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Monitoring the Ripening Dynamics of Maize Crops during the Harvest Period

(For the Purpose of Correct Harvesting Dates, Site-Appropriate and Use-Specific Optimised Maize Cultivation for All Types of Use)

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Abstract

Efficiency and product safety with simultaneous sustainability in environmentally friendly maize cultivation through periodic monitoring of the ripening dynamics in the period close to harvest is possible in a practical and future-oriented manner with three ripening methods developed for this purpose. The asynchronous ripening ratio of generative (grain) to vegetative plant parts (residual plant vitality) is the core of the systems biology DRA assistance system. From an economic and ecological point of view, a ripening ratio (SRI of 2.8) should be aimed for as a sign of the suitability of environmentally and ripening stable maize varieties for all types of cultivation. On the one hand, the aim is to specify the results of current variety tests with regard to ecophysiologically optimal maize ripeness, site suitability, phenotyping and reproducibility of performance and resistance. On the other hand in the future, autonomous forage harvesters will also use sensor technology to record the DM of intire plant and starch content while simultaneously using the total plant/starch (G/S) ripening method developed by the author, which, among other things, significantly improves the informative value of the DM content of the entire plant. It is then possible to precisely determine the start of harvesting and optimally coordinate the harvesting sequence of the fields by additionally displaying data on grain ripeness, the condition of the residual plants and the Silo maize Ripeness Index (SRI) on the monitor of the forage harvester.

This information can then be sent wirelessly to mobile devices so that the maize farmer can ultimately make a situation-based decision on harvesting, even if he does not know the crop. This information is the direct basis, with simultaneous identity of genotype and phenotype, for the upcoming site-specific and use-specific variety selection as well as the consequent reduction in the area under maize cultivation, including its utilization, which can then also be seen as a contribution to the social environmental economy.

Keywords: *DRA System, Harvesters with NIRS-Sensor, Optimal Environmental Factors, Reference Ripening Point, Silage Maize Ripening Index (SRI).*

INTRODUCTION

The determination of the harvest date with the current usespecific ripening system in Germany separately for silage or grain maize, based on their DM content according to the most diverse ripening provisions, is obvious, but has many serious weaknesses in detail (Haarhoff 1990; Miltner 1997; Eder 1999; Herrmann 2004; Meier, Bleiholder 2006).

Today and in the future, this is of little help for economic or ecological aspects for the ripening classification and harvest decision, especially in extreme ripeness, cultivation and environmental conditions (Ledrew, Daynard, Muldoon JF1984; Weißbach, Auerbach 1999).

The current ripeness system with the DM content of the whole plant as an indicator of ripeness or the two use-specific ripeness numbers for the variety selection of silage and grain maize (SRZ, KRZ) is only of limited significance for a comprehensive classification and evaluation of the phenotypic stability of the performance of all maize varieties, directions of use and locations of maize cultivation under all conceivable cultivation situations. It is also not possible to characterize and quantify the local ripeness, cultivation and environmental conditions, the ripening-specific variety type, an autonomous adjustment of the harvesting technique based on the dry matter and starch content and the determination of site suitability as the basis for a technically sound variety selection, also in view of the consequences of progressive climate change, with the degree of ripeness (DM

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content) of the maize crop (Amler 2004, 2013, 2016, 2019). Irrespective of this, the DM content of maize crops has been used as a measure of ripeness during harvesting, primarily for labor management reasons. However, this has proven to have extensive weaknesses.

Environmentally stable and unstable maize varieties scatter widely even with supposedly optimal DM content and often do not reach the ecophysiologically optimal maize ripeness of SRI => 2.6. The uncertainty in the ripeness assessment of maize crops increases as the environmental influence becomes stronger, since the ripening of the residual plant has a significantly higher effect on the DM content of the maize plants compared to grain ripeness (Amler 2016).

Product safety, environmental impact and sustainability can be precisely controlled and holistically evaluated for every phenotyped maize variety, at all locations and in every year with ever less manual effort by determining the ecophysiologically optimal maize ripeness as the final measure of crop management and "smart farming" using a single indicator or by applying the silage maize ripeness index (SRI). This is a contribution to environmental ecology, its economic effectiveness in the entire maize cultivation of all directions of use and unbroken acceptance in the comprehensively informed population (Amler 2016, 2019).

PRODUCT SAFETY

It is difficult to guarantee product safety throughout maize cultivation by stabilizing yield and quality in view of the mostly dominant environmental influences. Breeders use the practice of disclaiming liability on variety brochures. Despite breeding progress, which is reported from year to year in favorable locations, risk assessment in maize cultivation is possible with the ripeness, stress and selection indicator, the Silage maize Ripeness Index (SRI), on different practice fields (Fig. 1).

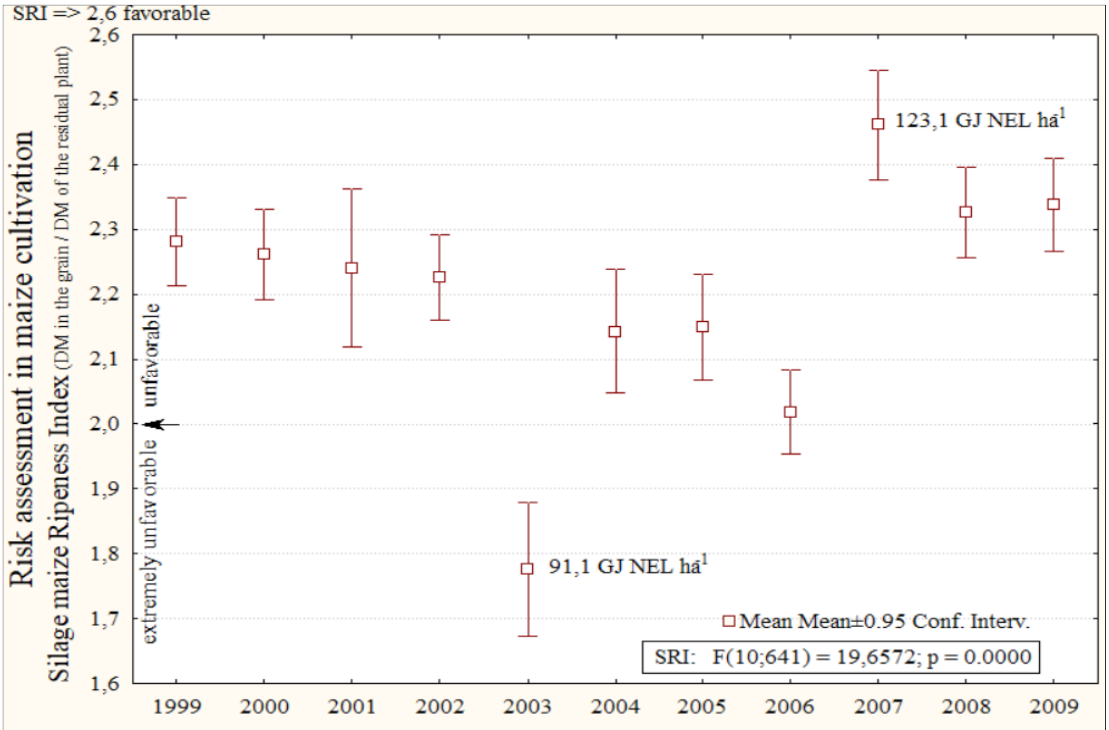

Fig. 1: Annual influences (SRI) and the level of net energy yield of four central German silage maize locations in the years 1999 to 2009 (Amler 2014)

The influence of the environment over the eleven years evaluated, as measured by the SRI, is clearly visible (Asch 2005). This must be counteracted and significantly reduced through breeding by selecting varieties that are more suitable for the location and use and by using modern cultivation methods, including a more precise determination of harvest time (Amler 2013). A risk in maize cultivation can only be determined to a limited extent over this short period of time. This requires long-term data series, e.g. based on the offsetting varieties in conjunction with the (G/S) ripening method.

Extreme cultivation years were, for example, 2003 and 2007. The difference between the two years, measured in terms of net energy yield, is 32.0 GJ NEL per ha.

For a cow herd with an annual milk yield of 8000 kg per cow and year and an energy requirement of 5.0 MJ per kg of milk, the difference in net energy shown corresponds to a milk production value of 6400 kg of milk per ha. Proof of environmental stability is undoubtedly the indispensable basis for the ripening and yield stability and site suitability of maize varieties at a high level of utilization and quality (Pigliucci 2001).

SILAGE MAIZE RIPENESS INDEX

The current representation of ripenss in maize cultivation is not very convincing if the DM content of the maize crop is used as a measure of ripeness. The SRI, on the other hand, is more accurate and multifunctional (Fig. 2).

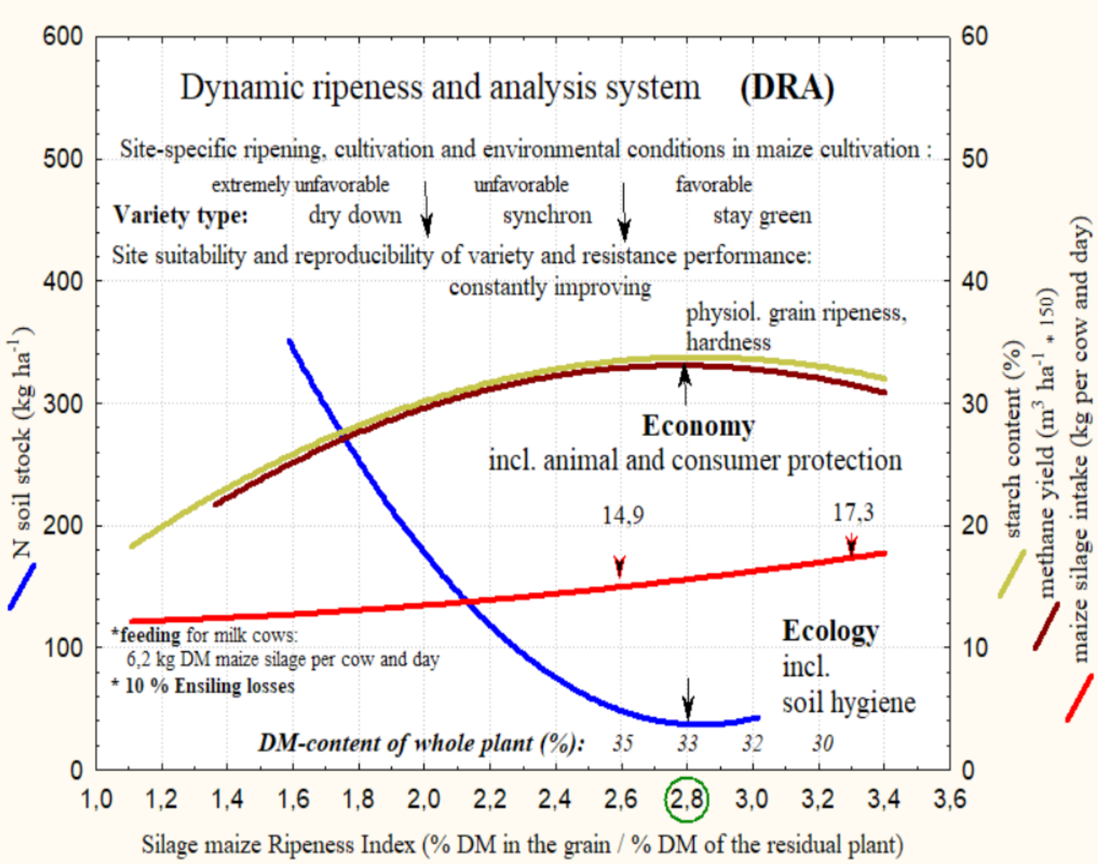

Fig. 2: Reference ripeness point of ecophysiologically optimal maize ripeness (SRI of 2.8) for all directions of use in harmony with economy and ecology (Amler 2015)

The more environmentally stable a variety is, the more pronounced the product safety, efficiency and sustainability in maize cultivation and the subsequent stages of production. The Dynamic Ripeness and Analysis System (DRA) shows the current problems holistically using the ripeness, stress and selection indicator, the Silage Maize Ripeness Index (SRI), without any alternative (Amler 2016).

The site-specific ripeness, cultivation and environmental (RCE) conditions in maize cultivation as a whole and the specific ripening variety types can be divided into three categories, as shown in Fig. 2.

However, the evaluation of both economic and ecological parameters can be carried out continuously, without ranges or upper limits. This means that the correct harvest time point (HTP) is reached at the maximum possible SRI. The DM ratio of grain to residual plant is then at its maximum. It is very variable and can, however, be in the suboptimal or pathobiochemical as well as desirable in the optimal, nutritive to dietetic feed value range. This ripeness ratio depends on the robustness of the variety as well as on the local RCE conditions. The range of ecophysiologically optimal maize ripeness starts at an SRI value of 2.6 and is open at the top.

The ecophysiologically optimal reference ripening point of SRI = 2.8 should be aimed for in the long term, where both economy and ecology have their respective optimal values. The differences in ripeness between the directions of use (gas, fattening, grain and milk), locations and years are then minimal and therefore insignificant. The order in which the fields are harvested and the allocation of silos are influenced by other characteristics (Ettle; Schwarz 2003):

- Maize for biogas should also be large-framed, mycotoxin-free, with a highly digestible cell wall and chopped short.
- Maize for bull fattening should be rich in starch, energy and structure.
- Stable grain maize with high grain potential has ecophysiologically reached its maximum starch value at an SRI of 2.8 and remains in the field to reduce residual moisture and broken grain losses, taking into account other economic and crop rotation aspects.
- At this point, maize with high cell wall digestibility can also be harvested for nutritive-oriented high-performance feeding, while maize for dietary-oriented feeding can be harvested at maximum SRI.

The physiological grain ripeness and grain hardness of ripening-stable maize varieties (SRI of 2.8) in turn result in higher passage rates of rumen-stable starch into the small intestine with better utilization rates associated with the increasing SRI. The DM content of the entire plant decreases linearly in this context. Plant health (mycotoxins, carotene), palatability and structural effectiveness improve measurably (Lotthammer1985; Drochner 1990; Oldenburg 1997; Hoffmann and Richardt 2010). In dairy cow feeding, maximum quantities of absolute forage are consumed with the same quality; a basic principle of ruminant nutrition in order to save concentrates.

In addition, the more precise, ripening-related crop management comprehensively improves the ecological conditions in the field, such as the minimized N soil stock as a result of better adapted fertilization to the development-related nutrient requirements, the elimination of silage leachate into the groundwater and no excessive contamination of the soil with Fusarium toxins. The latter in turn is important for the subsequent crop winter wheat (Amler 2019).

VARIETY SELECTION ACCORDING TO THE DRA SYSTEM

The DRA system concludes with the site-specific and use-specific variety selection. One example is the extended evaluation of a variety test (Table 1).

Table 1: Extended ripeness analysis of the harvest results of variety tests (mfr. ripeness group) using the G/S ripening method according to the DRA system (Amler 2020)

		ripeness		yield						feed quality			Ripeness analysis according to the G/S method of the DRA system			
		DM		DM		energy		starch		starch		energy density	DM content	DM content	Silage maize	SRI rank
Calculation basis = 100		32,8	100	172,1	100	105,1	100	47,6	100	26,9	100	6,1	grain	residual plant	Ripeness Index	
(average of 5 varieties)		%	rel.	dt/ha	rel.	GJ NEL ha	rel.	dt/ha	rel.	% T	rel.	MJ NEL/kg T	%	%	SRI *	
varieties	SRZ**												ökophysiologische Maisreife und Standorteignung (SRI)			
variety 30	S 250	31,0	95	169,7	99	107,0	102	48,2	101	27,8	103,3	6,3	66,0	24,6	2,68	1
variety 25	S 240	32,7	100	167,1	97	105,3	100	50,0	105	29,4	109,3	6,3	67,4	25,4	2,66	2
variety 20	ca. S 240	29,8	91	162,9	95	97,7	93	41,4	87	24,4	90,7	6,0	65,3	24,6	2,65	3
variety 24	S 240	31,5	96	165,2	96	101,6	97	45,8	96	26,8	99,6	6,1	66,6	25,2	2,64	4
variety 1	**S 240**	**32,2**	**98**	**165,1**	**96**	**103,3**	**98**	**47,0**	**99**	**27,4**	**101,9**	**6,2**	**67,1**	**25,6**	**2,63**	**5**
variety 5	**ca. S 250**	**31,8**	**97**	**174,1**	**101**	**104,9**	**100**	**47,5**	**100**	**26,4**	**98,1**	**6,0**	**66,9**	**25,6**	**2,62**	**6**
variety 29	S 250	32,2	98	169,6	99	104,7	100	47,4	100	27,0	100,4	6,1	67,2	25,7	2,62	7
variety 6	S 230	33,2	101	181,2	105	112,2	107	52,6	111	28,5	105,9	6,2	67,9	26,0	2,61	8
variety 11	S 240	32,9	100	163,1	95	98,9	94	45,7	96	27,5	102,2	6,0	67,7	26,1	2,60	9
variety 23	S 240	33,8	103	169,0	98	104,1	99	46,3	97	26,8	99,6	6,1	68,5	26,9	2,54	22
variety 18	S 240	31,7	97	173,1	101	103,3	98	40,8	86	22,7	84,4	5,9	66,9	26,5	2,53	23
variety 8	S 240	32,7	100	164,5	96	97,0	92	41,1	86	24,3	90,3	5,9	67,7	26,8	2,53	24
variety 19	S 250	32,2	98	173,3	101	102,5	98	42,5	89	23,3	86,6	5,9	67,3	26,7	2,52	25
variety 10	S 230	33,3	102	177,7	103	103,4	98	45,2	95	24,7	91,8	5,8	68,1	27,1	2,51	26
variety 15	S 230	35,3	108	170,7	99	103,3	98	48,6	102	27,6	102,6	6,0	69,5	27,8	2,50	27
variety 14	S 230	35,6	109	171,1	99	103,3	98	49,1	103	27,8	103,3	6,0	69,7	27,9	2,50	28
variety 26	S 230	34,3	105	161,5	94	94,6	90	41,2	87	25,0	92,9	5,8	68,8	27,8	2,48	29
variety 12	S 230	35,8	109	172,0	100	101,6	97	47,2	99	26,8	99,6	5,9	69,8	28,4	2,46	30
Trial average		33,0	101	169,7	99	102,9	98	46,2	97	26,5	98,5	6,0	67,7	26,4	2,57	

* Silage maize Ripeness Index (SRI) = grain ripeness (%) / residual plant ripeness (%), determined using the G/S ripening method with dry matter and starch content (%).

** Silage maize ripeness number (Germany)

In addition to the large number of test parameters, the extended ripeness and root cause analysis can also be used to determine the ripeness of the grains, the ripeness of the residual plant and the Silage maize Ripeness Index. The significance of the DM content of silage maize by including the starch content by providing a pre-programmed table of the G/S ripening method (Amler 2019).

The 9 best and worst varieties of the test were shown (excerpt). In general, it can be seen that the maize was harvested too late due to the method. Accordingly, the yield and quality levels are unsatisfactory. The diagram shows that within the medium-early ripening group, the later varieties were harvested at approximately the right time. Whereas the earlier maize varieties were harvested too late. This is also evidence of the excessively wide range of the medium-early ripening group.

The extended ripeness analysis also shows that both the target values for grain ripeness (approx. 63 % DM) and the ripeness of the residual plant (< 23 % DM) were outside the optimum range. In addition to showing the ecophysiological state of ripeness, the Silage maize Ripeness Index enables an exact ranking of the suitability of the varieties for the location. This also makes it possible to concentrate on a few top varieties that meet both the economic and ecological requirements of regional maize cultivation, including the social aspects of acceptance of extended maize cultivation (Amler 2016).

In addition to this extended ripeness analysis in variety tests, the findings can also be consistently implemented on the forage harvester with simultaneous use of the G/S ripening method if it is equipped with a sensor on the discharge manifold to measure the DM content and its starch content. Knowing the grain ripeness allows the grain cracker to be controlled autonomously, while the chopping length can be regulated automatically based on the result of the ageing of the residual plant. This is not only a relief for the forage harvester operator, but a basic requirement for autonomous harvesting machines (Amler 2019).

CONCLUSION

- The use of the DRA system to refine the results of current variety tests is essential and leads to greater product safety, efficiency and sustainability.

- Forage harvesters with sensor technology can produce optimized chopped material for specific uses in conjunction with the G/S ripening method.

- In addition, the information on variety selection is made more precise by proving the suitability of the location.

- The analysis of environmental factors and the phenotyping of maize varieties can lead to the stabilization of yield and quality levels with simultaneous acceptance of maize cultivation by the population.

Taking into account the mostly dominant environmental influence, a new ripeness, stress and selection indicator, the silage maize ripeness index (SRI), makes it possible to control the ecophysiological maize ripeness and production of the use-specific optimized chopped material during harvesting, conservation and feeding, also taking into account aspects of soil hygiene (avoidance of leachate, soil N and Fusarium toxins), in comparison to the DM content of the entire plant or the use-specific ripeness figures (SRZ, KRZ as components of a static ripeness system, the SRI answers the cardinal question of ecophysiologically optimal maize ripeness (SRI of 2.6 and higher), product safety, environmental influences and sustainability holistically and precisely.

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