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Plant spacing distribution in maize and its influence on rooting intensity and nutrient utilization

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The plant space distribution in forage maize cultivation is important for the success potential of the production system. The 2017 Amendment to the German Fertilizers Ordinance has led to introduction of yield-dependent, site and crop related limits for nitrogen fertilizer applications on farms. The aim of producing higher yields has always been pursued in agricultural production. In forage maize growing, changes in plant distribution have led to higher yields in all regions where this has been tested – Bavaria, Denmark, Thuringia, North Rhine-Westphalia, Schleswig-Holstein and Spain. The present multi-year results were collected from field trials (on-farm research method) conducted on commercial farms. A change in the distances between seed rows in forage maize leads to altered plant space distributions. This increases above-ground biomass and energy yields through better crop light availability and improved nutrient utilization. In the rooting area, changed plant distribution leads to more uniform rooting intensity of topsoil, which contributes to better nutrient utilization and improved erosion reduction.

Keywords
Plant space distribution, rooting intensity, nutrient utilization

Protection of soil at risk from water or wind erosion is also a factor of discussions on correct distances between crop rows. In erosion susceptible areas of Germany, an average 2.7 t ha^{-1} and year of topsoil is lost through erosion in rowcrops such as forage maize (Auerswald et al. 2009). Panagos and Borelli (2017) estimates that around 16% of total area (residential areas and farmland) in the EU is at risk from erosion, of which 12% is through water and 4.4% through wind.

Forage maize, which up until now has been cropped on lower yielding areas or in the livestock production regions of Germany, has in recent years also moved into arable cropping regions, its advance encouraged by demand in recent years for high quality silage feed for dairy cattle and the growing requirement from biogas plants. However, changes in the demand situation on the raw material markets have, in part, led to shrinkage of maize growing area in some regions. The remaining areas now have to meet the demand for feed and energy maize. Here, new crop growing strategies are needed.

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Aim of project

An important core question applies to the necessary distance between crop rows for optimum plant space distribution and space exploitation by maize plants. The aim of this investigation was to reproduce the uniformity of plant space distribution on the field surface and at the same time record the influence of the altered distances between seed rows on root growth intensity and associated nutrient utilization.

Distance between seed rows and plant space distribution

In the literature (Demmel et al. 2000; Peyker et al. 2008; Reckleben 2011) different results are available covering the theme distances between maize crop rows. In the first place, the aim is best possible plant space distribution for the individual maize plant as presented in Figure 1..

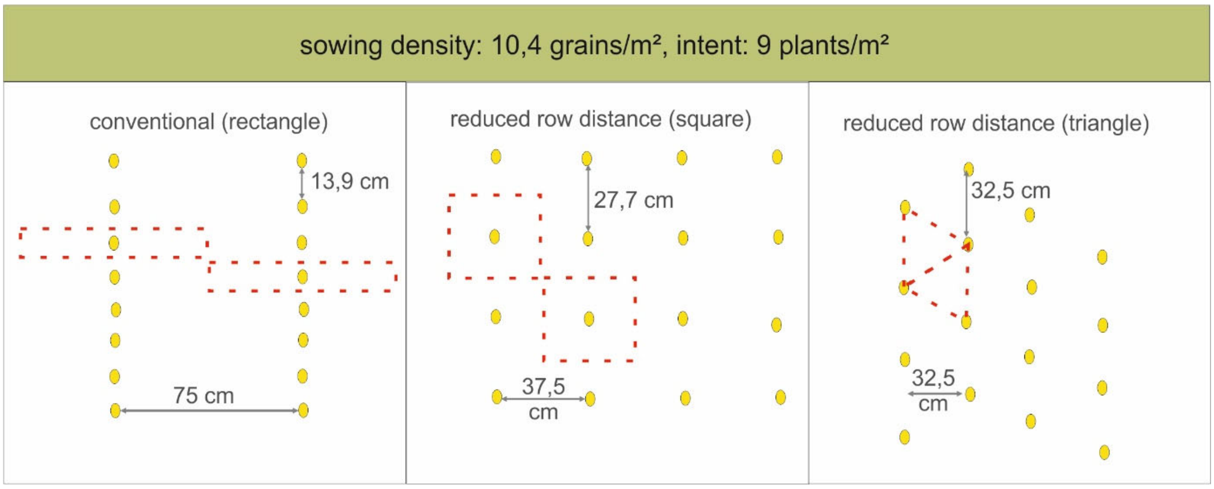

Figure 1: Seed spacing in the row at various row widths.

The better the distribution of individual plants on the growing area, the more beneficial the space distribution, the exploitation of available light, the root development and nutrient utilization efficiency (Demmel et al. 2000; Wulfes et al. 2001; Peyker et al. 2008; Griepentrog et al. 2011; Reckleben 2011; Morente et al. 2013). Higher yields through closer crop rows have been verified from all sources and all locations, as has reduced residual nitrate content indicating improved utilization of nutrients.

The mathematical optimal plant density of 9 plants per square meter by which the maize plant spacing along the row equals the distance between rows, is achieved with a distance between rows of 32.5 cm. With this, every plant in Figure 1 has the same surrounding room as its neighbor.

A standard for the quality of seed spatial distribution is achieved through the Morisita Index (Morisita 1962; Griepentrog 2014). The Morisita Index is based on random or regular discrete counts per area unit and is similar to other statistical parameters calculated from variance-mean relationships and independent of area scales and event densities. The Morisita Index is calculated with the following formula:

$$I = Q \frac{\sum_{i=0}^{Q} n_i \,(n_i - 1)}{N\,(N-1)}$$ Eq. 1

I = (Morisita-) Index value
Q = Sum of quadrats in the sampling area
n_i = Number of plants in the quadrat i
N = Sum of plants over all the quadrats

The index value l is thereby calculated from the number of quadrats (Q) in the sampled area, the number of plants in the given quadrat i (n_i) and all plants in the sampling area (N). Thereby, I can assume the value 0 (all plants uniformly distributed) over 1 (all plants randomly distributed) to Q (all plants in one quadrat). Influences hereby are the quality of the longitudinal distribution, measured as coefficients of variation (CV) dependent on seeding rate, and the lateral distribution depending on the selected distance between seed rows in the sampling area. In the selection of grid size, care should be taken that this should tend towards a smaller mesh to give more precise information.

Uniform spacing – i. e. spacing between rows in forage maize at 32.5 cm and an index value (I = 0) is difficult to achieve with modern precision seeding drills because space between the aggregates is very small with structural limitations also caused by sowing depth and seed hopper size requirements.

Drilling systems are available that offer the possibility of smaller distances between seed rows through staggered arrangement of the seed shares, although with poorer coefficients of variation in the longitudinal direction.

Material and methods

Für die Bewertung der Durchwurzelungsintensität und Nährstoffausnutzung wurden in mehrjähFor evaluating rooting intensity (Schroetter 2019) and plant nutrient utilization, various sowing techniques (drill sowing and precision seeding) and seed row distances (17.5 cm, 35 cm, 45 cm, 75 cm) were investigated in multi-year trials on a “geest“ (base-rich, sandy) soil location in Schleswig-Holstein to assess the respective influences on yield, rooting intensity and nutrition utilization by plants.

The 17.5 cm and 35 cm variations were established using a Horsch Focus 6 TD drill with under-seed fertilizer placement capability, the 45 cm and 75 cm variants with a Horsch Maistro 8 CC precision seeder.

Rooting intensity and nutrient supply were measured on three different occasions (BBCH 05 – after sowing, BBCH 18 – at 8-leaf stage, and BBCH 90 – at the end of cob development), sampling in each case repeated twice per variant in the measurement zone (Figure 2). Initially, the seedlings were dug up manually and photographed.

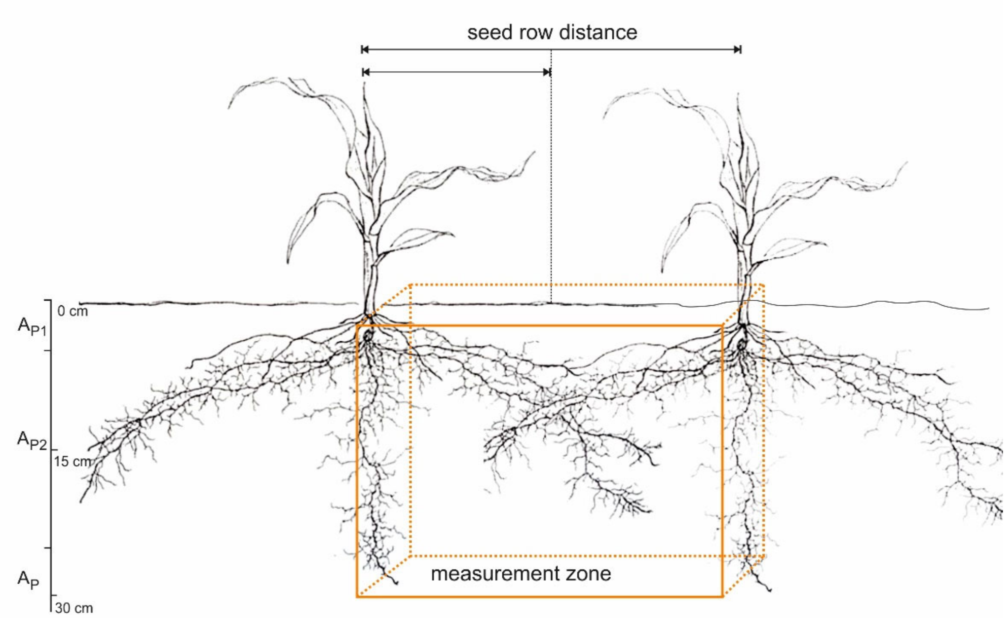

Figure 2 Measurement zone for rooting intensity and nutrient supply between two seed rows (altered according to Lichtenegger et al. 2009).

From the 8-leaf stage onwards, a 30 cm deep hole was dug by spade between two maize plants on opposing rows. From this starting point, the plant roots were one-by-one freed by hand or spade. This approach is necessary because maize develops a dense root network, particularly in the upper 30 cm of soil so important for erosion protection, with root length densities of 2 cm cm^{-3} (Lichtenegger et al. 2009; Schulte-Eickholt 2010; Krüger et al. 2011) After the roots were freed, they were then counted and photographed in every trial plot.

Yields were recorded through manual harvesting of individual plants at sampling points (m^2) with three times repetition and also through yield-mapping by the forage harvester (mass flow sensor with NIR spectroscopy for determining dry matter and forage material constituents).

In addition to own field sampling, photographs of vertical rooting profiles contributed to the results of the investigations into rooting intensity. Based on the photographs, three independent persons visually estimated the proportion of roots using a superimposed grid (Ø > 0.5 mm in classes 0%, 10%, 30%, 50%, 70%, 90% and 100%).

The following photograph (Figure 3) shows a typical exposure from 2018 in the variant precision seeding with 45 cm space between rows.

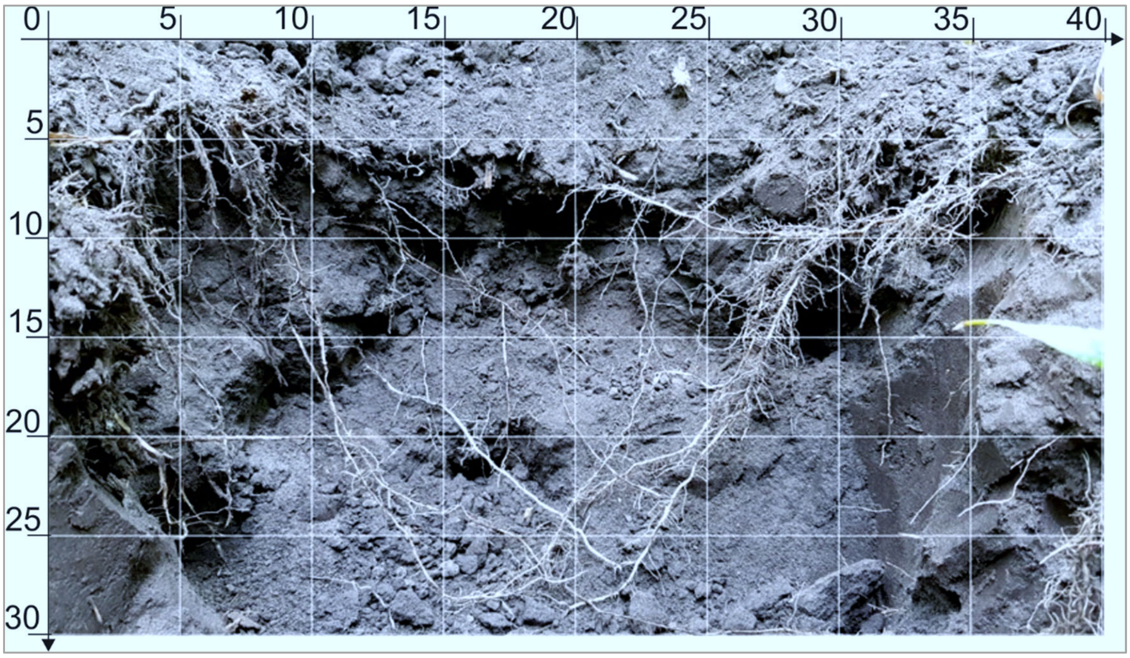

Figure 3: Photo from the measurement zone of the rooting intensity measurement with the example of 45 cm seed row width with 5 cm grid dimension (© Y. Reckleben).

Additionally, these photographs were analysed with CAD software (“CAD/CAS“) to estimate the proportion of roots. For this, each photograph is separated into its spectral ranges to facilitate exact determination of root mass. (Schulte-Eickholt 2010). At the conclusion of a measurement the number of root pixels is divided by the total number of pixels in the measurement range and in this way the percentage of rooting intensity determined. Such optical methods appeared suitable for consideration of changes in rooting intensity as indicator for underground plant development as accompanying parameter for above-ground plant distribution via the Morisita Index (I), in order to take into account the measuring of underground biomass in appropriate frequency under on-farm conditions (Dannowski & Werner 1997; Krüger et al. 2011). Additionally, nutrient samples were taken in the root horizon from measuring points in vertical and horizontal directions in order to evaluate different root intensity grids. These results are to be publicized later.

Results

The following illustrations show the results of rooting intensity (root proportion in comparison to soil proportion in the profile wall) of the pixel analysis compared with the average of the three independent visual estimates.

The CAD pixel analysis is able to show higher relative intensities of rooting in both years (Figure 4 and 5) compared with the visual assessments. These differences are attributable to overestimation of sand particles on the root hairs. However, the trends of both methods are commutated so that CAD pixel analyses can be further used. The advantage of CAD photo analysis is a higher sample throughput per time unit as well as a uniform and relatively objective registration of the roots in the photograph. In 2017, the development of rooting intensity increased between the variants with 17.5 cm distance between rows to 45 cm distance. Lowest rooting intensities between the rows were measured in the 75 cm variant. This was because from mid-May, enough soil moisture was continually available

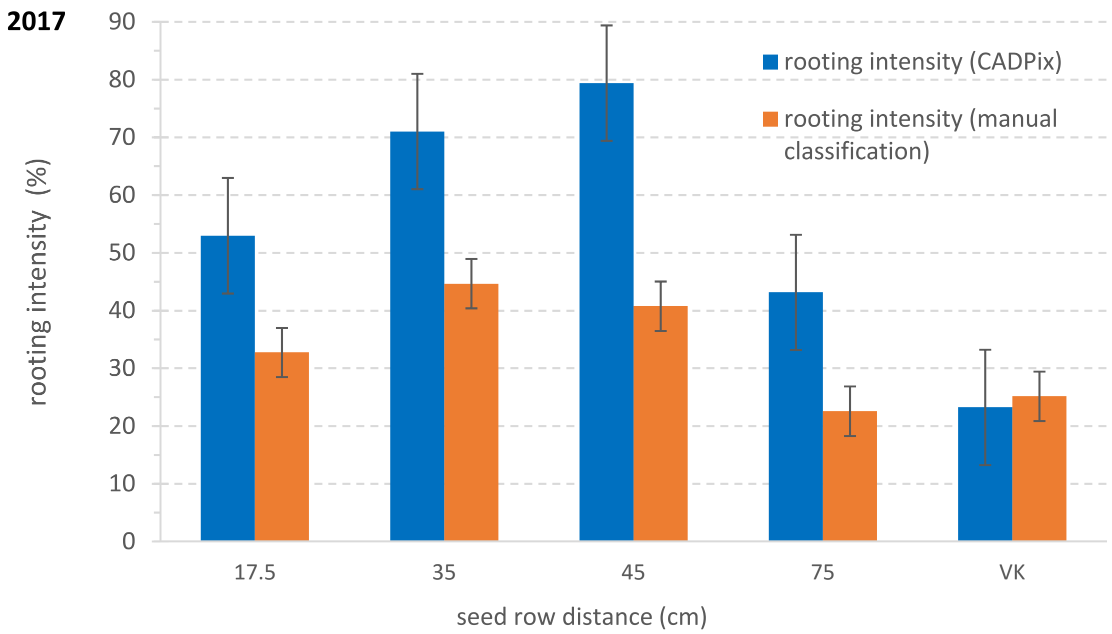

Figure 4: Rooting intensity with standard deviation with various seed row widths in 2017.

so that the roots could absorb sufficient nutrients from the soil. The visually recorded root systems were characterized by a higher proportion of fine roots (Ø < 0.5 mm). The variants with 75 cm space between rows showed in this respect the lowest proportion of roots in the measurement area because the distance to the next row of plants was greater. In 2018, a year characterized by lengthy dry periods, the recorded differences were less. Above all, the variants 17.5 cm and 75 cm had developed substantially more roots. Despite this, in this year too, the 45 cm distance between seed rows showed the highest rooting intensity.

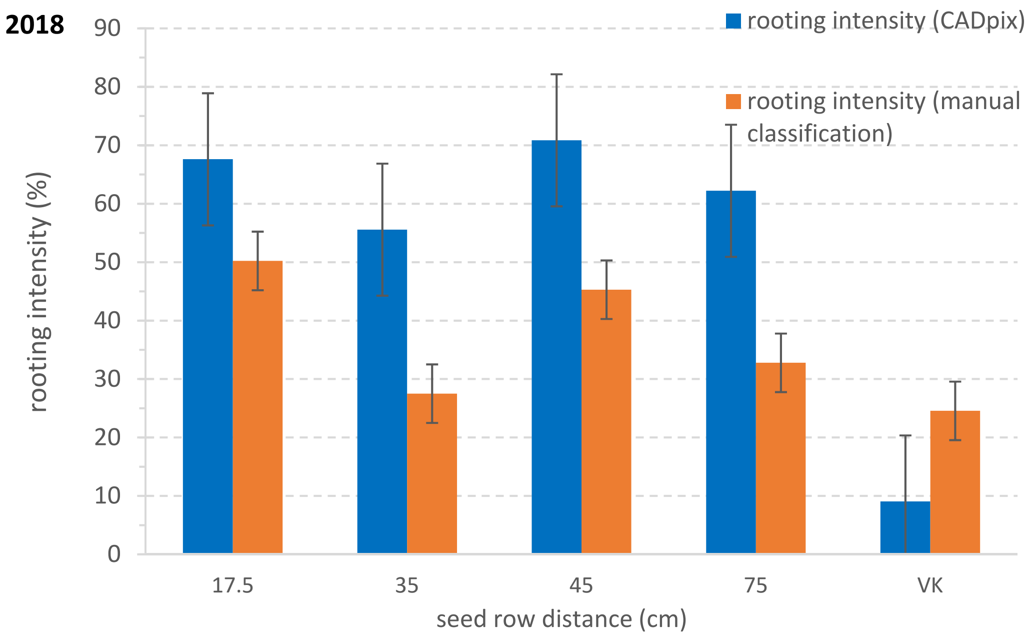

Figure 5: Rooting intensity (%) with standard deviation in 2018 at various row widths.

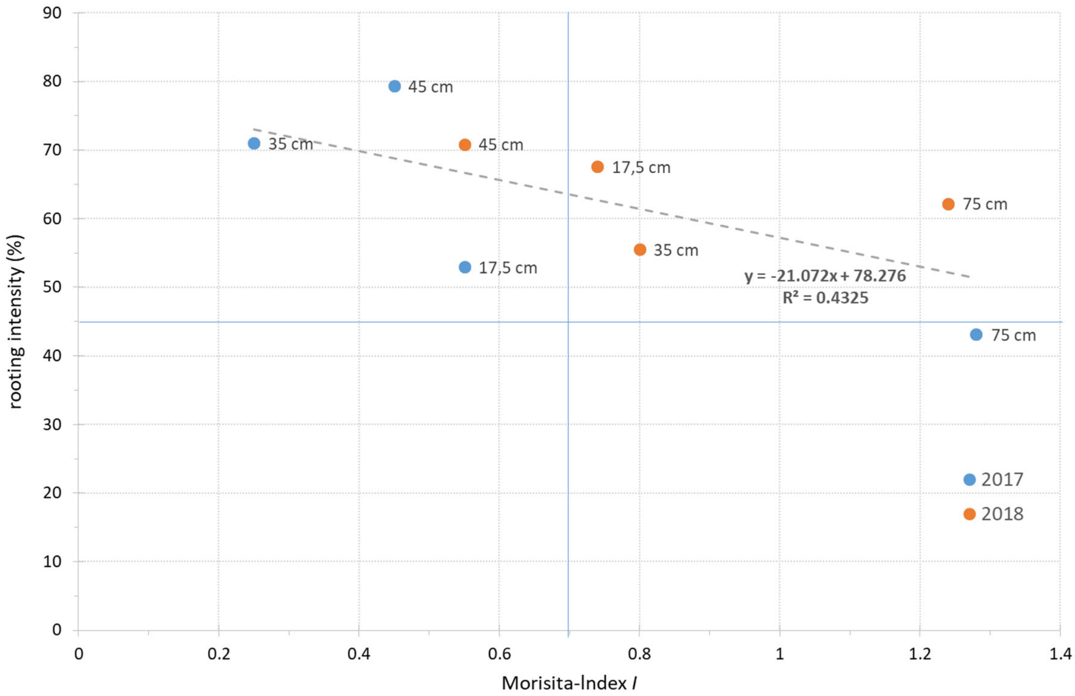

Figure 6: Relationship of Morisita Index and rooting intensity in 2017 and 2018.

The influence of plant space distribution on the soil surface – measured through the Morisita Index – on the rooting intensity is emphasized by Figure 6 for the years 2017–2018.

The higher the quality of the crop space distribution measured through the Morisita Index (l < 0.5) and therefore the spatial conditions for the individual plants, the higher is also the rooting intensity in the upper soil layer. With increasing reduction of the Morisita Index – through too wide spacing between the rows or poorer seed placement precision along the seed rows – the rooting intensity decreases. In the results presented here, the highest rooting intensity is shown in both years for the precision sown crop with 45 cm space between the rows. If a high rooting intensity of more than 70% in the upper soil layer is defined as the target, then three variants are represented (2 x precision sowing with 45 cm space between the rows and 1 x drilled seed with 35 cm space between the rows). The drilled variant can produce high rooting intensity rates. However, this is above all attributable to the narrower distances between the rows. Comparing the two trial years indicates that results are not constant in this respect. This is attributable to the random seed placement through the volume dosing. It was shown in both trial years that the comparably high l value for precision sowing with 75 cm space between the rows resulted in reduced rooting intensity. However, similar results occurred in drier years – as in 2018 – for drilled seed.

The intensity of rooting creates the basis for the expectation that the nutrient uptake in the root horizon will also be higher, an expectation confirmed by higher yields and less residual nitrate content from all sources (Demmel et al. 2000; Wulfes et al. 2001; Peyker et al. 2008; Griepentrog et al. 2011; Reckleben 2011; Morente et al. 2013). The question is to be followed-through with calculations using the information in the following Table 1.

Table 1: Results and calculated nutrient removal in 2017 and 2018.

2017		**Variant**			
Row width		**17.5 cm**	**35 cm**	**45 cm**	**75 cm**
Seeder		**Drilled seed**	**Drilled seed**	**Precision seed**	**Precision seed**
Morisita index value		0.55	0.25	0.45	1.28
Rooting intensity in %		52.96	71.01	79.39	43.15
Yield in t FM/ha		17.5	20.6	23.0	15.0
Nutrient removal in kg/ha [1)]					
	N	70.0	82.3	91.8	59.8
	P	19.1	22.5	25.0	16.3
2018		**17.5 cm**	**35 cm**	**45 cm**	**75 cm**
Seeder		**Drilled seed**	**Drilled seed**	**Precision seed**	**Precision seed**
Morisita Index value		0.74	0.80	0.55	1.24
Rooting intensity in %		67.60	55.56	70.85	62.21
Yield in t FM/ha		35.5	38.2	34.4	37.2
Nutrient removal in kg/ha [1)]					
	N	141.8	152.8	137.6	148.6
	P	38.7	41.6	37.5	40.5

[1)] Biernat (2018).

The harvested yields of forage maize in 2017 and 2018 presented in Table 1 are typical for the locality and show similar trends to those in the literature. (Demmel et al. 2000; Peyker et al. 2008; Reckleben 2011; Morente et al. 2013). The yield results were used for calculation of the major nutrients (N and P) important for the German Fertilizers Ordinance. The withdrawal of nitrogen in carting off the harvested forage in both years varied strongly between 59.8 kg ha^{-1} and 152.8 kg ha^{-1}, with phosphorous the variation over both years was 16.3 kg ha^{-1} to 41.6 kg ha^{-1}. The characteristics of both these years were very different – 2017 wet and cool, 2018 dry and warm. However, both showed their potential for the research into the questions of plant space distribution, rooting intensity and plant nutrient utilization.

Conclusions

Investigation into the important questions concerning plant space distribution and associated available space for the individual plants indicate that the correct variants influence yield positively. The more space available for the individual plants, the higher the resultant yield. Precision seed placement combined with narrow spacing between the rows results in reduced Morisita Index values and higher yields of biomass. With the same amount of fertilizer, this means that higher yields can only be achieved through improved nutrient exploitation in the root horizon. This could be confirmed in trials over several years. A high rooting intensity in the years investigated was, above all, achieved through an exact seed placement (precision sowing) with low Morisita Index values. Rooting intensity increased with narrower spacing between plant rows and so offered, on the one hand, the basis for improved nutrient exploitation and, on the other hand, the advantage of erosion reduction effects during crop growth and post-harvest.

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