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Adjustment of Fertilizer Dressings to Achieve High Quality and Optimum Price for Potatoes and Sugar Beet

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Summary

The quality of agricultural products has recently assumed greater importance. Quality is almost as important as quantity in determining the return to the farmer. Domestic consumers and the processing industry sometimes pay more for high quality especially when quality has an important influence on the efficiency of technological processes. Sugar factories and potato processors will pay more for high quality products.

Potato quality is much influenced by nitrogen and potassium fertilizers. The most important criteria are dry matter content and susceptibility to bruising. Quality requirements depend on destination of the potatoes: table, chips, starch manufacture etc.

Sugar beet quality determines the cost of sugar extraction. Internal quality can be judged by extractability index. Good quality beet have high sugar content, low α-amino N content, and low potassium and sodium contents. Nitrogen, potassium and sodium fertilizers all influence extractability.

Fertilizer advice should aim to achieve the optimum financial return to the farmer and must therefore take into account effects of fertilizer dressings on quality.

1. Introduction

Recently, the quality of agricultural products has become more and more important. Next to quantity, quality is for many products an important criterion in price determination. Not only the consumer but also the processing industry is sometimes willing to pay more for agricultural products of high quality, especially when technological processes require high quality products. Potatoes and sugar beet are typical examples of crops for which, in addition to a basic price for quantity, processing industries are willing to pay more for high quality.

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2. Sugar beet

2.1 Quality requirements for sugar beet

The quality requirements for sugar beet are both external quality or tare percentage and internal quality.

2.1.1 External quality

Impurities accompanying the beet to the factory include soil, crowns, leaves, weeds etc. A high tare percentage increases the cost of transport and the storage losses. The processing of sugar beet in the factory and the extraction of sugar are also adversely affected by high tare percentages. Finally, high tare percentages give rise to environmental problems with effluent water and recovery of soil.

The tare percentage due to crowns decreases during the growing season because the proportion beet/crown increases. The factories accept beet with a high proportion of crown but do not pay for it because the structure and the chemical compositions of the crown are such that the sugar cannot be extracted profitably. In Table 1 the compositions of the crown juice and of the juice of beet without crowns are compared *(Kadijk [1980])*.

The general opinion is that processing of the crown yields as much sugar as the damage it causes. It is necessary to remove leaves and petioles, because they have a strongly negative influence on the quality of the juice.

Table 1. Composition of the juice of crowns and of beet without crowns *(Kadijk [1980])*

	Juice of crowns	Juice of beet without crowns
Percentage sugar in dry matter	81.4	95.2
Colouring matter	7.4	0.8
Potassium	2.4	0.9
Sodium	0.5	0.07
Nitrogen	0.9	0.3

2.1.2 Internal quality

The internal quality of the sugar beet is mainly determined by its sugar content. The higher the sugar content, the higher is the internal quality of the beet. Secondly, internal quality is a function of extractability of the juice which is defined as the percentage of total sugar in the beet that can be extracted as white sugar. The remainder of the sugar is lost in the pulp, the lime-sludge and the molasses.

As is generally known, the quantities of potassium and sodium are of utmost importance for the white sugar yield. The content of nitrogen is of indirect importance because the negative influence of a high alpha-amino-nitrogen content has to be eliminated in the production process by adding alkali. The alkali is added in the form of NaOH which leads to an increase in molasse sugar *(van Geijn et al. [1983])*.

Low juice purity causes various problems in beet processing, such as corrosion in the evaporators, the formation of more invert sugar in the thick juice, a lowering of the pH, more sugar lost in the molasses and the Maillard reaction (colouring of the thick juice).

Various equations have been formulated to give a concrete form to the internal quality of sugar beet. Together with the results of sugar beet analysis such equations are very important tools in sugar processing. The most interesting equations are those supplying information on the alkalinity coefficient (A.C.) and on the total loss of sugar contained in molasses (Sm). To characterize the raw juice the A.C. is defined according to *Wieninger and Kubadinow [1971]* as:

$$A.C. = (K + Na)/\alpha\text{-}N$$

where K, Na and α-N are expressed in milli-equivalents per 100 g beet.

If the A.C. is high, there is no need to add alkali (NaOH). If the A.C. is low, addition of alkali is necessary to avoid the formation of invert sugar and the occurrence of corrosion with accompanying losses of sugar in molasses.

The lowest acceptable limit of A.C. lies between 1.8 and 2.3, depending on the factory *(Devillers [1983] and van Geijn et al. [1983])*.

To calculate the quantity of molasse sugar (Sm), various equations are described in the literature. In the equations of *Wieninger and Kubadinow, Akyar,* and American Crystal, the nutrients K, Na and α-N are expressed in me/100 g beet and in the equation of *van Geijn* in me/100 g sugar:

Wieninger and Kubadinow [1971]	$Sm = 0.349\ (K + Na)$ for $A.C. > 1.8$ $Sm = 0.628\ \alpha\text{-}N$ for $A.C. < 1.8$
Akyar et al. [1979]	$Sm = 0.182\ (K + Na) + 0.28\ \alpha\text{-}N$
American Crystal *(Hobbis et al. [1982])*	$Sm = 0.157\ K + 0.130\ Na + 0.215\ \alpha\text{-}N$
Van Geijn et al. [1983]	$Sm = 0.342\ (K + Na)$ for $\alpha\text{-}N \leq 17$ me/100 g sugar $Sm = 0.342\ (K + Na) + 0.513\ (\alpha\text{-}N - 17)$ for $\alpha\text{-}N > 17$ me/100 g sugar

To compare the different ways in which the Sm value is calculated, the 4 equations mentioned above were applied to data obtained in a field trial on a loamy soil in Ath (Belgium) in 1987. The field trial was a factorial design in which the influence of varying combinations of N, P and K applications on the levels of Na, K and α-amino N in sugar beet was examined. The field trial of Ath was a long term experiment from 1965 until 1987 *(Vanderdeelen et al. [1985])*. A review of the application of the 4 equations is given in Tables 2, 3 and 4 respectively for the factors nitrogen, potassium and phosphorus.

The extractability index (P) is calculated as:

$$P = 100 - Sm$$

According to Dutch criteria *(PAGV [1989])*, the extractability index is evaluated as follows:

P > 88: very good
P 88–85: good
P 84–80: moderate
P < 80: poor

Table 2. Composition of sugar beet and calculation of the % molasse sugar for a field trial on a loamy soil in Belgium (Ath, 1987). The data are means of four replications (basal fertilization 160 kg P and 240 kg K/ha)

N-fertilization (kg/ha)	me/100 g beet			% sugar content	Molasse sugar (%) (Sm)			
	K	Na	α-N		*Wieninger*	*van Geijn*	*Akyar*	*Am. Crystal*
0	5.64	0.41	1.19	15.92	2.11	2.07	1.43	1.19
120	5.70	0.47	1.79	15.89	2.15	2.11	1.62	1.34
180	6.04	0.45	2.32	15.51	2.27	2.22	1.83	1.51
240	6.24	0.50	2.84	15.06	2.35	2.45	2.02	1.66
300	6.23	0.55	3.11	14.54	2.37	2.65	2.10	1.72

Table 3. Composition of sugar beet and calculation of the % molasse sugar for a field trial on a loamy soil in Belgium (Ath, 1987). The data are means of four replications (basal fertilization 150 kg N and 160 kg P/ha)

K-fertilization (kg/ha)	me/100 g beet			% sugar content	Molasse sugar (%) (Sm)			
	K	Na	α-N		*Wieninger*	*van Geijn*	*Akyar*	*Am. Crystal*
0	3.83	0.79	2.39	14.64	1.61	1.58	1.51	1.22
120	4.93	0.54	2.31	15.33	1.91	1.87	1.64	1.34
240	6.04	0.45	2.32	15.51	2.27	2.22	1.83	1.51
360	6.63	0.46	2.33	15.42	2.47	2.42	1.94	1.60
480	7.06	0.42	2.27	15.40	2.61	2.56	2.00	1.65

Table 4. Composition of sugar beet and calculation of the % molasse sugar for a field trial on a loamy soil in Belgium (Ath, 1987). The data are means of four replications (basal fertilization 150 kg N and 240 kg K/ha)

P-fertilization (kg/ha)	me/100 g beet			% sugar content	Molasse sugar (%) (Sm)			
	K	Na	α-N		*Wieninger*	*van Geijn*	*Akyar*	*Am. Crystal*
0	6.04	0.48	2.12	15.38	2.28	2.23	1.78	1.47
80	6.08	0.46	2.21	15.53	2.28	2.24	1.81	1.49
160	6.04	0.45	2.32	15.51	2.27	2.22	1.83	1.51
240	6.11	0.52	2.23	15.20	2.31	2.27	1.83	1.51
320	5.81	0.49	2.38	15.54	2.20	2.15	1.81	1.49

2.2 Quality as a criterion for price determination

The external and internal qualities of sugar beets are very important for the processing industry because they determine the (supplementary) costs of juice extraction. Consequently the processing industries give a financial bonus for good quality in addition to a basic price for quantity.

Because of an over-production of sugar in the European Common Market a quota is laid down for every EC-country. This arrangement sets limits to the maximum production of sugar in each country. For example, the Netherlands has a contingent of 872 000 tons A+B sugar and Belgium a contingent of 826 000 tons A+B sugar. The sugar produced above this contingent is called C-sugar and must be sold at the world price.

The price received by the farmer is based on the quota and eventually on the world price for sugar if C-sugar is produced, but the real price the farmer receives is influenced by the bonus (or penalty) that the factory pays for good (or poor) quality.

2.2.1 Price determination in Belgium

Farmers are paid on the basis of net beet delivery. In consequence the tare percentage has an influence on the financial return for sugar beet because the gross beet delivery has to be reduced for the tare percentage.

The influence of the sugar content on the price is regulated as follows. The farmers receive 1785 Belgian francs (BEF) per ton sugar beet with 16% sugar. For every 0.1% sugar more or less a financial bonus or penalty is calculated according to the following rules:

Sugar content (%)	Financial bonus or penalty/0.1% sugar
16 or more	+0.9%
15 -15.9	-0.9%
14 -14.9	-1.0%
13.5-13.9	-1.2%
13.4 or less	-2.0%

Up to the time of writing, juice purity did not affect the financial return.

2.2.2 Price determination in the Netherlands (PAGV [1989])

The tare percentage has an important influence on the gross financial result. According to the Dutch arrangements (Sugar Union (SU) and Central Sugar Company (CSM)) a 4% reduction in tare percentage results in a financial advantage of 60–180 Dutch guilders (about 30 to 90 US$) per ha (Figure 1).

For beets with 16% sugar the farmer receives a basic price of 110 Dutch guilders per ton. For every percent sugar more (positive) or less (negative), 9% of the basic price more or less is paid.

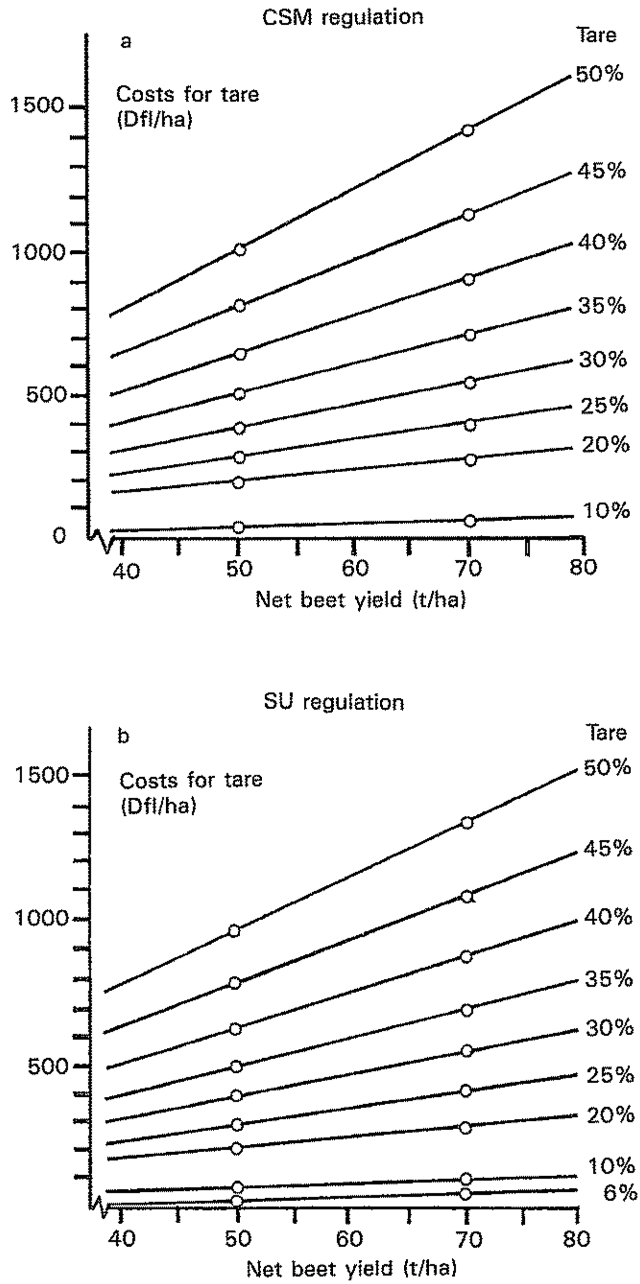

Figure 1. Influence of the tare percentage on the price paid to farmers in Dutch guilders (Dfl) per ha in the Netherlands, following the CSM- and the SU regulations.

Depending on the factory, a settlement is made to incorporate extractability of the juice in the sugar beet price. The extractability index is taken into consideration as 8% of the calculation for sugar content per % for every point of the extractability index (Figure 2).

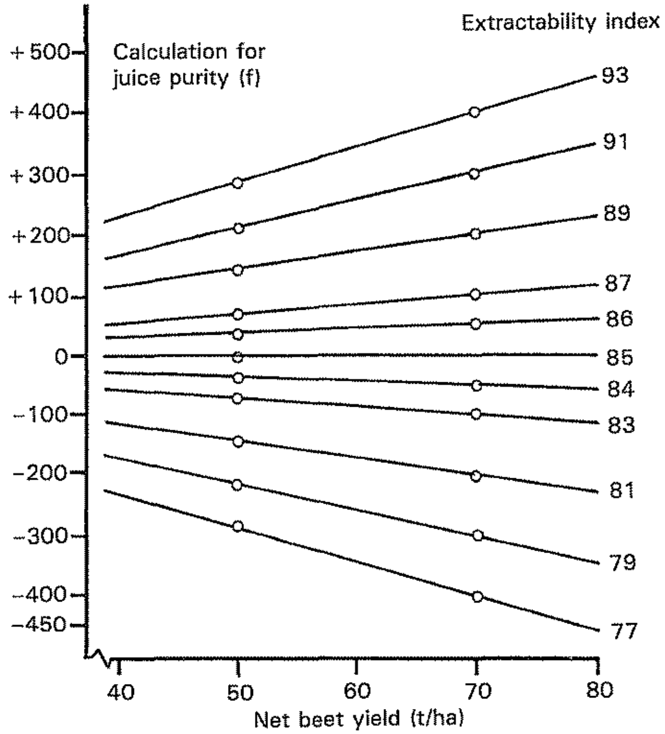

Figure 2. Influence of juice purity on the price paid to farmers for beets, in Dutch guilders per ha.
Basic price: Dfl 110 per t net beet with 16% sugar.
Calculation for sugar content: 9% of the basic price per %.
Calculation for juice purity: 8% of the calculation for sugar content per % for every point of extractability.

The conclusion can be drawn that depending on country and factory, the gross financial result of sugar beet growing depends on:

- root production;
- sugar content;
- tare percentage;
- extractability index;
- quota;
- world price for C sugar, if produced.

Table 5 compares the 2 price systems (The Netherlands, Belgium) for a beet production of 50 tons/ha with a tare percentage of 20%, a sugar content of 16% and a juice purity of 86 according to the equation of *van Geijn.*

Table 5. Calculation of the financial return of 1 ha sugar beet with a production of 50 t/ha, a tare percentage of 20%, a sugar content of 16% and a juice purity of 86 according to the equation of *van Geijn.* The comparison is made for 2 different price systems

	Price system	
Price determinants	Belgium	The Netherlands
Gross production (1)	50 t/ha	50 t/ha
Net production (2)	40 t/ha	40 t/ha
Basic price A+B sugar, 16% (3)	1 785 BEF/t	110 Dfl/t
Deduction for tare	(2)×(3)=71 400 BEF	160 Dfl
Deduction for extractability		48 Dfl
Compensation for pulp	(2)×130 F/t=5 200 BEF	–
Financial return*	76 600 BEF	4 192 Dfl

(*) 1 Dfl=18.85 BEF (5/4/1990)

2.3 Effect of fertilization on sugar beet quality

The quality of sugar beets is influenced by weather conditions, soil type, fertilization, etc. Fertilization has important effects on internal quality *(van der Beek [1989]); Boon and Vanstallen [1983]).* The results of Tables 2 and 3 indicate that this is especially true for nitrogen and potassium. On the basis of results obtained in the field trial in Ath (Belgium) (see above), the influence of varying fertilizer combinations on the production and quality of a number of crops was calculated and expressed as index values (Table 6). The results of Table 6 are based on results obtained in the 1972–1986 period. In that period sugar beets were grown twice.

Field tests with liquid manure indicate that the occurrence of too much mineral nitrogen in the subsoil (30–60 and 60–90 cm) in February–March has a negative influence on the sugar content of the beet. Experiments of the Soil Service of Belgium indicate that for each 100 kg of mineral nitrogen reserve in the soil (0–90 cm) the sugar content is lowered by 1.67%. The sugar content is lowered by only 0.55% for each 100 kg of fertilizer nitrogen applied at sowing time.

For making recommendations on fertilizer N to be applied to sugar beet the N-index method is used in Belgium and the N-min method in the Netherlands. In both methods it is customary to measure mineral nitrogen present in the soil to a 60 cm depth in February–March. The fertilizer nitrogen to be applied for the highest financial return is calculated as follows:

- on the basis of the N-index method for sandy, loamy, clay and lime soils:
  N rate = A–0.85 × N-index
  with A = 257 for harvest before 1 October.
  A = 264 for harvest between 1–15 October.
  A = 271 for harvest between 16–31 October.
  A = 277 for harvest after 31 October.
- on the basis of the N-min method for sandy, loamy and clay soils:
  N rate = 220–1.7 × N-min

The N-index is a function of several factors, such as the mineral nitrogen in the soil (0–60 cm), the soil carbon content (depending on soil type) and the quantity of organic manures applied.

Table 6. Yields without N, P or K fertilizer, relative to those on the normally fertilized plots ($N_2P_2K_2$), on a loamy soil (field trial of Ath). Production on the ($N_2P_2K_2$) plots = 100%. Soil Service of Belgium 1972–1986

		Nutrient not applied			Frequency of cultivation in 15 years
		N	P	K	
Potatoes:	tubers	<40%	70–79%	50-59%	3
	leaves	<40%	60–69%	60–69%	
Sugar beet:	roots	60–69%	95–99%	60–69%	2
	sugar	60–69%	95–99%	60–69%	
	crowns	70–79%	100%	70–79%	
Winter wheat:	grain	50–59%	95–99%	100%	5
	straw	40–49%	95–99%	90–94%	
Winter barley:	grain	40–49%	95–99%	95–99%	5
	straw	<40%	90–94%	85–87%	

3. Potatoes

3.1 Quality requirements for potatoes

The consumer as well as the potato processing industry appreciate potatoes of a good external and internal quality. The meanings of these terms are given below.

3.1.1 External quality

The following properties are important:

- the potatoes must be free of soil and sprouts
- good looking potatoes are:
  - tubers free of *Phytophthora, Fusarium* and scab;
  - fresh tubers, without bruises and other damage;
  - regularly shaped;
  - uniform in size.

3.1.2 Internal quality

Good quality potatoes have:
- low susceptibility to bruising;
- no subcutaneous discolorations;
- no discoloration after cooking or baking;
- no tendency to waxiness;
- no hollow hearts, and crinkle;
- a favourable dry matter content;
- a good taste;
- a limited content of reducing sugars.

The dry matter content of potatoes fluctuates in general between 18 and 27%. The dry matter content determines the cooking characteristics which are very important for the normal consumer. However also for the chips-, the French fried- and the starch industry, dry matter content of potatoes is an important quality factor, because it exerts a strong influence on the profitability of the production process and on the quality of the final product. For example, for chips processing a high dry matter content means a lower oil content in the chips. Moreover less water has to be evaporated off. The chips industry prefers potatoes with a dry matter content of 22–25%. French fried potatoes have a dry matter content preferably lying between 20 and 24%.

The content of reducing sugars in potatoes must be kept low to avoid discoloration during baking and drying. The discolorations are due to the Maillard reaction between reducing sugars and amino acids. The sugar content is dependent on variety, on temperature during storage, and on storage duration. For chips the best storage temperature range is 7–10°C, whereas for French fried potatoes and potatoes for the starch industry the best storage temperature is lower (5–8°C).

As indicated in Table 7, applications of nitrogen, potassium and chloride can have positive and negative influences on the quality of potatoes (*van Loon [1989]*).

Table 7. Quality aspects of potatoes which are positively (+) or negatively (–) influenced by ample application of nitrogen (N), potassium (K) or chloride (Cl) *(van Loon [1989])*

		+	–
1	Several types of secondary growth (e.g. elongated tubers, bottlenecks)		N
2	Dry matter content		N, K, Cl
3	Tuber size (>50 mm diameter)	N	N
4	Hollow hearts		N
5	Bruise susceptibility	N, K, Cl	
6	Baking colour		N
7	Texture of French fried		N, K, Cl
8	Nitrate content		N, K

3.2 Quality as a criterion for determining potato prices

Prices for potatoes are in general determined by the law of supply and demand. However, many farmers have a contract with the processing industry so that the (minimum) price is more or less fixed (guaranteed) for a certain quantity. This is especially the case for chips-, French fried- and starch potatoes. Prices depend strongly on industry-farmer agreements, and are difficult to describe. In general the price is based on quantity, provided the potatoes meet a certain quality requirement.

In the Netherlands, prices for table potatoes are determined by two arrangements – the AMV and the PF3 *(De Jong [1985])*.

The AMV sets the price to be paid to the farmer for potatoes on the basis of their quality. Potatoes of low external quality due to green color, damage, etc. are set aside and calculated as tare percentage. The AMV pays attention to the following internal quality properties: bruise susceptibility, subcutaneous discolorations, dry matter content, the percentage of waxy potatoes, hollow heart and crinkle, and calculates the quality index.

The PF3 quality evaluation for French-fried potatoes, is based on the same quality aspects, but is somewhat easier to calculate, especially for the percentage of waxy potatoes *(De Jong [1985])*.

In Belgium, no general quality payment system exists. Efforts were made in 1989 to create a quality label for potatoes under the supervision of a promotional organization (N.D.A.L.T.P./O.N.D.A.H.). In 1989–1990 the so called «A-label» (Figure 3) was commercialized for the first time, but only for the variety Bintje. Until February 1990, 650 t A-label potatoes had been sold. A first evaluation of the A-label potato indicates that the labelling was only a limited success, both for the interested farmers and for the distributors. A stable and guaranteed price seems necessary to remunerate the farmers for the extra efforts made *(Wullepit [1990])*.

In Germany the nitrate content of potatoes can be a quality aspect.

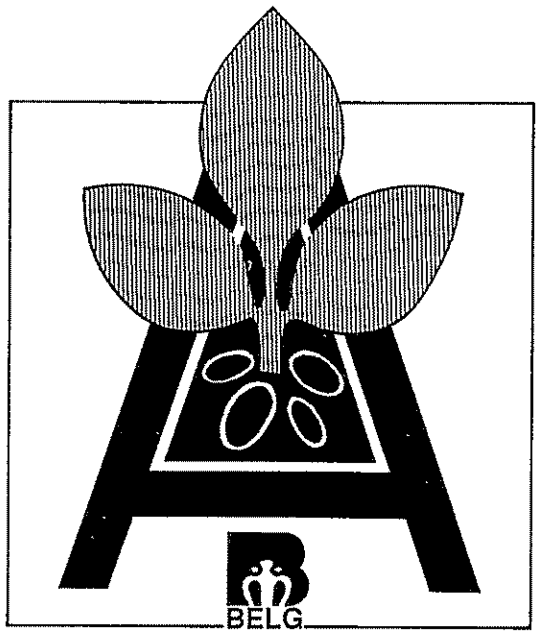

Figure 3. Promotion of the «A-label potato» by the N.D.A.L.T.P. of Belgium.

4. Conclusion

Technological processes require high quality basic products (sugar beet with a high sugar content and a high extractability or potatoes with a good external and internal quality) to result in high quality end-products with an optimal financial return. Processing industries give (sometimes) a financial bonus for good quality in addition to a basic price for quantity (yield).

The question how fast farmers respond to price incentives and adjust their organic and mineral fertilizer application can, in most cases, be answered by the law of diminishing returns. Therefore, fertilizer recommendations must result in the highest financial return. They have to take into consideration the basic price for quantity and the financial bonus for good quality or the financial penalty for low quality products.

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