Productivity Progress in Sugar Beet Production – With Special Emphasis on the Contribution of Breeding

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PRODUCTIVITY PROGRESS IN SUGAR BEET PRODUCTION - WITH SPECIAL EMPHASIS ON THE CONTRIBUTION OF BREEDING

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ABSTRACT

Sugar beet production during the past 50 years has been characterised by remarkable progress in productivity. In this contribution the influence of the different production factors on productivity and value added growth is analysed by regarding input and output development as well as price changes, with special focus on the breeding progress. During this period there has been a shift in the importance of the different factors of production for productivity development. Until the 1980s sugar beet breeding mainly initiated remarkable yield and quality improvements as well as seed and especially labour savings. Since then, technical progress in plant protection, mechanisation and organisation allowed considerable cost savings especially through labour savings and partly yield and quality growth. On the whole, the contribution of sugar beet breeding to value added growth during the last 30 years annually amounted to around 80 DM per hectare. During the last 20 years, based on beet price reductions, the seed related progress only amounted to around 20 DM per hectare, whereas cost savings and partly yield increases of 80 DM per hectare, based on chemical, mechanical and organisational technical progress, where considerably high. But, the remarkable benefit of various disease resistant varieties developed since the 1980s is not included here. As sugar beet cropping in large infested areas without the new resistant varieties would not be competitive any more, their benefit partly amounts to more than 2000 DM per hectare. With the technical optimisation of the production process for sugar beets being mostly completed now, further productivity progress is mostly expected from bio-technological progress.

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INTRODUCTION

Since the end of the 1950s, sugar beet yields, and especially sugar yields have dramatically increased. At the same time, it was possible to reduce the input of the means of production, in particular the labour intensity. Both developments have led to a considerable increase in productivity and income, although partly increasing input and output prices. In this article the development of productivity in sugar beet production and the contribution of the genetic progress to value added growth is analysed.

METHODOLOGY AND DATA BASE

The analysis of productivity development in sugar beet cultivation is based on field log data of the Association of South German Sugar Beet Producers (VSZ). These field logs comprise the most important input and output data as well as product and factor prices in sugar beet production of about 200 individual farms listed chronologically from 1967 until 1996. Based on this data base the productivity development can be derived by means of different productivity yardsticks (ZEDDIES and HENZE, 1982).

Relevant productivity measures are the **global gross productivity (1)**, which contrasts the total production volume with the total amount of all factor inputs and is the most suitable yardstick for calculating the productivity development of an agricultural production process

$$(1) \qquad \frac{Q_t}{A_t + K_t + B_t + I_t}$$

Q_t: Production volume; A_t: Labour input; K_t: Capital input; B_t: Land input; I_t: Purchased factor input

as well as **partial gross productivities**, which contrast the total production quantity to the input of individual factors or factor groups. It is true, that the productivity of individual factors is part of the partial gross productivity of the corresponding factor but cannot exactly be derived from it. Only by comparing two or more partial gross productivities or one partial with the global gross productivity changes in the composition of the factor input can be revealed. Examples for partial gross productivities are the **partial gross productivity of the farm-owned factor input (2),**

$$(2) \qquad \frac{Q_t}{A_t + K_t + B_t}$$

and the **partial gross productivity of the purchased factor inputs (3)**

$$(3) \qquad \frac{Q_t}{I_t} \quad .$$

Also the comparison of **partially and fully adjusted net productivities** shows changes in the structure of factor inputs. The most comprehensive measure here is the **productivity of the farm-owned factor input adjusted by the purchased input factors (4)**, which contrasts the production volume adjusted by purchased inputs to the volume of the farm-owned factor input

$$(4) \qquad \frac{Q_t - I_t}{A_t + K_t + B_t} \quad .$$

The **fully adjusted labour productivity (5)**, in which the production quantity adjusted by all other factors is compared with the farm-owned labour input, is the most suitable measure for labour productivity

$$(5) \qquad \frac{Q_t - I_t - K_t - B_t}{A_t} \quad .$$

The productivity change between two points in time is given as a relative value in which the absolute productivity change between the two points in time is related to the initial productivity. Accordingly, **the rate of change of the partial gross productivity of the purchased factor input (6) is**

$$(6) \qquad W_{\frac{Q}{I}} = \frac{\frac{Q_t}{I_t} - \frac{Q_0}{I_0}}{\frac{Q_0}{I_0}} = \frac{1 + W_Q}{1 + W_I} - 1$$

and the **global productivity change (7) is**

$$(7) \qquad W_{\frac{Q}{A+K+B+I}} = \frac{1 + W_Q}{1 + \frac{A_0}{Q_0} W_A + \frac{K_0}{Q_0} W_K + \frac{B_0}{Q_0} W_B + \frac{I_0}{Q_0} W_I} - 1.$$

Based on this, an attempt can be made to derive the contribution of individual input factors to productivity development in sugar beet production, in particular that of seeds.

A differentiated economic evaluation of individual progresses in breeding features incorporated in sugar beet seeds, such as improvements to the seed form, variety performance increases, disease resistance and herbicide tolerance as well as seed dressing, is carried out with the help of marginal utility analysis based on testing results of varieties recently certified in Germany, Belgium and France (BSA, IRBAB, GEVES).

DEVELOPMENT OF PRODUCTIVITY AND VALUE ADDED

The global productivity progress in sugar beet production during the period of 1973 and 1996 amounted to 6.04% per year (Table 1). This shows the relative change in the global output-to-input ratio, which can result from changes in output or input quantities or a combination of both (ZEDDIES and HENZE, 1982). Compared to the global productivity progress in agriculture of on average around 1-2% per year (HENRICHSMEYER and WITZKE, 1991), the progress in sugar beet production was considerably high.

The global productivity progress in sugar beet production on the one hand consists of the increase in yields by 1.79% per year and on the other hand of the decrease in intermediate inputs by 1.1% p.a., labour input by 6.96% p.a. and capital input by 1.54% p.a. Among the purchased inputs the input of seed (W_{IS}) and fertiliser (W_{ID}) decreased by around 3% p.a., whereas the use of pesticides (W_{IP}) increased by around 2.7% p.a.

Table 1: Development of structure and productivity in sugar beet production

	Year		1973/74-1977/78	1978/79-1982/83	1983/84-1987/88	1988/89-1992/93	1993/94-1995/96	**1973/74-1995/96**
1	Production value [DM ha^{-1}][1)]		5515	6856	7226	6840	6820	**6637**
2	Production volume [DM ha^{-1}] [2)]		4655	5250	5427	5629	5836	**5318**
	Growth rates [%] [2)]							
3	- W_Q	Output	0.90	- 0.52	3.29	3.62	1.55	**1.79**
4	- W_I	Intermediate Inputs	0.72	-2.00	-0.43	-1.70	-2.77	**-1.10**
5	- W_A	Labour	- 3.71	- 5.48	- 4.25	- 13.36	- 8.68	**- 6.96**
6	- W_K	Capital	4.62	0.53	- 2.18	- 6.63	- 5.71	**- 1.54**
7	- W_B	Land	0.00	0.00	0.00	0.00	0.00	**0.00**
8	- W_{IS}	Intermediate inputs – seed	- 3.14	- 3.73	- 2.27	- 3.67	- 1.66	**- 3.00**
9	- W_{ID}	Intermediate inputs – fertiliser	- 0.57	- 3.22	- 4.27	- 5.13	- 4.16	**- 3.41**
10	- W_{IP}	Intermediate inputs – plant protection	4.51	1.79	3.86	- 0.96	5.26	**2.68**
11	- W_{IM}	Intermediate inputs – fuel & repairs	2.80	- 2.71	2.42	0.31	- 7.89	**- 0.42**
	Productivity development [%]							
12	- $W_{Q/(A+K+B+I)}$		2.31	2.66	5.82	12.43	7.61	**6.04**
13	- $W_{Q/(A+K+B)}$		3.27	3.27	6.79	16.03	9.01	**7.56**
14	- $W_{Q/I}$		0.37	1.39	3.93	5.29	4.48	**2.97**
15	- $W_{(Q-I)/(A+K+B)}$		3.89	3.79	8.78	18.90	10.95	**9.13**
16	- $W_{(Q-I)/A}$		6.10	5.86	10.15	24.59	12.99	**11.84**
17	- $W_{(Q-I-K-B)/A}$		6.07	5.09	14.37	32.84	16.25	**14.81**
18	- $W_{Q/IS}$		4.22	3.45	5.75	7.53	3.32	**4.99**
19	- $W_{Q/ID}$		1.49	2.67	8.14	9.65	5.96	**5.55**
20	- $W_{Q/IP}$		-1.41	-1.82	-0.54	4.49	-3.51	**-0.30**
21	- $W_{Q/IM}$		- 0.76	2.27	2.29	3.20	10.58	**2.90**

[1)] at current prices; [2)] at constant prices of 1973

Source: VSZ (1997), own calculations

The global productivity progress cannot be attributed in a methodically correct way to single production factors. Although, the partial productivity progress of labour, capital and land by 7.56% p.a. and of purchased inputs by 2.97% shows, that the contribution of savings and quality improvement in labour, capital and land input was higher than that of purchased inputs altogether.

Contribution of sugar beet seed to the progress in productivity and value added

Whereas the optimisation of fertiliser, pesticide and machinery use mainly took place in the 1970s and 1980s, since then, productivity progress in sugar beet production mainly based on the progress in breeding. According to the calculations of MÄRLÄNDER (1991 and 1996), 80% of the increase in yield can be attributed to seed improvements and approximately 20% to other production factors, especially plant protection and machinery. Based on these assumptions the global productivity progress in sugar beet production would only amount to 4.58% p.a. if seed did not have any influence on yield or seed input (Table 2). The contribution of seed to the productivity progress accordingly amounts to 1.46% p.a.

Table 2: Relative productivity change in sugar beet production 1973-1996 [%]

		73/74 to 77/78	78/79 to 82/83	83/84 to 87/88	88/89 to 92/93	93/94 to 95/96	**73/74 to 95/96**
Global productivity change	$W_{Q/(A+K+B+I)}$	2.31	2.66	5.82	12.43	7.61	**6.04**
Productivity change, excluding seed effects	$0{,}2xW_Q/W_{(A+K+B+I-S)}$	1.43	3.21	3.14	9.26	6.68	**4.58**
Contribution of seed to productivity change[1)]		0.88	-0.55	2.68	3.17	0.93	**1.46**

[1)] excluding the effect of labour savings

EVOLUTION OF THE BREEDING PROGRESS

Seed performance on the one hand, is related to the variety performance, i.e. variety related characteristics like sugar beet yield and quality (sugar content, extractable sugar, amino-N, potassium, sodium) as well as tolerance or resistance to different diseases and pests (rhizomania, nematodes) or herbicides. On the other hand, seed performance is influenced essentially by seed production, with characteristics such seed form (monogerm, multigerm), seed quality (field emergence) and seed treatment (pelleting and incrustation of fungicides and insecticides) playing an important role.

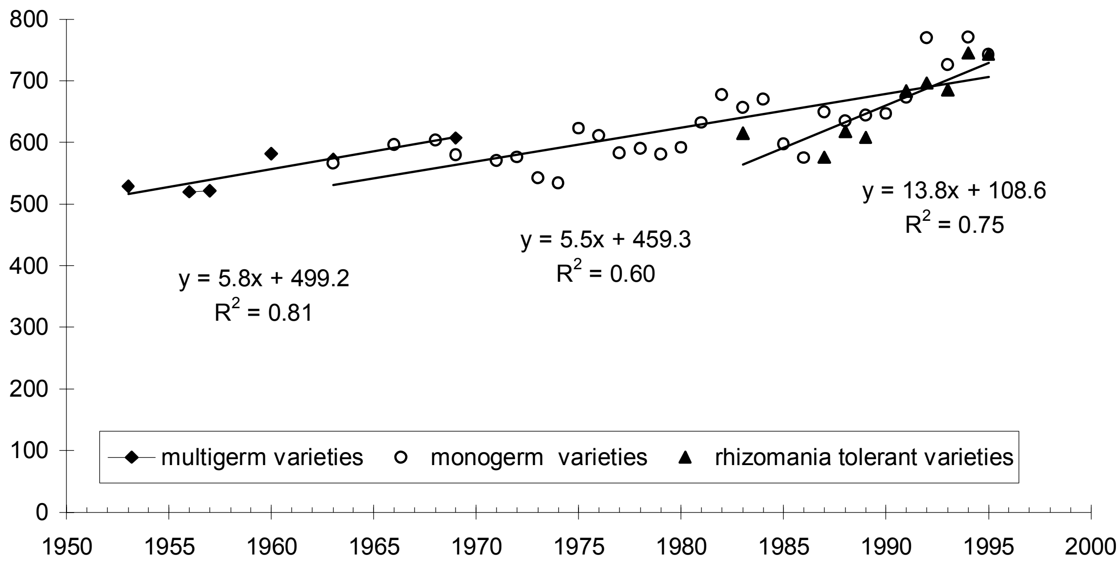
Evolution of the variety performance

In the past, the introduction of new variety attributes like genetic monogermity and rhizomania tolerance was closely related to losses in the yield and quality performance, but, in the same time, breeding progress as regards sugar beet yields as well as beet quality increased clearly after every innovation.

- Yield and quality

During the last 50 years the genetic potential in **sugar beet yields** annually increased by 4.4 dt/ha. Since 1980 the annual yield progress hardly doubled and amounted to 8.4 dt/ha. Initially, the genetically monogerm sugar beet varieties introduced in the mid-1960s achieved yields which were up to 8% below the yields of the multigerm varieties (Figure 1). After eight to ten years the difference was balanced out. The yields of the first rhizomania tolerant varieties introduced in the mid-1980s were, again, about 13% below those of the standard assortment on non-infested fields; through particularly high increases in yield of about 13.8 dt/ha p.a., currently there are no differences in yields any more. Whereas the principal objective in sugar beet breeding from 1950 until 1970 was to raise the sugar beet yields, since the early 1970s more and more emphasis was placed on increasing the **sugar content** and in particular the **extractable sugar content**.

Figure 1: Development of the genetic potential of sugar beets by variety attribute sugar beet yield [dt/ha]

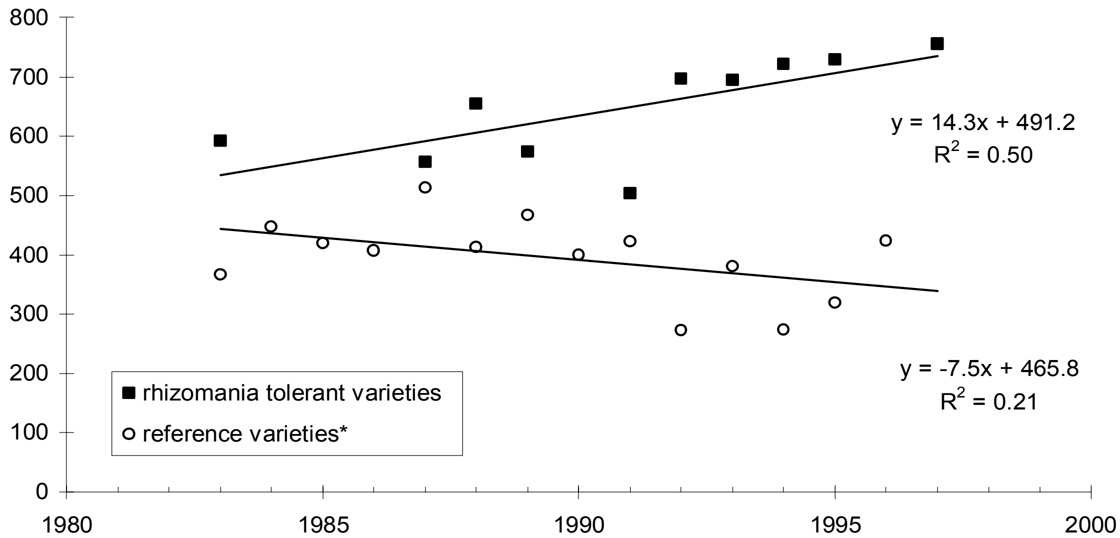


Source: BUNDESSORTENAMT (1997), own calculations

- Rhizomania tolerance

In rhizomania infested areas breeding progress of rhizomania tolerant varieties was even slightly higher than the performance increases of standard varieties without infestation. Beside the beet yields, in particular the content of extractable sugar has clearly risen. On sites with rhizomania infestation, yield progress of tolerant varieties even reached 14.3 dt/ha, whereas non-tolerant varieties with -7.5 dt/ha continued to loose yield performance as a result of increasing infestation pressure (Figure 2).

Figure 2: Development of the variety performance of sugar beets in rhizomania infested areas: sugar beet yield [dt/ha]; with $x_{1980} = 0$



*) 1983-85: Kawemono, Primahill, Monopur 1986-96: Hilma, Kawetina

Source: BUNDESSORTENAMT (1997), own calculations

- Nematode tolerance

In Germany, the first nematode resistant sugar beet variety was certified in spring 1998. As there is no means of combating nematodes chemically at present, the only possibility of coping with the problem at nematode infested sites is through an extended crop rotation, the cultivation of nematode resistant intercrops or main crops within set aside programmes. The only other possibility would be to abandon the competitive cultivation of sugar beets. Variety tests on nematode endangered locations show high superiority of nematode resistant varieties in the beet yield (+ 84 dt/ha) compared to standard varieties. In relation to the beet yield, the superiority in the sugar yield and extractable sugar yield is smaller, because of a lower sugar content (-0,75 %-points) and extractable sugar content (-1,1 %-points).

- Herbicide tolerance

It is to be expected that biotechnological progress is more likely to be achieved through genetic procedures than through traditional breeding methods in the future. Currently, genetic engineering is most successful in the field of creating herbicide tolerant sugar beet varieties. Depending on weed infestation, cultivation of herbicide tolerant varieties can lead to a reduced use of herbicides, as two or three applications will be sufficient instead of three or four (MORITZ, 1998). At the same time, the use of universal herbicides poses less threat to ground water supplies because of their improved biodegradable qualities. However, compared to conventional varieties at present a lower performance must be expected from the genetically modified sugar beet varieties and a corresponding technology surcharge is required, for example for increased fertiliser expenditure (PETERSEN et al., 2000). But, a continuous improvement in performance is to be expected; moreover, the first varieties are already rhizomania tolerant.

Evolution of the seed performance

- Seed form

Through the introduction of calibrated (technically monogerm) seeds, also called precision seed in the early 1960s, seed input decreased from about 30 kg per hectare to around 7 kg per hectare. A further clear reduction of the demand of seed and in particular of labour was achieved through breeding and producing genetically monogerm seeds in the mid-1960s. While seed demand decreased to 1.6 kg per hectare, or 4.8 kg per hectare including coat (=1,6 units per hectare), labour input was reduced by about 100 hours per hectare through the removal of the necessity for thinning when drilling at final distance**.** However, the achievable yield from the first genetically monogerm varieties was below the yield performance of the available multigerm varieties.

- Seed quality

Technical improvements during the process of seed production led to an improved germinating power and to a better field emergence through a more careful treatment of seeds. Accordingly, seed input could be reduced up to 1.1 units per hectare at present.

- Seed treatment

Extended performances of seed producers in the area of seed treatment e.g. pelleting and incrustation of insecticides and fungicides in the seed coat also contributed to the development of higher-grade seed. Through incrustation of pesticides in the coating material of sugar beet seeds the germ can be protected effectively against different pests and diseases from the very beginning and overall application of granulates can be replaced. It leads to improved field emergence, increased sugar yields through diminishing the virus infestation by lice and allows savings in labour input (MÄRLÄNDER et al., 1994).

ECONOMIC EVALUATION OF THE BREEDING PROGRESS

The genetic progress incorporated into sugar beet seed is based on different attributes, which are valued according to their economic benefit in agriculture, in the following section. This evaluation is based on a marginal analysis of the changes in costs and returns in sugar beet production (yield effects and factor saving effects) corresponding to the realisation of individual breeding advances.

Seed form

The use of pelleted genetically monogerm seeds in sugar beet production, in the beginning led to substantial losses of more than 300 DM per hectare compared to multigerm varieties, because of a drop in yield performance of 46 dt/ha (7%). On the other hand, labour costs could be reduced by about 1000 DM per hectare through labour savings. As seed costs for the new monogerm varieties were only little higher than for the common multigerm varieties, the use of the new seed form in agriculture led to a benefit of almost 700 DM per hectare and accordingly to a rapid market launch. By the end of the 1970s monogerm seeds had made up their initial yield losses through progress in breeding. Since then, the benefit of the use of monogerm seeds has increased in line to the rising wage level.

Variety performance

The economic benefit of the increase in variety performance is the result of a yield effect, a sugar content effect and a mixed effect. According to the quota situation and the corresponding achievable beet prices, the benefit of yield and quality improvements varies in a wide range. Aggregated over the whole period under observation, increases in yield and sugar content of sugar beet varieties in Germany led to an increase in value added of up to 2408 DM per hectare (1950-95) and 1767 DM per hectare (1980-95), respectively, depending on the quota situation. On the other hand, increases in variety performance within the last 50 years in Germany led to potential beet area savings of 1.0 % per year or almost 50 % over the whole period. Since 1980 the average area saving potential increased to 1.7 % per year. With a share of around 80 %, in the long-term average the main reason for the value added growth is based on advances in yield. As a result of the higher increase in sugar content since 1980, however, the influence of quality improvements on the whole benefit rose from 15% in the long-term average to 25 to 30%, in the period from 1980 to 1995.

Rhizomania tolerance

In rhizomania infested areas sugar beet cropping would not be competitive with other cultures without the new generation of rhizomania tolerant varieties, even under A quota conditions at current beet prices. At the time of their introduction into the market in 1983 rhizomania tolerant sugar beet varieties led to a benefit of 1491 DM per hectare for quota A beets and 955 DM per hectare for quota B beets. Because of increasing yields of tolerant varieties and increasing yield depressions in non-tolerant varieties, the benefit of rhizomania tolerance rose until 1995 to 4986 DM per hectare for quota A beets and 3152 DM per hectare for quota B beets. However, the latter figures are economically speaking not relevant, because if rhizomania tolerant varieties were not used, there would be no sugar beet cropping any longer. Compared to cropping competing cultures, the actual benefit derived from rhizomania tolerant sugar beet varieties in Germany is presently at 3896 DM per hectare for quota A beets and 1490 DM per hectare for quota B beets.

Nematode resistance

Assuming the effects observed by HANS (1988) in the case of an unfulfilled A quota there is a marginal benefit for nematode resistant varieties over normal varieties amounting to 776 DM per hectare. For an unfulfilled B quota the marginal benefit also amounts to almost 500 DM per hectare. Due to the fact that there is no systematic cultivation of C beets to be expected, the marginal benefit calculated for C beets has no significance.

Herbicide tolerance

Altogether the economic benefit of the use of herbicide tolerant sugar beet varieties depends on the weed infestation of the potential beet land. Herbicide tolerance is especially suitable for farms with a high weed infestation pressure and problematic weeds for which the control costs often amount up to 500 DM per hectare. For these farms, the benefit of herbicide tolerant beet varieties is around 300 DM per hectare because of cost savings for chemicals of 275 DM per hectare and the saving of one to two applications of 13,40 DM per hectare each. Contrary, farms that already have plant protection costs of under 200 or 250 DM per hectare would hardly take any advantage from herbicide tolerance.

Seed treatment

The marginal benefit of seed dressing with fungicides or insecticides depends on the infestation pressure. Assuming an average of 1.2 insecticide applications the marginal benefit of the use of Gaucho for example amounts to around 76 DM per hectare. With current costs for seed incrustation with Gaucho of around 122 DM per hectare, its use is only worthwhile in the case of big pest problems. But, a more than once application of insecticides requires a regular, time consuming control of the standing crop and furthermore does not entirely exclude the weather risk and possibly following yield decreases.

CONTRIBUTION OF THE DIFFERENT FACTORS OF PRODUCTION

During the whole observation period there has been a shift in the importance of the different factors of production for productivity development, i.e. biological, mechanical and organisational technical progress, as the production data of a sample of 200 South German Sugar Beet Growers (VSZ, 1997) shows in the following.

With annual yield improvements of 3,7 dt/ha, since the beginning of the 1970s the output in sugar beet production annually grew by around 109 DM per hectare (Table 8). For initially increasing and since the mid-1980s decreasing beet prices, between 1973 and 1983 the annual output growth of 220 DM per hectare was remarkable, whereas between 1983 and 1996 on average it only amounted to 24 DM/ha. But, the initially very high output growth is opposed by considerable input and factor price increases, which lead to only a small annual profit growth of 21 DM/ha between 1973 and 1983. Since then, decreasing seed, fertilizer, machinery capital and labour input through biological, mechanical and organisational technical progress allowed annual savings in variable costs of 23 DM/ha and in labour and capital costs of around 55 DM/ha, although increasing factor and labour prices. Consequently, together with the annual output growth of 24 DM/ha, since 1983 the profit could be increased by around 107 DM/ha annually.

Table 8: Input and output development at current prices [DM/ha]

	73/74-77/78	78/79-82/83	83/84-87/88	88/89-92/93	93/94-95/96	Annual change 73-96	73-83	83-96
Beets	4646	5717	6057	5933	6051	**109**	**181**	**54**
Pulps	602	751	721	561	495	**-3**	**22**	**-22**
Organic matter	219	244	256	199	191	**0,3**	**3**	**-2**
Others	122	145	193	147	83	**-3,6**	**14**	**-7**
Output	**5515**	**6856**	**7226**	**6840**	**6820**	**109**	**220**	**24**
Seed	159	208	225	227	214	**5**	**12**	**-1**
Fertilizer	731	823	691	451	340	**-12**	**23**	**-39**
Chemicals	214	277	336	391	454	**13**	**12**	**13**
Machinery	478	631	770	757	703	**15**	**40**	**-4**
Interest	55	68	71	64	60	**1**	**3**	**-1**
Others	138	167	179	177	187	**3**	**4**	**3**
Variable Costs	**1774**	**2174**	**2273**	**2067**	**1957**	**24**	**93**	**-23**
Gross margin	**3741**	**4682**	**4953**	**4773**	**4862**	**85**	**127**	**53**
Labour	810	867	854	614	386	**-12**	**22**	**-38**
Capital	619	954	1146	1057	858	**15**	**57**	**-17**
Land	391	534	661	672	620	**12**	**28**	**0,3**
Profit	**1921**	**2328**	**2292**	**2429**	**2998**	**70**	**21**	**107**

Source: VSZ (1997), own calculations, ZIMMERMANN, ZEDDIES (2000)

CONCLUSIONS

The **seed related productivity progress** is contributed by yield and quality improvements as well as seed savings. Until the beginning of the 1970 additionally labour savings through the introduction of monogerm seeds were remarkable. Under the assumption that 80% of the yield progress in sugar beet production in the past was related to seed and 20% were based on other production factors, especially plant protection and mechanisation, during the past 30 years seed initiated annual increases in value added by 80 DM/ha only through the yield and seed effect. During the last 20 years, based on beet price reductions, the seed related progress only amounted to around 20 DM per hectare, whereas cost savings and partly yield increases of 80 DM per hectare, based on chemical, mechanical and organisational technical progress, where considerably high. But, the remarkable benefit of various disease resistant varieties developed since the 1980s is not included here. As sugar beet cropping in large infested areas without the new resistant varieties would not be competitive any more, their benefit partly amounts to more than 2000 DM per hectare. With the technical optimisation of the production process for sugar beets being mostly completed now, further productivity progress is mostly expected from bio-technological progress, increasingly focused on very specific location issues, like certain diseases or weed and pest problems.

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BIOGRAPHY

BEATE ZIMMERMANN, German, born in 1966, studied Agricultural Sciences with special emphasis on Agricultural Economics at the University of Hohenheim in Stuttgart, Germany, between 1986 and 1992. In 1997 she obtained her PhD in Agricultural Economics. Since then, she has been working in Research at the Department of Agricultural Economics and Farm Management at the University of Hohenheim.

JÜRGEN ZEDDIES, German, born in 1942, studied Agricultural Economics at the University of Göttingen in Germany between 1962 and 1966. He obtained his PhD in Agricultural Economics in 1969 and finished his professional dissertation in 1974. In the same year he became Professor of Agricultural Economics at the University of Hohenheim. Since 1989 he is a member of the Scientific Advisory Council at the Federal Ministry of Agriculture in Bonn and since 1997 also of the Grants Committee of the German Research Foundation (DFG).