1.4	72.6	+8
Jun. 2017	19.1	+2.7	48.5	-27	18.1	+2.1	42.2	-46
Jul. 2017	19.2	+0.3	118.1	**+79**	18.6	+0.3	153.7	**+81**
Aug. 2017	18.3	+0.1	87.5	**+46**	18.1	+0.1	110.2	**+45**
Sep. 2017	14.1	-0.6	44.3	-21	13.8	-0.6	71.2	-1
Oct. 2017	12.5	+1.6	26.1	-46	12.2	+1.6	39.5	-40

The maize crops in the trials were rated weekly in the early growth season (n=40 plants per trial variant and site). In addition to the plant height and growth stage according to the BBCH-scale (Biologische Bundesanstalt für Land- und Forstwirtschaft 2001), the leaf color was also determined. Young maize plants often have P-deficiencies, which are recognizable by the purplish coloring of the leaves. This was visually determined by comparing with color charts with whole number values between 0 (no deficit recognizable) and 4 (strong and large discolorations). In addition to the weekly visual rating, leaf samples of the developing eighth leaf (BBCH 18) were taken in each plot in all test areas. The leaves were analyzed for nitrogen and phosphorus contents.

Results and Discussion

The growing variables were determined weekly during early growth. In addition, leaf analyses were carried out to verify the visual evaluations of the different growth stages. The maize was harvested as either whole plant maize silage or kernel maize, whereby the necessary analyses were carried out on both harvested types.

Early Growth

The early growth evaluation exemplarily shows the influence the P fertilizer variants had upon growth in the test area Rheinbach that had 37.5 cm rows (Figure 4). The variants with 75 cm rows show comparable results and follow the same trend: In the early growth stages, the variants are still very close together. After week 21, the crops grew apart and the differences in the fertilized plots in the test areas are more pronounced. The continuously fertilized plants clearly have a slower growth in comparison to the plants in the precisely fertilized plots in the test areas. As expected, the control plants (without starter fertilizer) show the lowest average plant height. Effects were seen with respect to the type of fertilizer application as well as the amount of fertilizer.

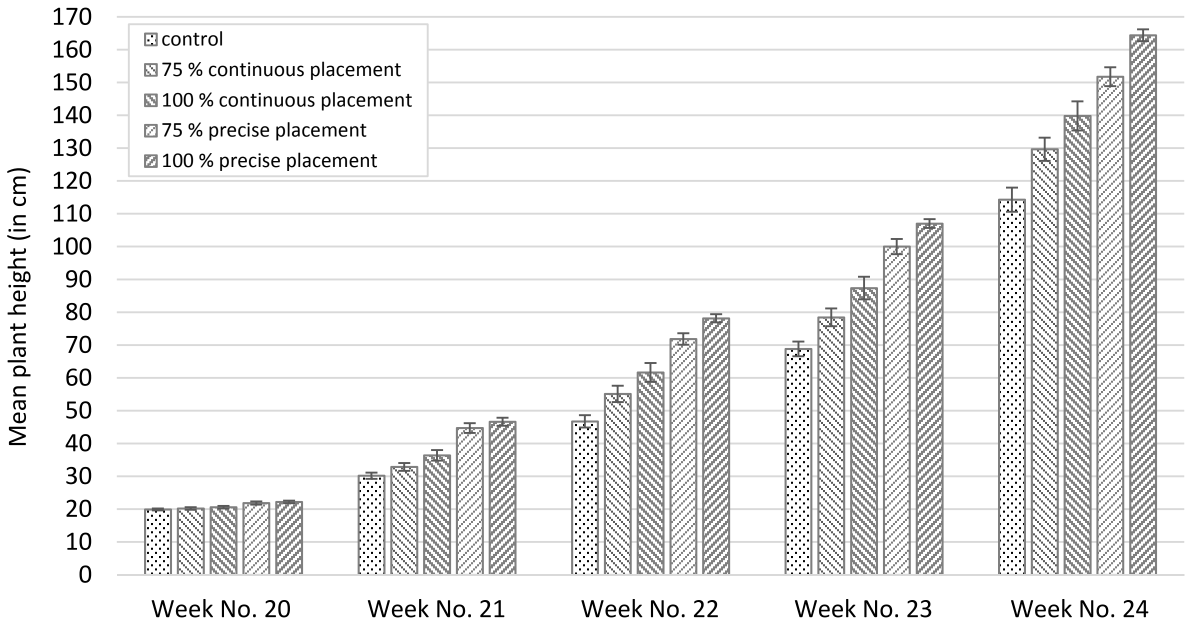

Figure 4: Development of the average plant height of the 37.5 cm row plants in the test area Rheinbach for the time period week 20 to week 24; graphic shows the 90 % confidence interval (error bar above each respective column)

Comparing the variants 100 % continuous to 75 % discontinuous shows the significant effect ($p < 0.1$) that the discontinuous starter fertilizer had upon the average plant height in week 24, perhaps due to the higher nutrient concentration that caused better nutrient availability.

Table 5 summarizes the average plant height at the point in time from when the plants changed from early growth development to crop development; for all test areas and variants (BBCH 19/30, measurements from 12.–18.06.17), all normalized to the variant 100 % continuous. Measurements fulfil the 90 % significance level ($p < 0.1$), which is primarily due to the relatively small differences between the variants in the test area Weilerswist, which had soil that was better supplied with nutrients. Especially noticeable is that the plants that received the highest discontinuous concentration of the fertilizer also showed the fastest crop development.

Table 5: Mean relative plant height (in %) normalized to the respective 100 % cont.-variant at the end of the early growth stage (BBCH 19/30). Comparisons are only possible within each column. Means that are identified with the same letter do not differ significantly ($p < 0.1$)

		Unit	Rheinbach	Weilerswist	Lippstadt	Mean of all test areas
Soil texture			sL	sL	lS	
75 cm normal rows	Control	%	68 ^{A}	94 ^{A}	87 ^{A}	83 ^{A}
	75 % continuous	%	98 ^{B}	100 ^{B}	98 ^{B}	99 ^{B}
	100 % continuous	%	100 ^{B}	100 ^{B}	100 ^{B}	100 ^{B}
	75 % discontinuous	%	114 ^{C}	102 ^{BC}	108 ^{C}	108 ^{C}
	100 % discontinuous	%	122 ^{D}	104 ^{C}	111 ^{C}	112 ^{C}
37.5 cm narrow rows	Control	%	79 ^{A}	91 ^{A}	-	85 ^{A}
	75 % continuous	%	90 ^{B}	97 ^{B}	-	94 ^{B}
	100 % continuous	%	100 ^{C}	100 ^{C}	-	100 ^{B}
	75 % discontinuous	%	115 ^{D}	104 ^{D}	-	110 ^{C}
	100 % discontinuous	%	123 ^{E}	106 ^{D}	-	115 ^{C}

In addition to the growth development, visually recognizable disease symptoms were rated and documented. Signs of P-deficiency are especially noticeable in the early growth corn plant shown in the left photograph in Figure 5 with clearly purplish leaves.

For the most part, the typical symptoms of P-deficiency – purplish leaves – appeared to any extent only in one test area (Rheinbach - Rhineland) in the spring of 2017. The intensity of the discolorations was directly related to the amount and type of application of the starter fertilizer. The precisely applied fertilizer clearly reduced visual symptoms of P-deficiency. Less than 10 % of the rated maize plants that received the precisely applied fertilizer – the discontinuous variants – showed P-deficiency symptoms. In contrast, over 50 % of the continuous variants showed medium or strong P-deficiency symptoms. The leaf analyses of the plants showed no significant differences in the nitrogen or phosphorus contents. This allows the conclusion that the discontinuous variants had a higher absolute nutrient uptake, since these variants, in analogy to plant height, had a larger plant mass under comparable nutrient uptake. These results allow the conclusion that fertilizer, i. e., a phosphate-nutrient- deposit, placed precisely near the seeds leads to better early growth in the maize plants than the traditional fertilizer deposit as a continuous fertilizer band.

Figure 5: Visual comparison of the deficiency symptoms between the control plants (left photograph) and the 100 % discontinuous variant (right photograph) in the test area Rheinbach (photograph taken on 29.05.17). The maize plant in the left photograph clearly shows P-deficiency symptoms, whereby the maize plant in the right photograph has no visually visible nutrient deficiency symptoms

Yield Results

The harvest of the silage maize in the plots of the test areas started at the end of September 2017 (BBCH 87, harvested on 21.09.17). The entire crop, i.e., the whole maize plant, was cut and chopped and the evaluation of the contents of the harvest was carried out by the LUFA. The results of the yield amount show that the different variants tended toward approximately the same yield, even though there were significant differences during early growth.

The differences are not as clear as they were in the spring. However, the 100%-variants with precise starter fertilizer placement clearly have a significant difference: The yield is up to 15% larger between the control and the maximally supplied variant. Yet, if the comparison is between – as was at the beginning – the 100% continuous variant and the 75% discontinuous variant, then the differences are clearly not so far apart; since they dropped to maximal 2% and are not significant (Table 6). Nevertheless, the initial hypothesis is verified since the discontinuous variant is definitely not weaker. This supposed equivalence between both variants was to be examined. The growing maize plant is seemingly capable of balancing the difference in supply, if the external conditions are favorable. The subsequent multi-year field trials will show if these initial insights will also hold true and can be replicated under other weather conditions. There were mild temperatures at the field emergence and the vegetation start. The summer was warm and rainy. These are good conditions for a continuous mobile nutrient uptake from the soil and intensive element turnover at ideal temperatures for C4-plants. Whether cold or wet conditions have a different impact upon starter fertilizer will be seen in further trials.

Table 6: Absolute and normalized silage maize-dry mass yield of the narrow row sowing variants in Rheinbach and Weilerswist. Comparisons are only possible within columns. Means identified with a common letter do not have significant differences (p < 0.1)

		Rheinbach	Weilerswist	Mittelwert
Soil texture		sL	sL	
Yield silage maize dry mass (in t/ha)	Control	18.8 (97 %) A	16.2 (95 %) A	96 % A
	75 % continuous	18.9 (97 %) A	17.0 (100 %) A	98 % A
	100 % continuous	19.4 (100 %) A	17.0 (100 %) A	100 % A
	75 % discontinuous	19.9 (102 %) AB	16.9 (99 %) A	101 % AB
	100 % discontinuous	21.8 (112 %) B	17.7 (104 %) B	108 % B

The yield for kernel maize was similar as the yield for silage maize, as shown in Table 7. The yield for the variants are closer, the difference between the control and the discontinuous variant is significant. All in all, the yields that were weaker at the beginning grew stronger and approached the stronger ones. If the yields from the corn maize with the starter fertilizer variants are compared, there are significant differences between the 100 % discontinuous variants and the 100 % continuous variants ($p < 0.1$).

Table 7: Absolute and normalized kernel-dry mass yield of the normal sowing row variants for all test areas. Comparisons are only possible within columns. Means identified with a common letter do not have significant differences (p < 0.1)

		Rheinbach	Weilerswist	Lippstadt	Mean
Soil texture		sL	sL	lS	
Kernel yield dry mass (in t/ha)	Control	11.3 (96 %) A	10.2 (96 %) A	9.1 (96 %) AB	96 % A
	75 % continuous	11.9 (102 %) A	10.5 (99 %) A	9.2 (97 %) A	99 % AB
	100 % continuous	11.7 (100 %) A	10.7 (100 %) A	9.5 (100 %) AB	100 % AB
	75 % discontinuous	12.3 (105 %) AB	10.4 (97 %) A	9.9 (104 %) AB	102 % BC
	100 % discontinuous	12.6 (107 %) B	10.7 (100 %) A	10.4 (109 %) B	106 % C

Conclusions and Outlook

At the begin of the vegetation cycle, the variants supplied with precisely placed starter fertilizer were better off, even under reduced nutrient amounts in the soil. There were significant differences in all test areas. During the vegetation cycle, this advantage decreased and the variants become more similar in the continued vegetation phase. This clearly shows that the young maize plants are able to use the starter fertilizer close to the seedling more efficiently than the fertilizer placed between the individual seedlings. The fertilizer concentration close to the seed is naturally higher if the amount from the interplant-space is summarized there. However, the maize plants seem to be able to use the supply.

In the trial period represented here (one year), the growth advance declined after about four to six weeks. Thus, it is expected that the easily available P-supply was depleted after this period and the plant roots took the nutrients out of the soil.

It is surmised that unfavorable weather in the summer months can increase the advantages of the discontinuous variants even more. In 2017, the wet and warm summer weather conditions were in general very conducive for growth. A dry cold spell in the springtime can put strain on poorly supplied maize plants. In such cases, early access to a nutrient supply would be beneficial. Precisely placed starter fertilizer provides an advantage in early growth, which was verified in the research project. Additional trial years will show if more demanding weather conditions will also show differences when the precisely placed fertilizer depot is used.

The initial hypothesis that precisely placed starter P fertilizer directly near the seed enhances (early) growth seems to have been verified after this first years of field trials. If the standard amount of P-fertilizer used in sowing is concentrated and applied under the seed, 25 % of the amount can be reduced. Especially noticeable in the vegetation season 2017 was that this measure was not only equivalent, but also significantly better in the early growth stage as the usual 100 %-variants.

The subsequent field trials in the years ahead will solidify the initial insights and results from the field and provide new results and knowledge. Moreover, the technology will be further developed to enable a precise placement of the starter fertilizer near the seed.

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Acknowledgement

The research project is funded by the Federal Ministry of Food and Agriculture (BMEL). The authors would like to thank KWS Saat SE for supplying the seed. Moreover, we especially wish to thank all of the farmers who agreed to let us carry out the trials on their fields.