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Original Paper

Effect of different fertilizers and no-till versus strip-till on silage maize yield in a dual cropping system

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The effect of different fertilizers (digestate, Urea^{stabil}) and their combinations with strip-till/no-till technology on yield and selected quality parameters of the maize hybrid KWS Kampinos (FAO 200) in a dual cropping system (winter rye – maize) was assessed in two-year field trials (harvest 2021–2022). A significant influence of year was found in most monitored parameters. A total of 6 variants were compared, 2 variants with no-till and 4 variants with strip-till. After using the strip-till method, the silage maize yield increased significantly (11.8–15.4 t DM.ha^{-1}) compared to the no-till method, either on the unfertilized variant (8.3 t DM.ha^{-1}) or after applying fertilizer Urea^{stabil} (11.44 t DM.ha^{-1}). When using the strip-till method, no significant differences in the yield of silage maize (average over 2 years) were demonstrated between these three fertilized variants: Urea^{stabil} (14.03 t DM.ha^{-1}); digestate + Urea^{stabil} (15.4 t DM.ha^{-1}), digestate (14.2 t DM.ha^{-1}) at total dose of 120 kg N.ha^{-1} for each variant. The dry matter content of the silage biomass was insignificant between all the variants (32.0–34.1%). Differences in quality parameters of silage under the influence of fertilization variants were minimal (crude protein, starch, ash, ADF) or none (NDF). From the results obtained, it can be concluded that maize can be successfully grown and fertilized with strip-till soil conservation technology.

Keywords: winter rye, maize, digestate, Urea^{stabil}, yield, strip-till

1 Introduction

Maize (*Zea mays* L.) silage is the most important annual forage crop in the Czech Republic (Skládanka et al., 2014). The cultivation of cover crops or the so-called "dual system" (winter rye – maize), which is used to protect the soil from erosion, to reduce soil water evaporation and nutrient losses from the soil, and to supply primary organic matter in the form of stubble, roots and their exudates, is becoming increasingly important agri-environmentally. According to Everett et al. (2019), the use of dual cropping systems can also be generally considered as a method to reduce N losses through leaching from the soil, by up to 40–70% compared to winter fallow (Pazdera et al., 2023).

Smith (2019) reported that when winter rye was harvested as a pre-crop before planting silage maize, there was a reduction in silage maize yield compared to no-till seeded maize (Pazdera et al., 2023). Also, Singer et al. (2007) stated that depending on climatic conditions in particular, profitability may be reduced due to a decrease in silage yield (Pazdera et al., 2023). According to Raimbault et al. (1991), the possible reduction in maize yield after rye is due to reduced soil moisture and lack of nitrogen availability (Tollenaar et al., 1992), large amounts of post-harvest residues (Raimbault et al., 1991) and the allelopathic effects of rye (Tollenaar et al., 1992). When rye is used as an intercrop, the environmental benefits are immediate and the long-term economic benefits are achieved by maintaining soil fertility (Reicosky & Forcella, 1998). In a dual winter rye-silage maize system, a reduced yield of subsequently grown

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maize was observed compared to the production of maize as a sole crop, but total forage biomass production was higher in the dual rye-maize system (Tollenaar et al.,1992; Pazdera et al., 2023). Thus, the dual system offers the potential for increased profitability in roughage production while being environmentally friendly due to improved soil carbon accumulation and elimination of nitrate accumulation (Pazdera et al., 2023).

Digestates from biogas plants (BPS) are a suitable organic fertilizer for nutrition and fertilization of rye and maize before sowing and during the growing season, because they are characterized by the presence of all macro and microbiogenic elements, with emphasis on N and K. It is a readily available nitrogen fertilizer with a C : N ratio of up to 10. Due to the recent increase in the price of mineral fertilizers or their limited availability (or a combination of both), digestate has become, in many farms, a valuable source of nutrients (Lošák et al., 2014).

The main advantages of strip tillage are (Sundermeier et al., 2006) soil protection by leaving plant residues in between rows, reducing water stress in deeper tillage (compared to full-scale deeper tillage systems), better soil conditions for plant development in the rows compared to uncultivated sowing technologies (Hermann et al., 2012), local fertilizing of plants, which can save fertiliser costs and better sowing conditions (earlier sowing date, lower starting fertiliser rates).

Strip-till technology is usually associated with differential fertilization, with fertilizers deposited in different soil layers or zones with increased nutrient use by plants, such as better rooting or greater moisture security (Brant et al., 2016). Zonal fertilizer application, according to Brant et al. (2017), is the targeted application of fertilizers to specified zones with higher fertilization efficiency. The fertilizer is usually deposited at sowing in the treated strips to a shallower depth, namely 0.05–0.1 m and close to the seed. This local application of fertilizer is one of the main advantages of strip tillage and can save fertilizer costs (Sundermeier et al., 2006).

No-till farming (no-till or direct seeding) is the technology of growing crops or pastures without disturbing the soil by any tillage. Direct drilling can also reduce soil erosion, which cultivation can cause, especially in sandy and dry soils on sloping terrain. An increase in the amount of water infiltrating the soil, the retention of organic matter in the soil or nutrient cycling are considered to be benefits of this technology. Conventional no-till systems use herbicides to control weeds, organic systems use a combination of strategies. For example, Derpsch et al. (2010) report planting cover crops as mulch to suppress weeds.

The main advantages of no tillage are (Neugschwandtner et al., 2020) good bearing capacity of the soil and accessibility of the land, low risk of soil compaction after passage of machinery, intact soil capillarity and prevention of soil evaporation and protection against erosion by mulch on the soil surface.

The aim of this study was to investigate in a 2-year field experiment the effect of different fertilizers ($Urea^{stabil}$ and digestate) in combination with a strip-till system on yield and quality parameters of silage maize grown in a dual cropping system (winter rye – silage maize).

2 Materials and methods

2.1 Experimental site, climate and soil conditions

Field trials were conducted in the years 2020/2021 and 2021/2022 on the land of ZD Nové Město na Moravě (Czech Republic). The experimental site is located 594 m above sea level. The soil type is Cambisol KA, with a Cambrian brown (braunified) horizon. The total rainfall was 711.8 mm (2021) and 619.1 mm (2022), while the July–September rainfall was 252.9 mm (2021) and 211.2 mm (2022). The average annual temperature was 7.8 °C (2021) and 8.92 °C (2022).

Temperature is important for maize. The ideal temperature requirement should be around 13 °C on average (Skládanka et al., 2014). In 2021, the average temperature in the sowing-harvesting period (May–October) was 14.3 °C and in the same period in 2022 it was 15.4 °C. Maize is sensitive to temperature fluctuations during the growing season.

The soil was extracted according to Mehlich III (0.2 mol.dm^{-3} CH_3COOH + 0.25 mol.dm^{-3} NH_4NO_3 + 0.013 mol.dm^{-3} HNO_3 + 0.015 NH_4F + 0.001 M EDTA). Determination of available phosphorus content in the leachate was carried out colorimetrically, potassium by flame photometry and magnesium by AAS. The mineral nitrogen content (N_{min}) was given in two items as nitrate nitrogen (NO_3^-) in mg.kg^{-1} and ammonium nitrogen (NH_4^+) mg.kg^{-1} of soil (Klement & Prchalová, 2013) and was calculated as the sum of nitrate and ammonium nitrogen. Soil exchange reaction was determined by potentiometric measurement of hydrogen ion activity in a leachate with 0.01 M $CaCl_2$. Determination of humus content was carried out by the modified Tjurin method (Valla et al., 2002). The sulphur content of the soil was then determined in ammonium acetate solution (Pazdera et al., 2023). The basic agrochemical characteristics of the soil are given in Table 1 and Table 2.

Digestate was applied on 11 September 2020 and on 23 September 2021 at a rate of 30 t.ha^{-1} to the soil surface

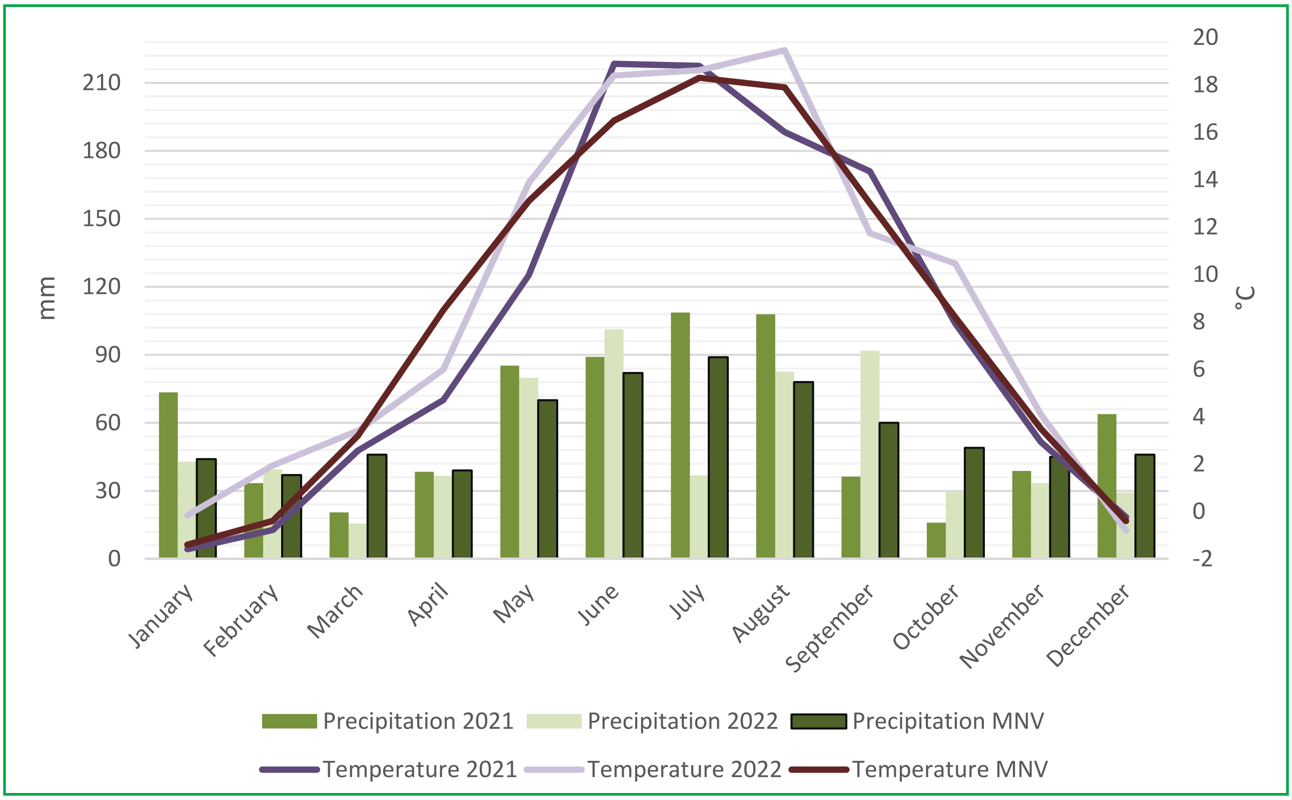

Figure 1 Average monthly temperature (°C) and precipitation (mm) in 2021–2022
Source: Pazdera et al., 2023; ČHMÚ, 2022
MNV – monthly normal value (1991–2020)

with a hose applicator and then this digestate was plowed to a depth of 30 cm. The chemical composition of the digestate is shown in Table 3.

2.2 Crop cultivation and experimental variants

The sowing of winter rye variety KWS Progas was carried out on 18 September 2020 and 29 September 2021 at a rate of 100 kg.ha^{-1} with a Väderstad Rapid A 800S pneumatic drill.

Rye was harvested in both years on the 17 May 2021 and on the 10 May 2022. The size of the plots for yield determination was 150 × 6 m, i.e., 0.09 ha.

After the winter rye harvest the stubble was destroyed using a total herbicide with wetting agent (18 May 2021; 11 May 2022). The maize variety KWS Kampinos was then established in different variants which differed regarding tillage (strip-till versus direct sowing) and fertilizer type (control, Urea^{stabil}, digestate) (Table 4).

Table 1 Agrochemical analyses of the soil (0–30 cm) before the establishment of the rye experiment and before autumn digestate fertilization

Year	Depth (cm)	pH ($CaCl_2$)	N_{min} (mg.kg^{-1})	Nutrient content (mg.kg^{-1}) (Mehlich III)					Humus (%)
				P	K	Ca	Mg	S	
2020	0–30	5.94	21.2	87.5	390	2,920	236.4	2.5	2.24
2021	0–30	6.54	20.3	52.5	263	2,650	293	1.3	2.28

Table 2 Agrochemical soil (0–30 cm) analysis before sowing maize in spring 2021 and 2022

Year	pH ($CaCl_2$)	N_{min} (mg.kg^{-1})	Nutrient content (mg.kg^{-1})					Humus (%)
			P	K	Ca	Mg	S	
2021	5.87	18.6	90	463	950	210	5	2.54
2022	5.69	19.7	78.8	240	1,050	270	1.3	2.38

Table 3 Chemical composition of the digestate

	2020	2021
Dry matter content (DM) (%)	6.52	7.12
Combustible substances content in DM (%)	72.54	70.79
pH	7.66	7.82
Nutrients (% in fresh matter)		
N_{tot}	0.50	0.62
$N\text{-}NH_4^+$	0.291	0.316
P	0.063	0.082
K	0.569	0.565
Mg	0.049	0.029
P	0.183	0.118

In the strip-till variants (variants 3–6), the digestate was applied in one operation to the soil below the maize sowing depth and a strip of soil was liquefied to a maximum width of 30 cm. Sowing was then carried out with a precision drill Monosem NG plus 4 into these strips (using GPS). For the variants without strip-till (var. 1, 2), direct sowing into the winter rye stubble was carried out. For the variants with urea (var. 2, 4, 5), the application of Urea^{stabil} was made broadly on the winter rye stubble.

Fertilization included controls with no fertilization (variants 1 and 3), sole Urea^{stabil} application (variants 2 and 4), sole digestate application (variant 6) and a combination of Urea^{stabil} and digestate application (variant 5). For the fertilizer Urea^{stabil} 100% N use was assumed while for the application of digestate, 60% an-use was assumed, based on the current principles and regulations for vulnerable areas of the Czech Republic (Wollnerová et al., 2020). Thus, the total N rates were identical (120 kg N.ha^{-1}) for the variants fertilized in spring (var. 2, 4–6), Table 4. Urea^{stabil} (46% N) is urea with the urease inhibitor.

Silage maize was harvested in both years at the vegetative stage of milk-wax maturity, on 5 October 2021 and 10 October 2022. Harvesting was fully mechanised and chemical analyses of plant biomass were carried out in the laboratory according to accredited procedures. Plant material: N by Kjeldahl method, P by colorimetry, K by flame photometry, Mg and Ca by AAS.

2.3 Analyses of plant material

The total N content of the samples was determined using the Kjeldahl method. Crude protein (CP) was calculated by multiplying the content of nitrogen with 6.25. The ash content was determined by dry oxidation. Crude fibre was chemically determined. Van Soest et al. (1991) characterize crude fibre as a cell wall composed of cellulose, hemicellulose and lignin, which together form neutral detergent insoluble coarse fibre (NDF). In addition to NDF, the acid detergent insoluble crude fibre (ADF) is also determined. The principle of the method is the separation of the ADF from the neutral detergent matrix (NDF), based on the acid hydrolysis of the NDF while denaturing the matrix proteins (Třináctý et al., 2013). Starch was determined by the hydrolytic method, namely polarimetrically.

2.4 Statistical analysis

The obtained results were statistically processed by one-factor and multi-factor analysis of variance (ANOVA) followed by testing using Fisher's least significant difference (LSD) at p <0.05 in Statgraphics Plus 5.1.

3 Results and discussion

The results from a two-year trial are presented in Table 5. They confirmed earlier results by other authors (Hermann et al., 2012; Brant et al., 2016) that the application of digestate at a rate of 30 t.ha^{-1} before sowing is sufficient in terms of ensuring sufficient yield. The results showed statistically significant inter-annual differences for all parameters monitored. In terms of DM yield (t.ha^{-1}), there is a statistically significant effect of the use of strip-till technology, with higher DM yields of 54.1% (2021) and 32.2% (2022) for variant 3 compared to variant 1

Table 4 Types and rates of fertilisers and N rates for each variant and tillage method

Variants	Spring applications to sown maize		
	fertiliser type/spring fertiliser rate	tillage	total nitrogen rate from spring application (kg.ha^{-1})
1	–	no-till	0
2	Urea^{stabil}/260 kg.ha^{-1}	no-till	120
3	–	strip-till	0
4	Urea^{stabil}/260 kg.ha^{-1}	strip-till	120
5	digestate/20 t.ha^{-1} Urea^{stabil}/130 kg.ha^{-1}	strip-till	120
6	digestate/40 t.ha^{-1}	strip-till	120

(no-till), respectively, in both years. There are significant differences in average yields between variants 2 and 4 (11.44 t.ha^{-1} for variant 2 and 14.03 t.ha^{-1} for variant 4), both of which were fertilized with the same dose of Urea^{stabil}. The only difference is in the use of strip-till technology for variant 4, which yielded 15.3% more in 2021 and 31.6% more in 2022 than variant 2. Strip tillage has many advantages, including the fact that the stubble protects the soil from erosion or siltation and the post-harvest residue on the soil surface prevents evaporation. Undisturbed soil provides the necessary capillary moisture for rapid germination while being rich in immediately available nutrients, oxygen and water, which promotes rapid and healthy root development. The tilled strip is mineralized, contains ample nutrients, and provides good seed-to-soil contact (Brant et al., 2017). The combination of tilled soil in the tilled strip and untreated soil covered with mulch in the inter-rows has a positive effect on soil water availability, infiltration and erosion processes, and other physical as well as chemical and biological soil properties, and also significantly affects root development. The management of post-harvest residues and the use of intercrops play an important role. Strip-till also allows for the application of manure or digestate during tillage into the soil profile (Brant et al., 2016). All these factors had an impact on the yield increase for strip-till technology compared to no-till. The average dry matter content of silage maize (%) of all the variants was 29.0% in 2021 and 36.9% in 2022, which can be explained by the higher temperature and lower rainfall in 2022 as the maize crop matured. The lower dry matter content of silage maize (<29%) can lead to the formation and release of silage fluid, resulting in large nutrient losses and poorer fermentation. Conversely, a higher dry matter content (>35%) can lead to poorer smothering, heating and mould development in silages, higher nutrient losses and a decrease in energy concentration (Doležal, 2019). Zeman et al. (2006) reported that feeding higher dry matter corn silage results in a greater proportion of starch reaching the small intestine, which

Table 5 Maize dry matter yield results at silage maturity (2021–2022) and silage nutritive value (average results)

Parameter	Year	Variants						Values from literature*
		1	2	3	4	5	6	
Yield in DM (t.ha^{-1})	2021	8.09a	12.6b	12.5b	14.5c	17.2d	14.4c	11.5–30
	2022	8.4a	10.3b	11.1b	13.6c	13.5c	14.07c	
	average	8.3 A	11.4 B	11.8 B	14.03 C	15.4 C	14.2 C	
Dry matter (%)	2021	29.4ab	29.1ab	27.7a	30.02b	29.1ab	29.0ab	30–38
	2022	36.1a	35.8a	36.3a	38.2a	37.1a	38.0a	
	average	32.7 A	32.4 A	32.0 A	34.1 A	33.1 A	33.3 A	
CP (% in DM)	2021	8.1b	7.6b	6.9a	7.9b	7.7b	7.6b	6.5–8
	2022	7.6a	8.02a	7.1a	7.8a	7.8a	7.5a	
	average	7.8 B	7.8 B	7.0 A	7.9 B	7.7 B	7.5 AB	
Starch (% in DM)	2021	36.7d	32.02bc	26.5a	33.8cd	28.3ab	29.5abc	28–35
	2022	36.1a	36.7a	35.03a	33.6a	33.7a	34.4a	
	average	36.4 B	34.4 AB	30.8 A	33.7 AB	31.03 A	31.9 A	
Ash (% in DM)	2021	3.6a	3.4a	4.4b	3.8ab	3.6a	3.9ab	4–6
	2022	3.2ab	3.07a	3.2ab	3.6b	3.4ab	3.3ab	
	average	3.4 AB	3.3 A	3.8 B	3.7 AB	3.5 AB	3.9 AB	
ADF (% in DM)	2021	22.9a	25.6a	26.03a	25.5a	26.06a	26.0a	21–27
	2022	20.5a	21.9a	23.9a	25.4a	24.0a	22.3a	
	average	21.7 A	23.8 AB	25.0 AB	25.4 B	25.03 AB	24.1 AB	
NDF (% in DM)	2021	44.9a	47.4a	44.3a	44.4a	47.7a	45.4a	35–50
	2022	57.0b	55.5ab	51.5a	56.6ab	59.0b	56.1ab	
	average	51.0 A	51.4 A	47.9 A	50.5 A	53.4 A	41.9 A	

Source: * Zeman et al. (2006); Třináctý et al. (2013)
Different letters (a, b, c, d, e) indicate significant differences in a given year between variants for a given parameter (p <0.05); different letters (A, B) indicate conclusive differences in a given variant and parameter between years; DM – dry matter, CP – crude protein, ADF – acid-detergent fibre, NDF – neutral-detergent fibre

is more favourable and efficient in terms of utilisation for the actual carbohydrate metabolism than the rumen digestion process. To improve the availability of starch in maize silage, it is essential to improve the processing of maize grain (Beauchemin & Yang, 2005). Maize silage is an important source of not only the required energy source in the form of starch but also coarse structural fibre (Saylor et al., 2021). Our values are consistent with the literature, as the general principle is that the higher the dry matter content, the shorter the length of the cut must be. At dry matter contents above 35%, the length is shortened to 6–8 mm. In this context, Bal et al. (2000) note that reducing the particle size of maize silage will increase starch digestibility throughout the digestive tract. According to Cooke & Bernand (2005), extending the theoretical length of maize silage cuttings beyond 19 mm and poorer maize grain processing causes a reduction in organic nutrient digestibility and dairy cow performance. Quality maize silages are generally easily digestible feeds with low degradable N contents (8–9%) and are therefore combined with protein silages (clover, alfalfa) in mixed rations (Zeman et al., 2006). Our results in both years are similar to other published works. The difference in crude protein (CP) content between the treatments was also minimal. Jendrišáková (2010) reported that the CP content depends on many factors, but it is minimally affected with increasing maize dry matter content. The average starch content was 31.1% in 2021 and 34.92% in 2022. Starch is the main source of energy in maize silage and has a major effect on dairy cow performance. The total starch content contributes 45–50% of the total energy content of maize silage, with another 25% being NDF and the rest being sugars, pectins, organic acids and fat (Mitrík, 2010). The average ash content was 3.8% in 2021 and 3.30% in 2022, which is a positive result even when compared to literature sources. Acid-detergent dietary fibre (ADF) is a fraction of fibre insoluble in acidic environments and the digestibility of energy and organic nutrients of feed decreases with increasing ADF concentration (Doležal et al., 2019). Average ADF values were 25.4% in DM in 2021 and 23.0% in 2022, which is in agreement with other published results (Horst et al., 2020). Neutral-detergent fiber (NDF) is the fraction of fiber insoluble residue in neutral solution and its important role is to participate in the maintenance of proper rumen function and is also closely associated with dry matter intake (Zeman et al., 2006) and is also a source of energy. The difference of NDF compared to ADF is that the hemicellulose it contains has a positive effect on digestibility and filling capacity (Doležal et al., 2019). The average values of NDF were 45.7% in dry matter in 2021 and 55.94% in 2022. According to Mitrik (2010), the NDF content in the highest quality maize silage should be ≤38% in dry matter.

4 Conclusions

The results of this two-year trial have shown that silage maize can be successfully incorporated into a post-harvest system of winter silage rye, fertilised with pre-sowing digestate using rye stubble as an anti-erosion factor, using both traditional technology (without strip-till) and using this soil-protecting strip-till technology. The results of the two-year trial confirmed that the yield of silage maize grown with the more environmentally friendly strip-till technology was higher compared to the no-till technology. When using the strip-till method, no significant differences in the yield of silage maize were demonstrated between these three fertilized variants: Urea^{stabil}, digestate + Urea^{stabil} and digestate at total dose of 120 kg N.ha^{-1} for each variant. It was confirmed that the application of digestate (alone or in combination with Urea^{stabil}) is very suitable for growing of silage maize. Several factors must be taken into account when evaluating the yield and quality results, such as the cultivation system used (strip-till or no strip-till), the total nitrogen dose from the spring application of fertilizers, the type of fertiliser used (Urea^{stabil}, digestate) or their combination, soil nutrients supply, the average monthly temperature and the amount and distribution of rainfall in a given year.

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