Technologie- und Förderzentrum
im Kompetenzzentrum für Nachwachsende Rohstoffe

9

Berichte aus dem TFZ

Maize as Energy Crop for Combustion

Agricultural Optimisation of Fuel Supply

TFZ

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– Agricultural Optimisation of Fuel Supply

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Maize as Energy Crop for Combustion

Agricultural Optimisation of Fuel Supply

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Berichte aus dem TFZ 9

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1 Introduction and problem definition

While the use of renewable raw materials in Europe continues to increase, it becomes visible, that certain biofuel resources such as favourably priced fuel wood are in some regions already becoming scarce [8]. In addition, wood is not available in every country or region – depending on the cultivation practices and the given climatic and soil conditions. Therefore annual agricultural crops move into the focus. Especially with the increased prices of fossil fuels herbaceous plants like straw, grass or whole cereal plants move closer to economic profitability [2].

However, reasons for the presently low use of annual agricultural crops for combustion are various. Compared to wood herbaceous plants show some unfavourable fuel properties. These parameters affect the combustion process either in a technical or ecological way. Technical problems can for example be due to the presence of chlorine, sulphur, potassium, nitrogen, magnesium or calcium that can cause corrosion or slagging problems in the combustion plant and consequentially reduce useful plant life. Other chemical components like nitrogen and ash content but again chlorine and sulphur can result in excessive pollutant emissions or – in the case of heavy metals – remain in the ash and lead to problems in the disposal.

On the one hand there are possibilities to adjust the combustion plant to unfavourable fuel parameters. At the same time critical chemical elements of agricultural crops can – within certain ranges – be manipulated by the cultivation techniques. On this account every energy crop should undergo a profound and broad assessment before being used as combustion fuel.

2 Goals

The here presented research on the influencing cultivation factors for fuel quality optimisation is focused on maize as an annual agricultural crop which is used as whole plant. The aim was to minimize possible disadvantages by applying useful agricultural methods for fuel quality enhancement. Under practical scale conditions the content of critical elements in the harvested and provided crop has to be reduced. The full process chain was thus investigated - from cultivation methods to harvesting time and storage conditions - in order to identify any practical means for achieving and maintaining a suitable fuel quality from whole maize plant cultivation.

The research was embedded in the NESSIE-project ("New small scale innovative energy transforming combustor based on baled biomass"), an EU-project which ended with the installation of a newly developed maize bale furnace. The biomass CHP-plant (1970 kW thermal and 280 kW electric capacity) was implemented at Dürnkrut, a small town of around 1700 inhabitants in Lower Austria. The maize producing farmers are located in the region around the plant. Within the EU funded project the TFZ’s responsibility comprised the definition of the characteristic parameters for the optimised fuel supply as well as the agronomic test field plan with test field planting, regular cultivation, yield and quality aspects. In order to consider practical scale conditions (e.g. farmers cultivation techniques, local machine equipment) as well as given local site conditions (e.g. soil or precipitation) the trials were part of the farmers lots.

3 Work plan and applied methods

3.1 Cultivation situation during the testing period

All testing lots are located in the area of Dürnkrut, which is situated 500 m above sea level, the mean annual temperature averages between 8 an 9 °C with hot summer and cold winter and a mean precipitation of only 500 mm. The maize production trials were carried out over three consecutive years whereas the year's specific weather conditions have to be taken into account by interpreting the testing results: While 2003 was extremely dry and hot, the year 2004 was close to the long term average weather conditions mentioned above. 2005 can be characterised with a cold and wet spring, an average summer and warm and dry autumn.

The focuses of the testing series were:
Year 2003: preliminary field trials
Year 2004: extended field trials
Year 2005: completion of ongoing trials and follow-up trials.

For the project's first cultivation period (2003) almost 60 hectares of agricultural land were provided by five farmers applying their individual farming practices. In order to minimize non-systematic impacts of prevailing site conditions, e.g. soil conditions and hydro-regime, the testing lots were limited to four fields of approximately 16 hectares. All selected lots were sown in row distances between 70 an 75 cm with a planting density of 60000 to 75000 kernels per hectare. Sowing of maize was done at more or less the same time between the 21st and 26th of April 2003. Harvesting and baling was done with uniform farm machineries on all lots, whereas fertilisation and plant protection happened according to the farmer's particular practice.

According to the first year's results extended field trials of 60 hectares maize cultivation were set up in the second year (2004) in order to repeat and thus review the given results of 2003 as well as to differentiate the first year's trials. Cultivation techniques were applied in a more uniform way than in 2003: All lots were sown in row distances of 70 cm with a sowing density of 70000 kernels per hectare. Also the type and amount of fertilisation (400 kg/ha multi nutrient fertiliser "Vollkorn" with NPK content of 20/8/8 and potassium as KCl and 260 kg/ha nitrogen fertiliser "NAC") as well as the plant protection product (1,8 l Monsoon and 0,8 l Mikado) was kept uniform on each lot – unless it was a fertilisation or ecological testing lot. The field trials were limited to six lots of 24 hectares in total. Baling was done with two different machines (Claas and Vicon).

For the trials' third year 65 hectares of land were provided by six farmers, but only one testing lot of a 10 hectares size was selected for all implemented field trials in 2005. Due to the cold spring sowing was delayed till May, the 3rd 2005. Fertilisation and weed control were done as in 2004.

3.2 Determination of fuel parameters and analysing methods

For data evaluation the main target parameters were calorific value, moisture content, ash content, nitrogen, potassium and chlorine, they were consistently determined. Selected samples were additionally analysed for phosphorus, sulphur and silicon. Calcium, magnesium and hydrogen were measured as auxiliary parameters on some samples. Due to the fact that the calorific value represents the energy content of the biofuel, the intention is to keep it as high as possible. All the other mentioned parameters are critical parameters that affect the combustion process either in a technical or ecological way. Technical problems due to corrosion can be caused by chlorine, sulphur and potassium. Excessive magnesium and calcium contents effect slagging problems in the combustion plant and consequentially they lead to a reduced plant life. Other chemical components like nitrogen and ash content but again chlorine and sulphur result in excessive pollutant emissions or – as for heavy metals – remain in the ash. They should be kept as low as possible.

The analyses were done according to DIN or CEN standards either in the TFZ’s laboratory or external. The underlying measuring principles are noted in Table 1. All chemical data are given in percent of dry matter.

Table 1: Measuring principles for the determined fuel parameters

Analysed parameter	**Measuring principle**
Nitrogen (N)	Combustion via heat conductivity (Dumas)
Chlorine (Cl)	X-Ray Emission and Y-Ray fluorescence analysis (XRF).
Potassium (K), Phosphorus (P) Calcium (Ca) Magnesium (Mg)	Classical digestion (550 °C), dilution in HCl, measuring by ICP-AES combustion (inductive coupled plasma – atomic emission spectrometer)
Sulphate (S)	Microwave pressure digestion, measuring by ICP-AES combustion (inductive coupled plasma – atomic emission spectrometer)
Silicon (Si)	Hydrofluoric acid digestion, dilution in HCl, measuring by ICP-AES combustion (inductive coupled plasma – atomic emission spectrometer)

Generally a sound evaluation of any specific variety or treatment effects can not be made in the implemented field trials, this would require an extensive randomised experimental plot design with several treatment steps and replications under homogeneous site conditions. As such requirements can not be achieved in a fully practice oriented accompanying research, all data and results are subject of coincidental influences and thus should be interpreted carefully.

3.3 Crop characterisation

3.3.1 Plant section analyses and time series

In order to assess whether fuel quality can be optimised by the harvesting of selective plant parts, several plant sections were analysed. For determining the distribution of the physical and chemical parameters within the maize plant a specific number of whole plants were separated into sections. The plant samples were randomly selected from one lot and cut 10 cm above the ground according to the cutting level of the harvesting machine. As a consequence of the first year’s results the sectioning was slightly varied in 2004 – as shown in Table 2. In order to additionally monitor any element changes within the plant over the time span from the plant's total height development to harvesting time, plant sections in 2004 were taken at three different times.

Table 2: Sampling conditions in 2003 and 2004

Plant sections in 2003	**Plant sections in 2004**
Stalk increments: 0- 10 cm 10- 20 cm 20- 40 cm 40- 60 cm 60- 80 cm 80-100 cm > 100 cm Leaves and tassel Husks Ears (= sum of cobs and kernels)	Stalk increments: 0- 10 cm 10- 20 cm 20- 30 cm > 30 cm Leaves Tassel Husks Cobs Kernels
Number of sampled whole plants: 11	Number of sampled whole plants: 15
Sampling date: Sept., 1st 2003	Sampling dates: Aug. 15th 2004 Oct. 14th 2004 Nov. 25th 2004
Maize variety: "Suarta"	Maize variety: "Clarica"

For the time series 12 to 15 whole plants were randomly selected from a single lot and they were cut just as the plant section samplings in a height of 10 cm. In 2003 this was done in a more or less biweekly rhythm between September, 1st and November, 30th, whereas in 2004 the samples were taken three times i.e. in August 17th, October 13th and November 21st. In order to achieve comparable analysis data it was necessary that sampling was always done at dry weather conditions.

3.3.2 Site condition effects

To consider the influence of prevailing regional site conditions – e.g. soil characteristics, precipitation and temperature – on the physical and chemical maize parameters, the maize of two testing lots in different directions of Dürnkrut/Lower Austria were compared. Additionally a maize field in Strassmoos/Bavaria was sampled in order to provide a comparison to a further location. The given site conditions are described in Table 3. An all three lots the variety Clarica had been chosen due to its predominant and long-term use in the eastern part of Austria. Cultivation was done in an uniform way with 400 kg/ha multi nutrient fertiliser "Vollkorn" with NPK content of 20/8/8 (potassium as KCl) and 260 kg/ha nitrogen fertiliser "NAC", the plant protection product was done with 1,8 l Monsoon and 0,8 l Mikado. For sampling twelve randomly selected whole maize plants were taken on each testing site. Due to the specific weather conditions sampling on the three sites could only be done within a time difference of three weeks.

Table 3: Comparison of site conditions in Dürnkrut/Austria and Strassmoos/Bavaria

Dürnkrut / Lower Austria, Austria	**Strassmoos / Bavaria, Germany**
500 m above sea level	380 m above sea level
Annual mean temperature 8-9°C	Annual mean temperature 7-8 °C
Annual mean precipitation 500 mm	Annual mean precipitation 700 mm

3.4 Choice of variety

To consider the chances for fuel manipulation by the choice of variety, three different maize varieties were compared concerning the determined main target parameters. The selection of the trial varieties was made by the FAO-number – a parameter to express the vegetation time to reach maturity – and by the drought resistance. The variety Clarica was chosen due to its predominant and long-term use in the eastern part of Austria, it is relatively drought tolerance and has an early harvesting. Contrary to this Reseda shows a very late harvesting time but as well a high drought tolerance, wherefore its main production area is situated in Hungary. The third variety, PR39F58, was new on the market at that time; it is not drought tolerant and has early harvesting time. The main characteristics of the varieties are summarised in Table 4.

Reseda and PR39F58 were sown on the same trial lot, Clarica on a second one. Sowing was done at the end of April with the same sowing density, fertilisation and plant protection.

Table 4: Agronomic characteristics of the chosen maize varieties for fuel parameter comparison

Maize variety	**FAO-number**	**Description**
Clarica	310	High drought tolerance, early harvesting time, long-term use in Eastern Austria
Reseda	450	High drought tolerance, very late harvesting time, Hungary as main production area
PR39F58	320	New breeding, on sites with sufficient water supply, middle early harvesting time

3.5 Cultivation methods

3.5.1 Conventional versus ecological cultivation

Apart from the choice of variety cultivation methods were regarded for their influence on fuel characteristics. One testing lot was cultivated with the variety Clarica in the conventional way but without any fertiliser. On the second testing lot the variety Clarica was sown and farmed without any fertiliser, too, but in an ecological way of soil preparation and weed control. By cultivating peas as intercrop the soil's nitrogen supply was supposed to be reconditioned. For interpretation of the results it is necessary to mention that it had been the first year of the field transformation from conventional to ecological cultivation.

In 2004 a comparison of a conventional and fertilised lot with the ecological cultivation method was arranged. While the ecological field was the same as the year before with the same above mentioned cultivation method, the conventional one was fertilised with 400 kg/ha multi nutrient fertiliser "Vollkorn" 20/8/8 with potassium as KCl and 260 kg/ha nitrogen fertiliser "NAC", the plant protection product was done with 1,8 l Monsoon and 0,8 l Mikado.

Samples of about 15 randomly selected whole plants of each variant were taken on October 13th, 2003 and October 21st, 2004 respectively.

3.5.2 Irrigation versus non-irrigation

Due to the high impact of the drought in 2003 a trial with an irrigation variant was deemed useful and accomplished in 2004. A field with the variety Clarica was subdivided into two, whereas one part was irrigated with 35 mm by a gun sprinkler machine with a 40 m throwing radius during the time span of August 11th and 18th. The period was chosen because of the main water demand of maize in the months of July and August. For optimum build-up of ears, for their number and their maturation, the best irrigation time is shortly before the tassel development. Any irrigation after that time would support an increased leaf development and delayed maturity, which was not desired. Sampling was done on October 28th, 2004.

3.6 Moisture content manipulation

3.6.1 Swath drying

In order to investigate possible means to reduce moisture content before baling, two swath drying trials were set up. With these trials the drying intensity of harvested maize plants was examined and compared to the moisture contents of non-harvested maize. One testing field was set up in Pulling/Bavaria. A part of it was harvested on September 13th and the swath arranged on a plastic net directly on the ground in the shape of a swath. An initial moisture content determination was done and the weight of the swath was quantified. Every few days a sample of the non-harvested maize was taken to analyse the moisture change in the still growing crop. Simultaneously the moisture content of the swath was measured by weight determination.

A second swath drying trial was set up in Dürnkrut/Austria with an earlier start in August. In this trial a part of the field was harvested on August 17th, 2004 and the swath was left on the ground without special arrangements (see Figure 1). The initial and subsequent moisture content course was determined simultaneously every one or two weeks – depending on a minimum period of three days without rain or fog. Eight whole maize plant samples were collected from each variant for moisture determination. Because of a swath height of 20-30 cm, sampling was done by taking a mixture of four plants from the bottom layer close to the ground and four from the top of the swath. On September 10th a further swath was implemented on the same testing lot applying the same sampling rules as above.

Figure 1: Set up of a swath drying trial on August 17th, 2004

3.6.2 Storage behaviour

Using maize as biofuel most bales have to be stored over several months or sometimes even up to a year before combustion. The storage suitability had therefore been investigated by determining a change of the bales' moisture content over the full storage period of almost one year. The storage trial was set up in two different ways: one open bale depot on the field covered with a plastic cover to protect the bales against rain and snow, the second one underneath a roof beside a farm-house.

For the depots 26 bales were randomly selected and numbered with forest spray paint. In order to prevent the bales from losing material while at the same time ensuring a normal air access, each selected bale was enwrapped in a wide meshed plastic net (see Figure 2) and weighed with a load cell affixed on a tractor (see Figure 3). For this a Flintec DMS weighing cell (type UB6 C3) with a maximum load of 510 kg and a reading accuracy of 50 grams was used. For determining the moisture content at the trial's beginning, five whole maize plants were sampled during the harvesting operation from the parallel swath of each selected bale.

Figure 2: Bale enwrapping in a wide meshed plastic net at the beginning of the storage trial on November 5th, 2004

Figure 3: Bale weighing at the beginning of the storage trial on November 5th, 2004

A three layered field bale depot was set up with 84 bales, the selected test bales were located in the middle layer inside and on the outside as well as in the top layer as mapped in Figure 4. A view on the complete outdoor depot is given in Figure 5.

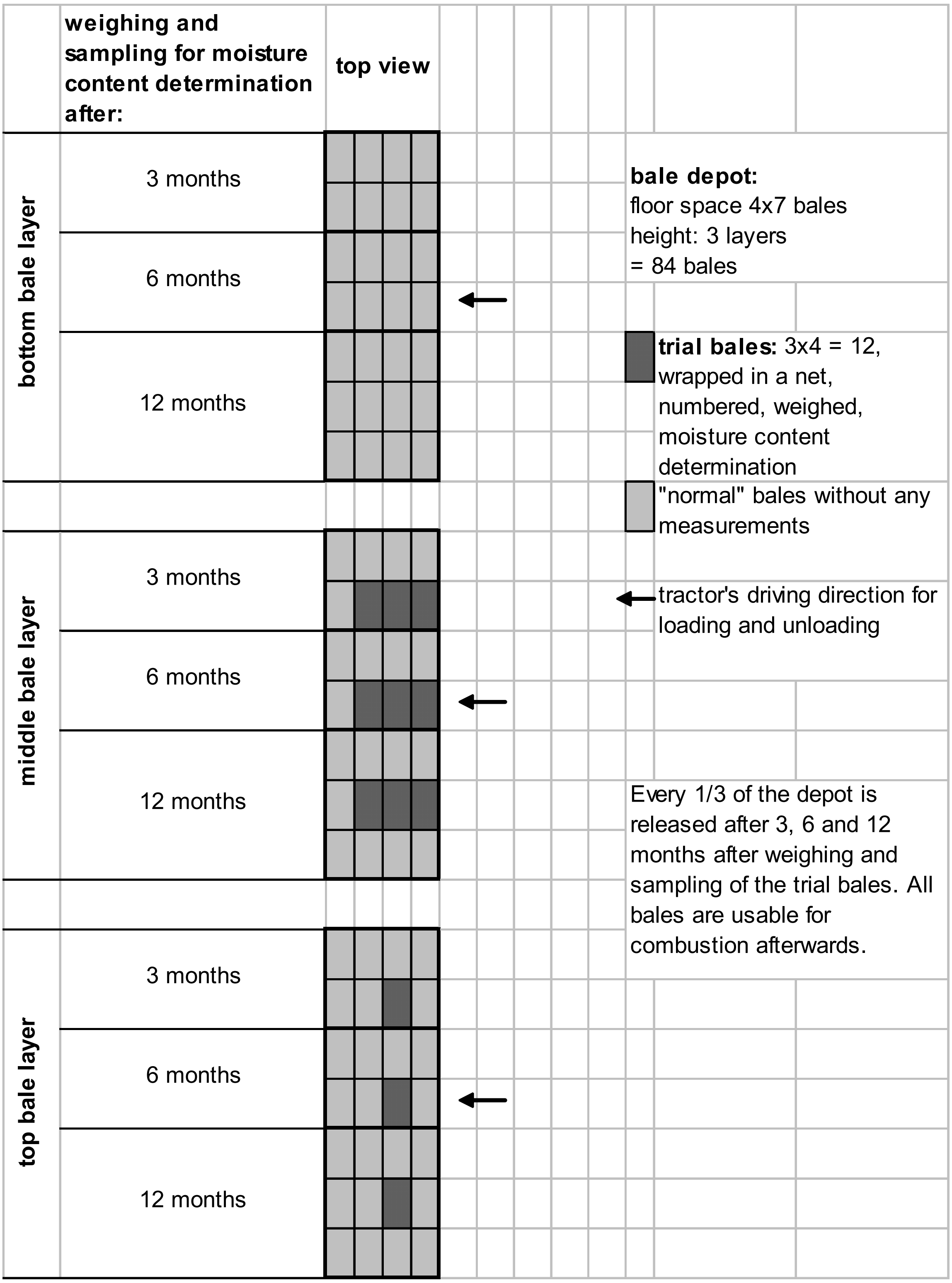

Figure 4: Plan of the outside maize depot set up on the field

Figure 5: Plastic covered field maize depot arranged on November 5th, 2004

The intention was to set up the same depot in a shed, covered by a roof instead of plastic plane. But because of the bales' high moisture content at the time of storage, the risk of self-ignition had to be considered. Therefore the fourteen test bales were piled up on each other, each separated by an EU-pallet for better air access (see Figure 6).

Figure 6: Roof covered maize depot in a shed arranged on November 5th, 2004

After three and six months 1/3 of the field depot was released. The selected test bales were weighed and afterwards sampled each at four locations using a purpose built core drill for bale sampling (see Chapter 3.8). The sample material was used for moisture content determination. Because of the fact, that the baling machine was not working correctly, the bales were relatively loose and not very easy to handle. While the test was still accomplishable after three and six months, the bales were getting more and more unstable over the time. On this account the intended twelve months measuring had to be cancelled.

The bales of the roof covered depot were weighed after eleven months, additionally a sample for moisture content determination was taken from two selected bales.

3.7 Yield determination

The yield determination is one of the most important parameters to quantify the economic efficiency of maize cultivation for combustion. Thus a field trial was set up on a 10 ha lot in 2005. As described in Table 5 six different maize varieties were sown in parallel stripes, each with two variants of sowing density (three for the variety KWS 1393). Fertilisation and plant protection was done uniformly.

The yield determination was done in two consecutive days at the end of September 2005. According to statistical randomised trials a minimum of 80 maize plants had to be sampled of each variant. Table 5 specifies the necessary length of row for each variant containing at least 80 maize plants. For each variant three repetitions were done.

A row of the given length was harvested by manual cutting and the material was weighed in a plastic net with a load cell affixed on a tractor (see Figure 7). For this the already mentioned Flintec DMS weighing cell (type UB6 C3) with a maximum load of 510 kg and a reading accuracy of 50 grams was used (Chapter 3.6.2). After weighing six whole maize plants of each repetition were taken for moisture content determination.

Table 5: Description of sampling lots for yield determination

Maize variety	FAO-number	Sowing density [kernels/ha]	Distance between rows [m]	Length of row for sampling [m]
KX 5222	350	150.000	0,75	8
		75.000	0,75	15
KWS 1393	430	150.000	0,75	8
		90.000	0,45	21
		75.000	0,75	15
Garbure	370	90.000	0,45	21
		75.000	0,75	15
Gavott	250	90.000	0,45	21
		75.000	0,75	15
KWS 2345	270	90.000	0,45	21
		75.000	0,75	15
Campesino	210	90.000	0,45	21
		75.000	0,75	15

Figure 7: Weighing of maize plants for yield determination

3.8 Moisture content determination of baled maize

The sampling for moisture content determination was done by the use of a core drill as shown in Figure 8. Each bale was sampled by a minimum of four times. Subsequently the moisture content was determined in the compartment dryer. The advantage is that after sampling, the maize bales still keep their stability and can further on be used for combustion. However, a method for rapid moisture determination for maize bales is still missing.

Figure 8: Core drill for maize bale samplings

4 Results

4.1 Crop characterisation

Maize is a relatively uninvestigated solid biofuel. Commonly wood or grain straw and recently even also grain kernels are used as biofuels. The evaluation of maize fuel properties, which is presented in the following results, therefore requires a set of reference data for better comparison and orientation. Hence, as a preceding information for the following chapters, such data are presented in Figure 9, it shows the quality characteristics of spruce wood, wheat straw and grain kernels.

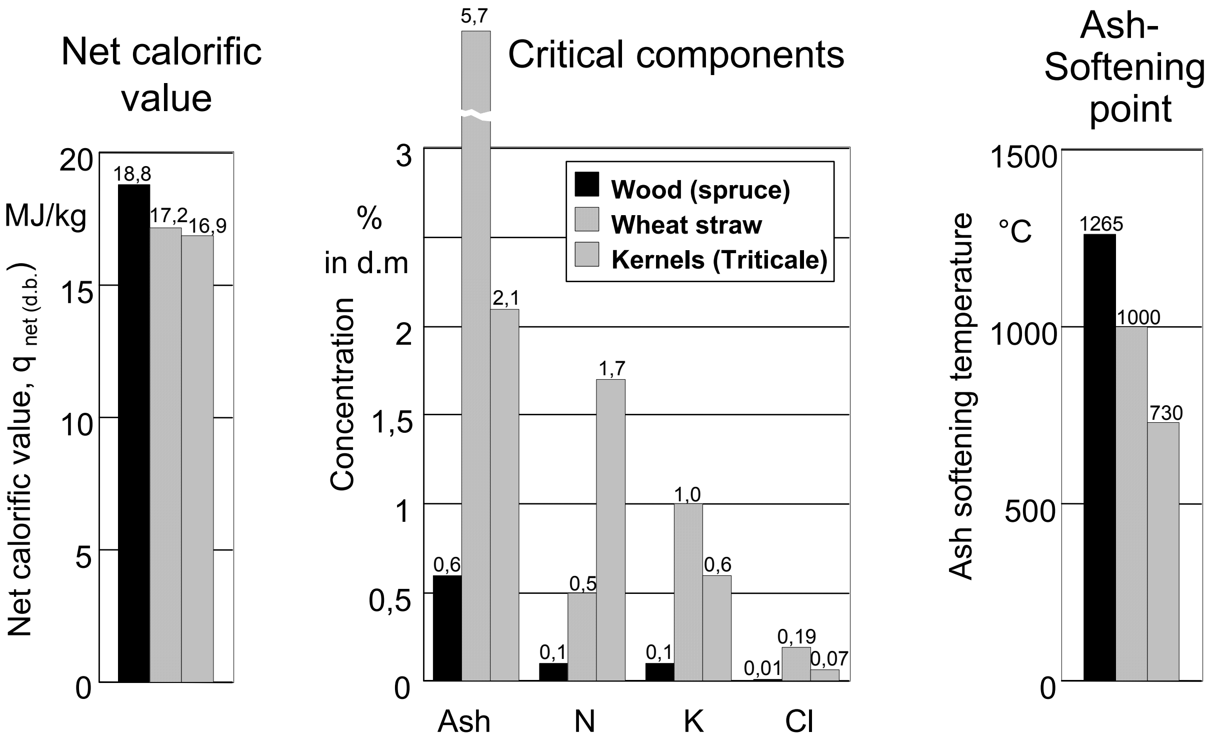

Figure 9: Orientation values of biofuel quality characteristics of spruce wood, wheat straw and grain kernels (source: database of TFZ [3])

4.1.1 Time series / Harvest timing

The variety Clarica was sampled in a two-weekly interval between September 1st and November 30th 2003. The goal was to evaluate and quantify any changes of element concentrations during the end of the vegetation period. A proper choice of harvesting time could then lead to an optimized fuel quality.

Moisture content. To account for the moisture content, the values decrease quickly in the first part of September to remain at approximately the same low level around 15 % until the end of measuring time (see Figure 10). The graph shows the strong effect of the harvesting time on moisture levels. Due to the fact that a moisture content level of less than 20 % is considered appropriate for storage, the here presented results reflect suitable storing conditions. However, due to the unusually warm and dry summer in 2003 the observed moisture content was deemed atypically low and should therefore be interpreted carefully (for comparison with the data of an average summer see Figure 14, Chapter 4.1.2). In particular the period between the end of June and end of August, when maize has the highest sensibility towards water stress, almost no rainfall occurred in 2003. The local precipitation data showed 24 mm in June, 32 mm in July and 11 mm in August. Due to the extreme drought, the plants had already ripened prematurely at the beginning of September.

Calorific value. The calorific value is around 7 % lower than wood, it ranges from 16,7 to 18,0 MJ/kg for the whole plant. It was analysed during the extended field trials in 2004 in combination with the plant section analyses, therefore this characteristic of maize fuel is discussed in the respective Chapter 4.1.2.

Ash content. After a short decrease between the beginning of September and mid of October the ash content remains more or less stable with no mentionable range between 2,1 and 2,7 %. In general these ash contents have to be classified as low.

Nitrogen, potassium and chlorine. Similar to the ash content the chemical parameters nitrogen, potassium and chlorine largely remain constant with a hardly observable decrease over the time. While the contents of nitrogen are relatively high in comparison to wood or wheat straw (see Figure 9), potassium is in between wood and straw and chlorine is rather low. Once more, these courses have to be interpreted in view of the climatic abnormality of 2003: no leaching of chemical elements could have happened this season. At the same time it was not expected for chlorine, due to the low level, but it could have been a possible reason for a decline of potassium.

Phosphorus, calcium, magnesium, sulphate and silicon. While silicon and calcium decrease in the first six weeks of the measuring period, phosphorus, magnesium and sulphate do not show any mentionable concentration change during the vegetation period.

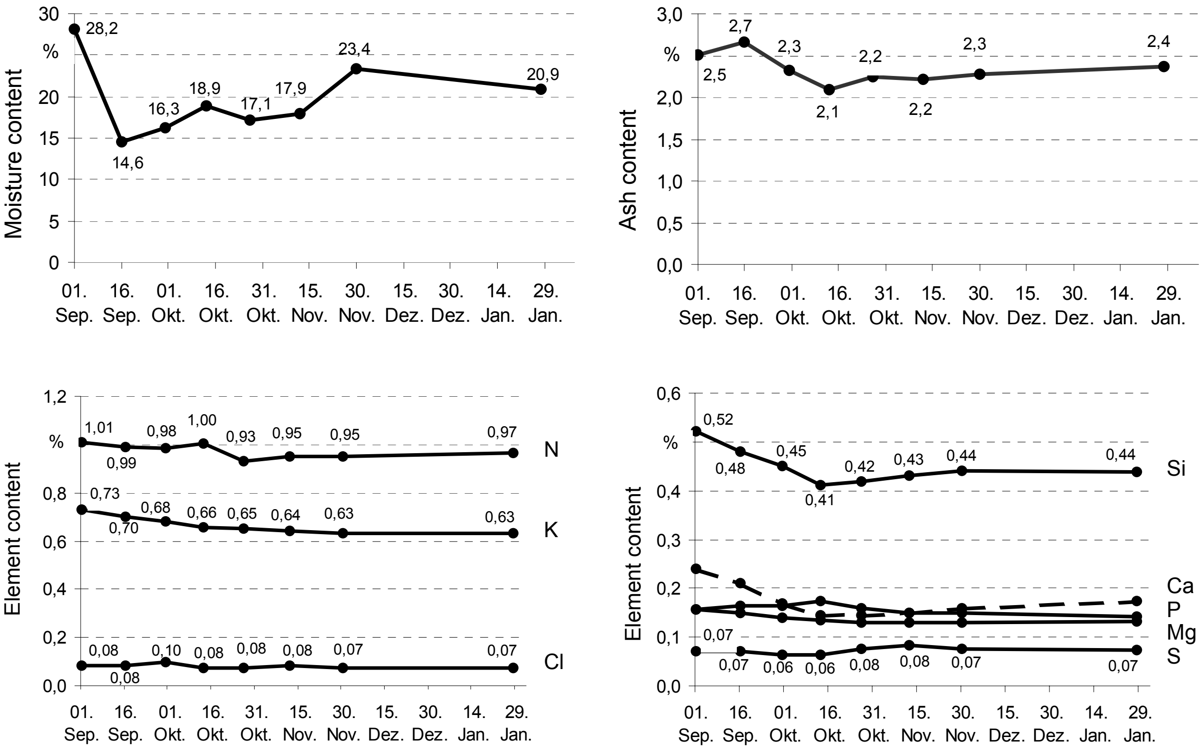

Figure 10: Biofuel properties of maize whole plants depending on harvesting time (all data based on dry matter)

4.1.2 Plant section analyses and time series

Mass proportions. Fully developed mature maize plants show a quite unequal distribution of the masses in the different plant sections. The ears (including husks) contribute around 60 % of the whole plant mass (see Figure 11). The time series of 2004 shows the decreasing stalk and leaf mass over the last part of the vegetation period while the ears fraction is increasing. This ratio has to be taken into account by evaluating the analysed parameters stated below.

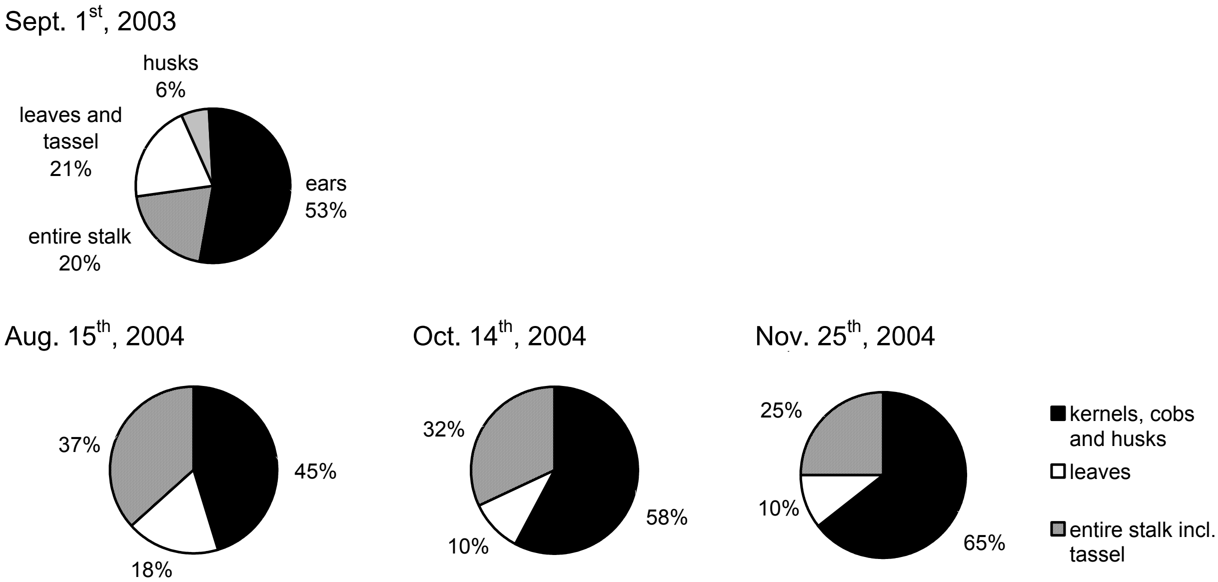

Figure 11: Typical weight proportions of maize plant sections at different years and times

Calorific value. Compared with data base values from an earlier research at TFZ [3], the calorific value (dry base) of maize is in between that of spruce wood (18,8 MJ/kg) and grain kernels (16,9 MJ/kg). The differences within the plant sections (16,7 – 18,0 MJ/kg) are marginal (see Figure 12). The comparison of values in August and November shows a slight change: The calorific value of the stalk increases and of the leaves and ears is reduced over the time. Overall, the calorific value of maize whole plants remains relatively constant over the vegetation period.

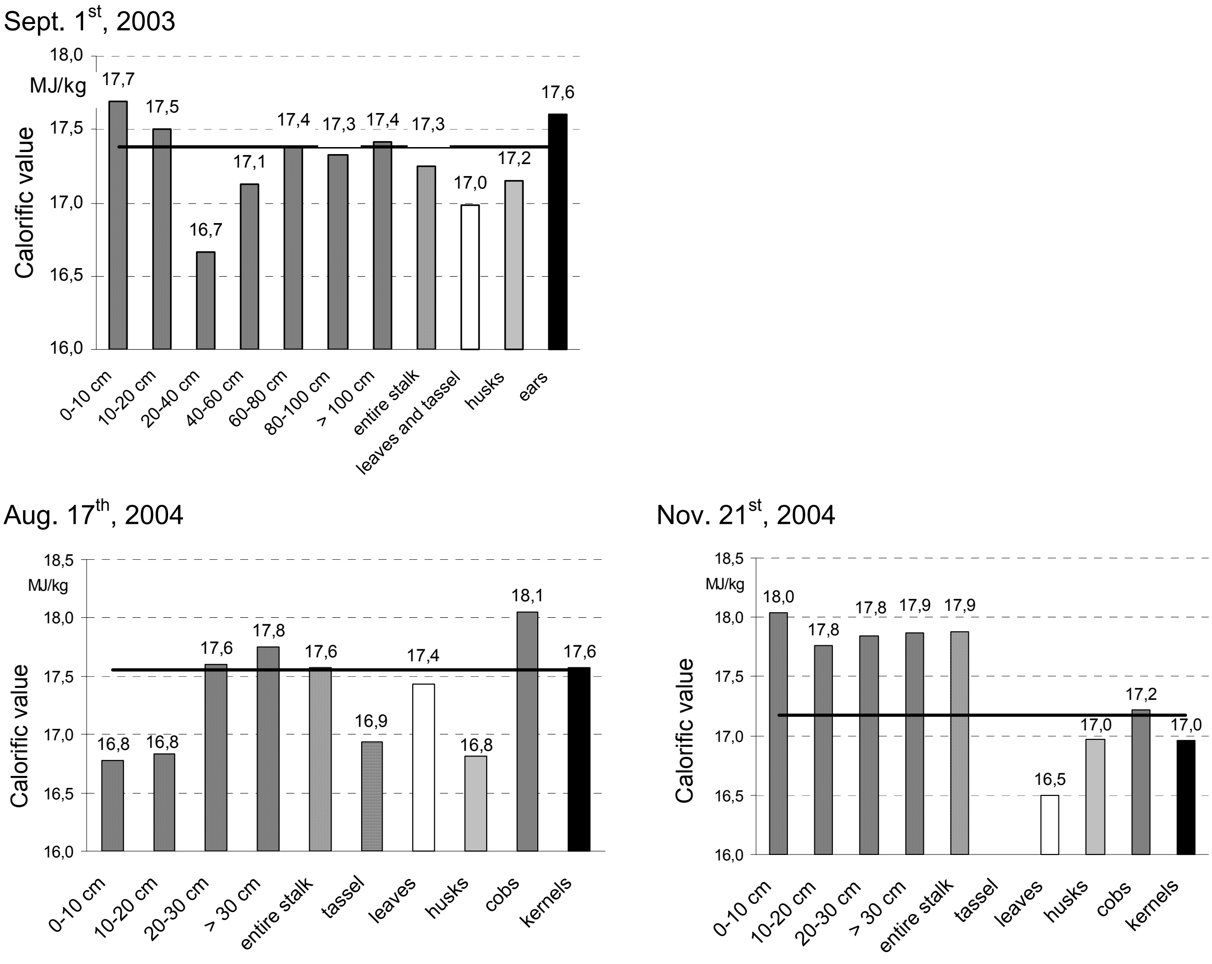

Figure 12: Typical calorific values of dry matter of maize plant sections in different years and seasonal stages (black line: whole plant average). All data based on dry matter

Ash content. The average ash content in whole maize plants shows a relatively low value (see Figure 13). Ash contents are inversely correlated with the calorific value, so that the here analysed low content of non-combustible minerals (ash) usually results in a higher calorific value of a given fuel resource. The ash content of around 4 % in August is in accordance with former ash content studies for different whole crop plants [3]. With the proceeding vegetation period it decreases by almost 50 % down to an average of 2,3 % in November. Such reductions had also been reported for other herbaceous plants [7]. In the here conducted sectional studies a noticeable peak value was observed in the leaves. It could be caused by dust and soil particle adhesions which are likely to be enhanced by the relatively large and rough surface.

The decrease was observed consistently for each maize plant section. But the ash content can be even more reduced by late harvesting; then the high ash containing leaves have already partly been dropped and would usually be left on the ground. In this respect a winter or early spring harvest would lead to an improved fuel quality in terms of ash content, although biomass losses would be high. Altogether, the ash content level at the end of the vegetation period is unexpectedly low, it can even be compared to that of short rotation forestry crops.

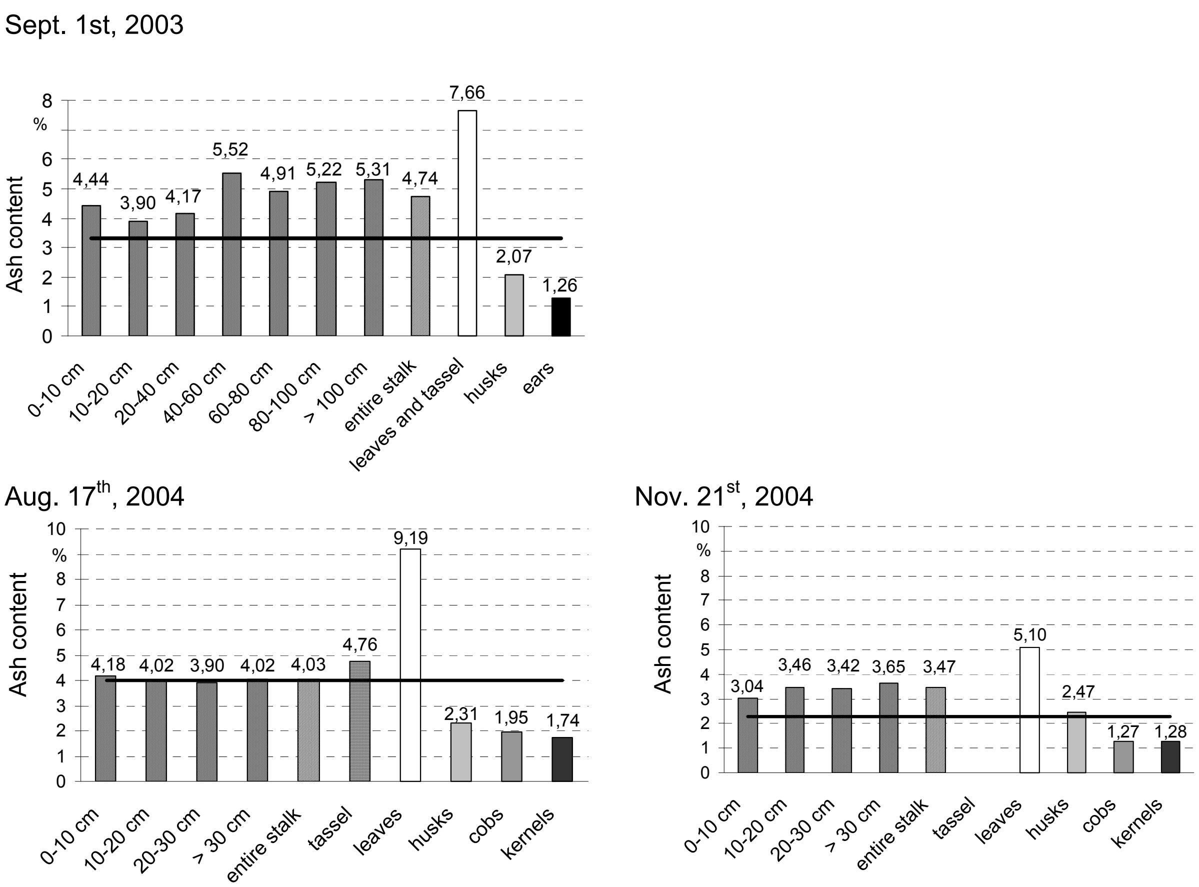

Figure 13: Ash content in dry matter of maize plant sections in different years and maturity stages (black line: whole plant average)

Moisture content. In terms of moisture content the plant sections show a wide range from 72,3 % in the stalks to 24,4 % in the leaves and tassel. This difference of about 50 percentage points within the plant can even increase to 60 points as shown in October 2004. This inconsistency can cause problems in storage and combustion. Furthermore is would make the calibration of any rapid moisture content determination device extremely difficult, because most such systems are sensitive towards variable densities in the sample or feedstock [4]. However, at the end of the maturity stage the moisture content range within the plant is only around 20 percentage points – a fact that has to be considered for choosing the proper harvesting time.

During the progressing maturity the moisture content of the whole plant is strongly reduced from 73 % in August to 16,7 % in November. But the requirement of less than 20 % moisture in the whole maize plant is only met by the middle of November. Again, the graph shows that moisture content is highly influenced by the harvesting time. Because the weather conditions of 2004 were close to the long term average, these results can be taken as representative – contrary to the ones of 2003. But harvesting in November is problematic in most regions of Germany and Austria due to impassable ground or wet plants. Therefore frost harvest or harvesting in early spring during dry weather conditions could be a possible alternative.

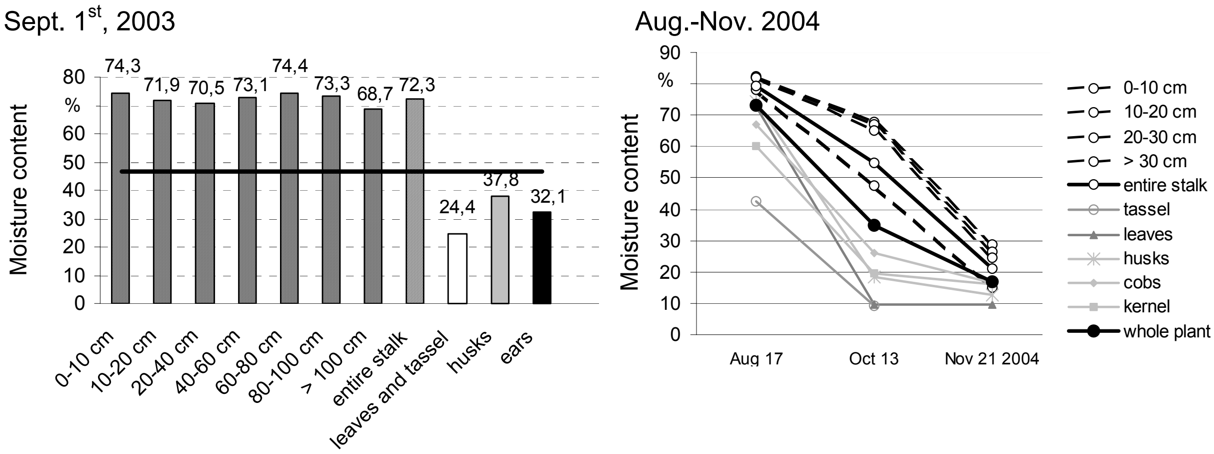

Figure 14: Moisture content in fresh matter of maize plant sections and as a function of time (black line in left graph: whole plant average)

Nitrogen. The element nitrogen averages between 0,9 % and 1,2 % of the maize whole plants, which is in line with the results of 2003 (see Figure 15 and Figure 10). The concentrations in the different stalk sections are similar to 2003 as well, so that the weather condition seems not to affect the nitrogen content at all. The absolute nitrogen content descends in every plant section especially during the first part of the observed period, leaching effects could be one possible explanation for that. Even though nitrogen has constant excessive values during the vegetation period, it underlines once again, that a late harvesting is advantageous. Figure 16 shows a translocation of nitrogen mainly from the leaves into the kernels (a common procedure for annual plants), reaching 68 % of the total share in October. No major changes happen after that time.

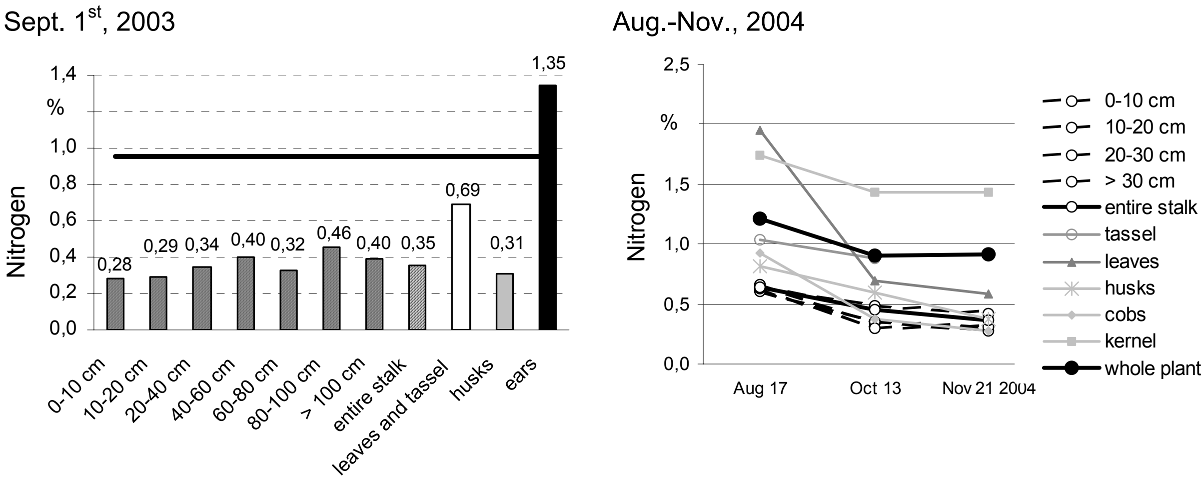

Figure 15: Nitrogen content in dry matter of maize plant sections and as a function of time (black line in left graph: whole plant average)

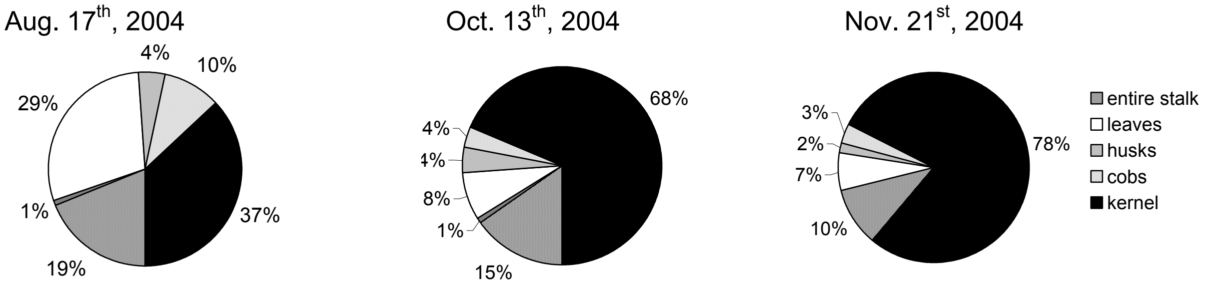

Figure 16: Relative distribution of nitrogen in the maize plants over time

Phosphorus. The absolute phosphorus values are increasing after a period of descending (see Figure 17). Looking at the distribution in the crop, phosphorus is mainly located in the kernels, this applies particularly for the end of the vegetation period due to nutrient translocation processes into the grain.

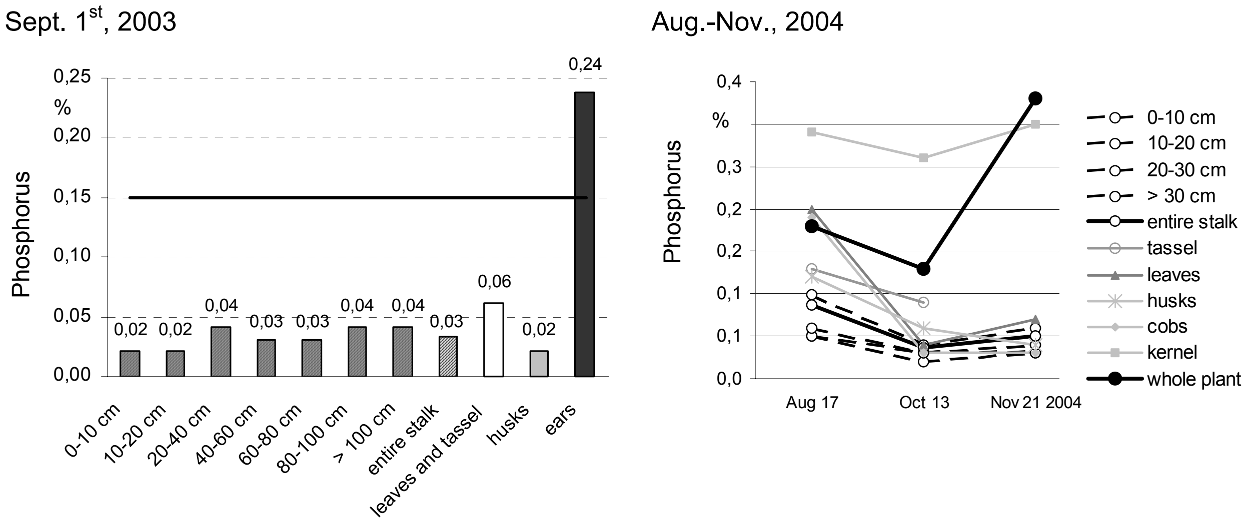

Figure 17: Phosphorus content in dry matter of maize plant sections, as a function of time and the relative phosphorus contents within the whole plant (black line in top graph: whole plant average)

Potassium. Contrary to nitrogen and phosphorus, potassium is mainly located in the stalk with about two to three times higher values compared to the other plant sections (see Figure 18). Concerning the function of time, potassium remains in straw rather than in grain. The ongoing descend even after entering the stage of physiological maturity is originated in leaching effects. Again, a late harvest can here be advantageous. However, with almost 1 % the potassium concentration in maize is a bit lower than for wheat straw but still slightly excessive. It can contribute to slagging problems in the combustor.

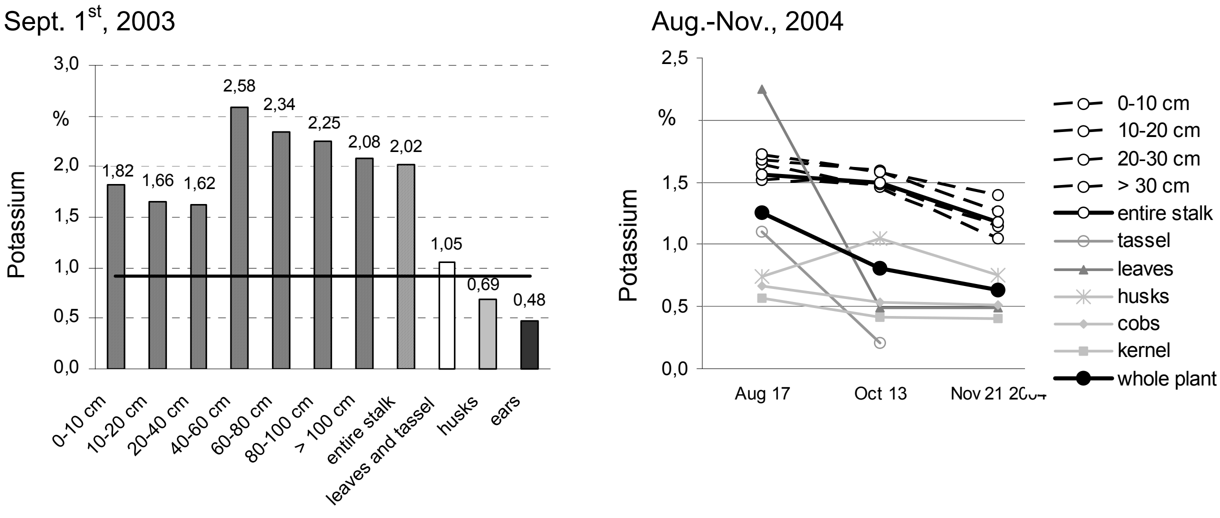

Figure 18: Potassium content in dry matter of maize plant sections as a function of time (black line in left graph: whole plant average)

Chlorine. Due to its corrosive effects chlorine can reduce the useful life of a boiler. Therefore the lowest possible chlorine content in the crop is desirable. Figure 19 shows a strong decrease of chlorine in the leaves in the first part of the regarded period; while the stalk decline happens rather at the end of the period. From a literature review (e.g. [9]) a chlorine concentration in the whole plant was expected to be in the order of 0,3 %. In the here presented analyses this level was hardly ever reached by any plant section. The plant's average content falls from 0,16 % in August to 0,04 % in November 2004; these data are above the value of September 2003 but are still far lower than expected. Obviously the use of whole maize as energy crop is here not associated with a risk of excessive chlorine concentrations in the fuel. Expected leaching effects are not identifiable because of already low concentrations.

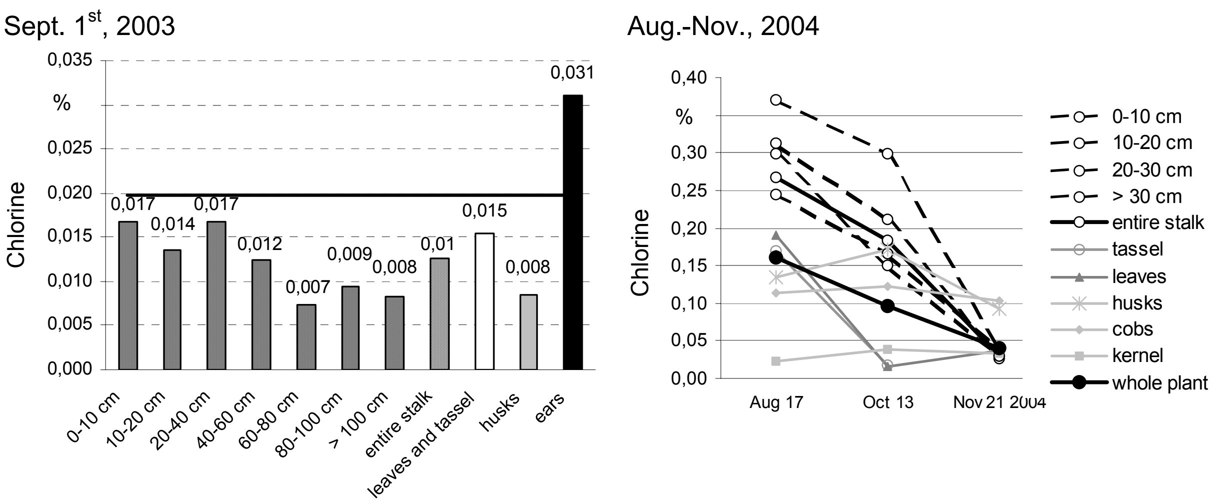

Figure 19: Chlorine content in dry matter of maize plant sections and as a function of time (black line in left graph: whole plant average)

Other major elements (S, Si, Ca, Mg). In general, most of the major elements of Figure 20 show concentration differences between the vegetative and generative plant sections. E.g. sulphate is mainly located in the ears, calcium increases with the height of the stalk, magnesium and silicon have their highest concentrations in the leaves. A reason for the magnesium concentration in the leaves can be the relatively high chlorophyll concentration in this plant section. The silicon peak goes along with the ash content in this plant part (see Figure 13) and is likely caused by dust and soil particle adhesions on the rough and large surface of the leaves.

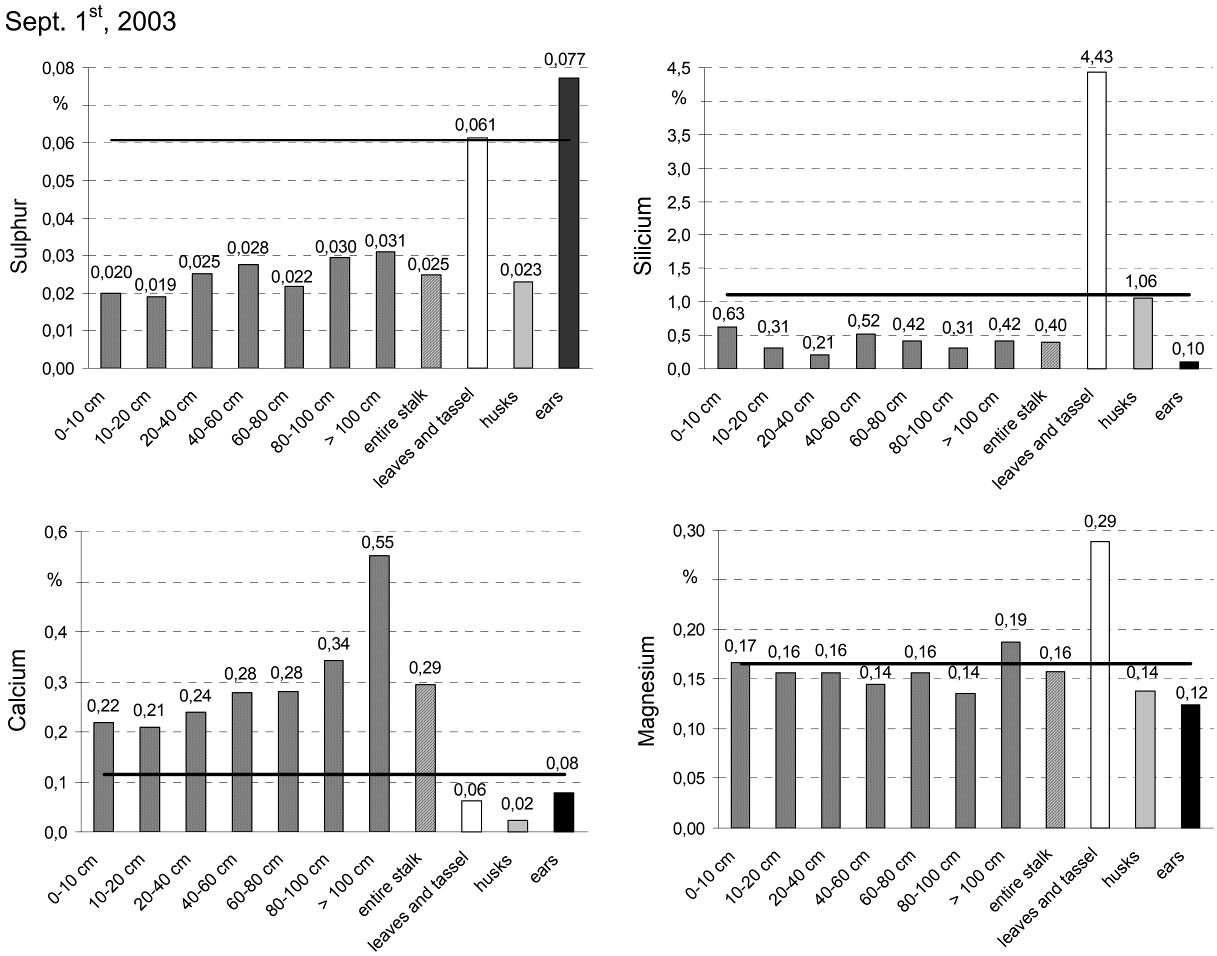

Figure 20: Sulphate, silicon, calcium and magnesium content in dry matter of maize plant sections (black lines: whole plant average)

All plant section data of 2004 were quite exactly in line with the ones of 2003, therefore these data are here not separately shown. This is particularly remarkable in view of the very different climate conditions: 2003 was extremely dry and it was followed by an average climate in 2004 with wet and cool spring. Due to this fact, the here presented parameters are obviously not influenced by climate conditions. Only the moisture content highly corresponds to the annual precipitation and temperature.

Generally it can be concluded, that chances for reducing unfavourable element concentrations by higher crop cuttings or by selective plant harvest (e.g. stalks only) are low, because benefits for one parameter are usually compensated by disadvantages for the other (e.g. nitrogen and potassium).

Heavy metals. The uptake of heavy metals by plants can vary within a wide range and depends on various influences such as site conditions, soil type, nutrient and pollutant availability and crop variety. Heavy metal content in the crop is therefore highly variable, thus usually a larger number of samples is required for a sound assessment of such data.

It was therefore not the goal to identify or quantify influencing factors on the heavy metal content but to provide some general estimation about these characteristics for whole maize plants. This was done by collecting 18 maize samples (whole plants) over the vegetation period from different maize varieties and cultivation methods; the average values of the analyses are listed in Table 6. Due to the fact that there is a lack of published maize data a direct comparison of the here presented results is currently not possible. Therefore a generalisation of these findings are here not be made. But in order to gain an idea about the magnitude of heavy metal contents in maize plants the analysed data is compared to those of coniferous wood as well as of grain straw as reported from the NAWARO-Database of TFZ [3].

The results in Table 6 show a noticeably higher element content for iron, copper, molybdenum and nickel in maize plants compared to coniferous wood or grain straw. Generally the heavy metal contents are closer to those of wood fuels than to grain straw. Generally perennial plants can accumulate heavy metals over many years, thus they usually show higher values than annual plants. In the here presented comparison this was only the case for cobalt, manganese and zinc.

However, from such heavy metal concentrations no direct conclusion upon the contamination of the combustion ash should be drawn as the ash composition is strongly depending on the actually prevailing combustion conditions and on the type and degree of ash fractioning by secondary flue gas treatment. In consideration of this fact it is worth to examine heavy metals in the ash after fuel use.

Table 6: Heavy metal contents of maize whole plants in comparison to published heavy metal data of general coniferous wood and general crop straw

	Sampling of the trials in Dürnkrut/Lower Austria	Published data for comparison (Hartmann et al. 2000) [3]	
Element	maize whole plants [mg/kg d. b.]	coniferous wood [mg/kg d.b.]	grain straw [mg/kg d.b.]
Chrome	4,75	4,50	4,62
Cobalt	0,33	0,35	0,14
Iron	433,32	307,40	163,10
Copper	5,88	3,45	2,21
Manganese	36,16	344,70	22,00
Molybdenum	2,53	1,12	0,38
Nickel	4,72	4,23	0,69
Zinc	31,03	37,64	9,42

4.1.3 Site condition effects

Moisture content. The comparison of the maize variety Clarica on two different testing sites in Dürnkrut/Lower Austria and one field in Strassmoos/Bavaria is shown in Figure 21. The moisture content (MC) differs largely between the three sites with 63 % in the Bavarian maize plants and only 35 % and 20 % respectively in the plants around Dürnkrut. This wide data range shows the strong correlation between the moisture content and the local climate (higher precipitation and lower temperature in Bavaria than in Dürnkrut, see Chapter 3.3.2, Table 3). The climate dependency corresponds to the measured low moisture contents during the unusually dry summer 2003 (see Figure 10) contrary to the much higher data of the average summer 2004 (see Figure 14). Beside the climate the prevailing soil conditions have a high influence on the water supply. However, the time span between the sampling days of one to two weeks has to be taken into account. The strong descend of the moisture content especially in October has already been illustrated (see Figure 14).

Critical elements. Basically for all critical elements no appreciable differences can be found between the sites. The data suggest, that the examined parameters are rather crop specific instead of being site specific. This should be specially pointed out for chlorine which is equally very low at all locations.

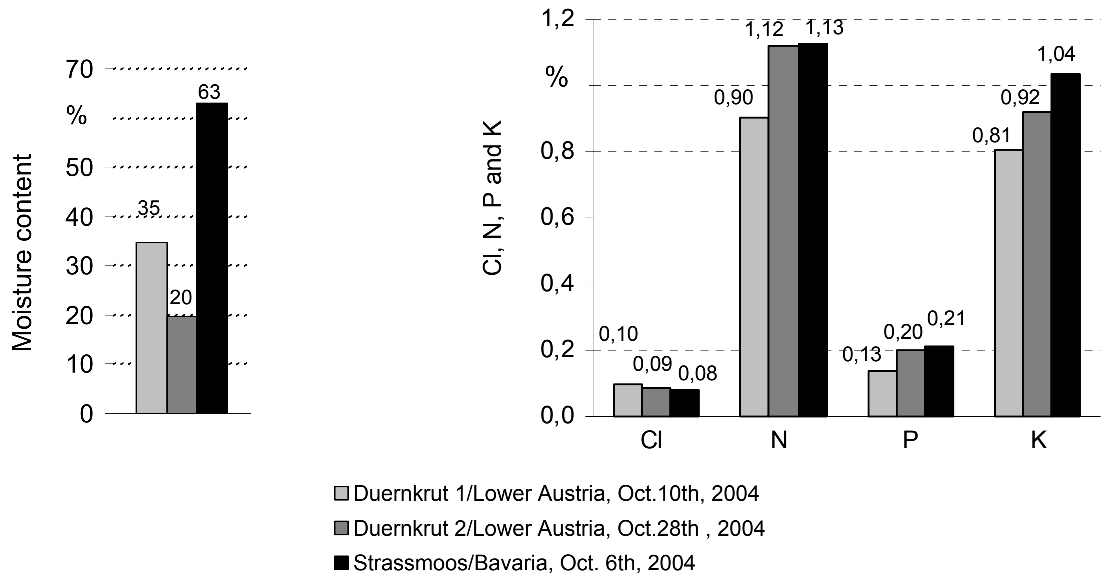

Figure 21: Moisture content, chlorine, nitrogen, phosphorus and potassium concentration of maize from two sites in Lower Austria and one site in Bavaria

4.2 Choice of variety

For every analysed parameter the data are in the expected range, comparable to the results already noted in this report. No mentionable difference between the three varieties can be determined: the calorific values are almost exactly constant, which was expected because this parameter was already shown to be little variable. The same applies for the ash content which is quite uniformly on a rather low level compared to grain straw. Despite their different maturity times (see Table 4) the moisture contents of the chosen varieties are rather homogeneous, which can be explained by the still relatively early sampling time in mid-August, when every variety – independent of its FAO-number – is still in the period of growth.

As for the critical elements, the chlorine level is generally very low in maize plants (see Chapter 4.1.3), so that no major improvements by choosing a variety are expected. For nitrogen, phosphorus and potassium concentrations definite differences between the varieties could not be found. Chances for fuel manipulation by the choice of variety are therefore very low.

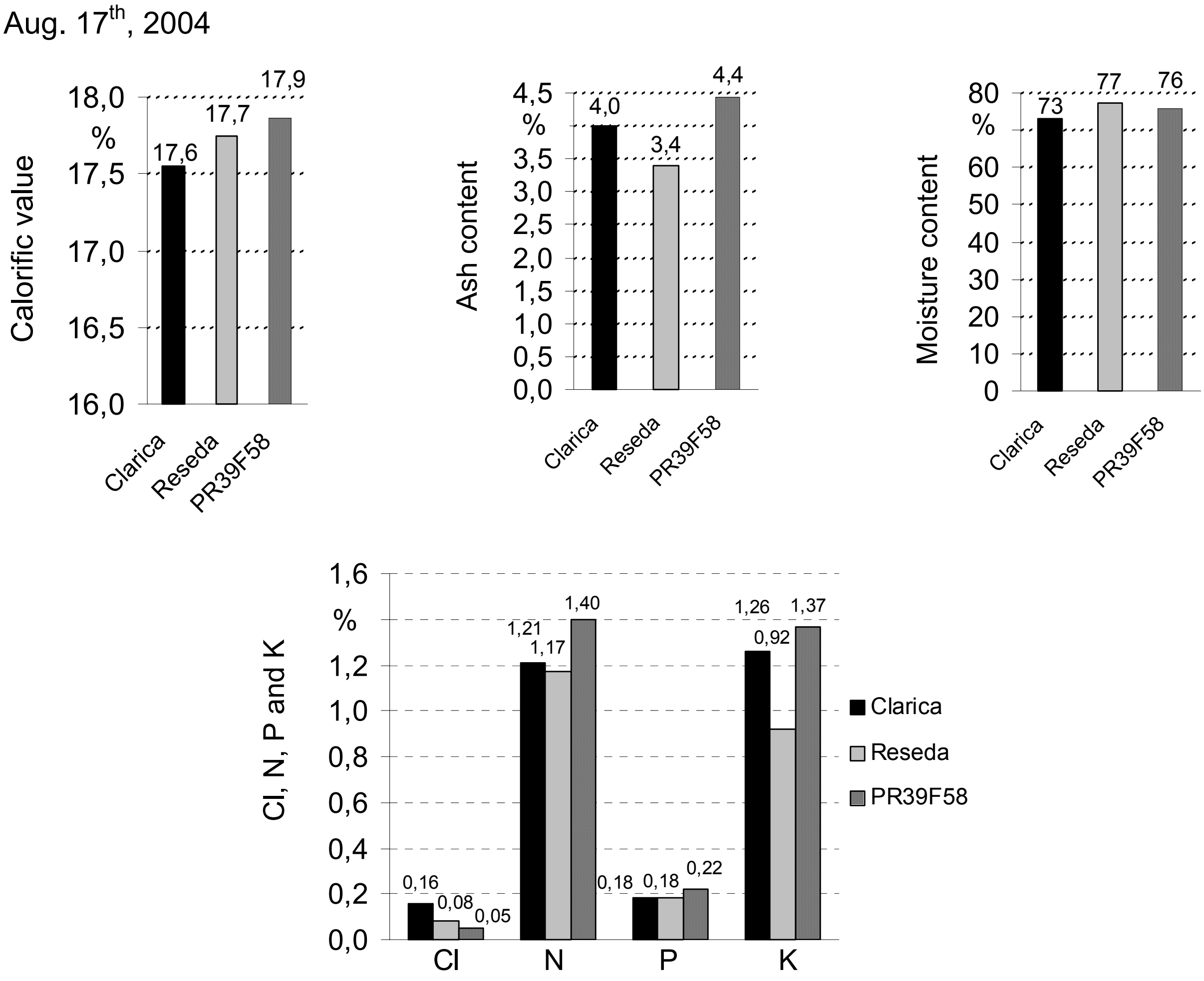

Figure 22: Moisture content (w.b.), ash content, calorific value and chlorine (Cl), nitrogen (N), phosphorus (P) and potassium (K) concentrations of three maize varieties with different maturity times. All values related to dry basis (d.b.), except moisture (w.b.)

4.3 Cultivation methods

4.3.1 Conventional versus ecological cultivation

The data of this trial (see Figure 23) are all in the range of the previously discussed results. As expected, no differences of the stable parameter calorific value arose between the conventional, non fertilised and the ecological cultivated maize plants. Similarly there is no effect on the ash content. According to the drought in 2003 the moisture content is so low, that no high ranges between the variants can be expected. Also for the analysed chemical parameters no clearly differing data between the two cultivation methods were found. However, in every case the ecological variant shows slightly higher values than the conventional, non-fertilised one – an indication that the ecologically cultivated land was not suffering from nutrient shortage. At the same time it has to be considered, that it was the first year after shifting from conventional to ecological practices.

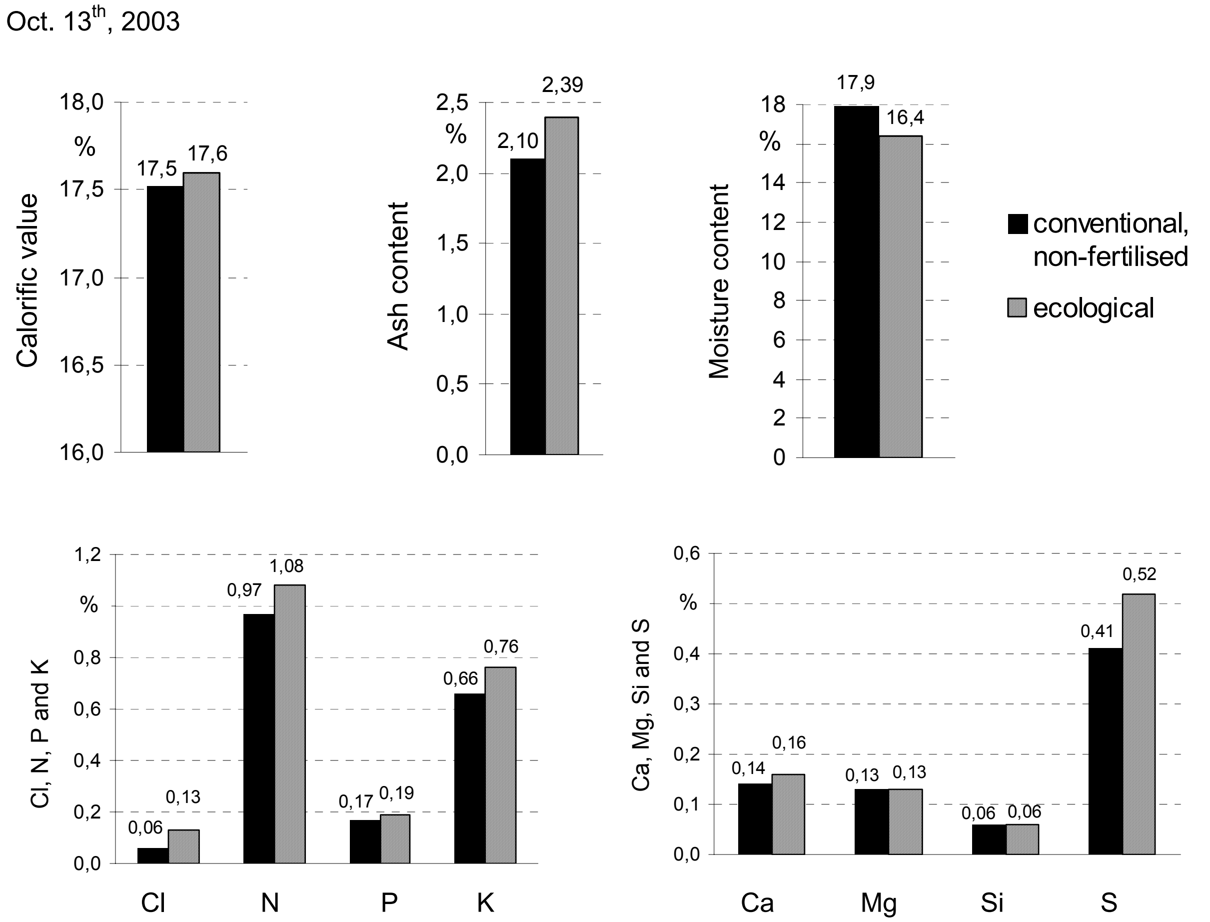

Figure 23: Biofuel properties of maize variety Clarica with conventional/non-fertilised and ecological cultivation. All values related to dry basis (d.b.), except moisture (w.b.)

The trials were repeated in 2004, whereas the conventional lot was this time fertilised, the results are recorded in Figure 24. As there had been no significant changes for calorific value and ash content over the time or between varieties, sites or cultivation techniques, these parameters were here not analysed any more.

The moisture content of ecological produced crop is more than twice as high compared to the conventionally cultivated maize. A possible reason could be that the ecological farming method conserves a favourable soil structure and therefore can maintain a high moisture storage capacity. However, site effects have to be considered as well because the trials were conducted of different locations.

As already recognised in 2003 (Figure 23), the critical parameters – except phosphorus – are slightly higher in ecological farming compared to conventional cultivation. Figure 24 shows almost the exact values and proportion as observed in 2003. The fertilised plants contain only 1/3 of the chlorine compared to the ecological trial field. But again, both values are still very low in contrast to other data for herbaceous fuel given in literature. The slightly higher nitrogen and potassium indicates an effectual nutrient supply by ecological methods.

Obviously the frequently reported effects of fertilisation on fuel quality and in particular on the chlorine content (see [3], [5], [6]) can not be confirmed by the here presented research practical scale with maize crop. However, it has to be pointed out that such effects could only be scientifically proved by applying a randomized experimental plot design with several treatment steps and replications under homogeneous site conditions. At least the here presented results suggest, that fertilisation induced quality effects are in practice difficult to achieve and may even be unrealistic in the case of maize crop.

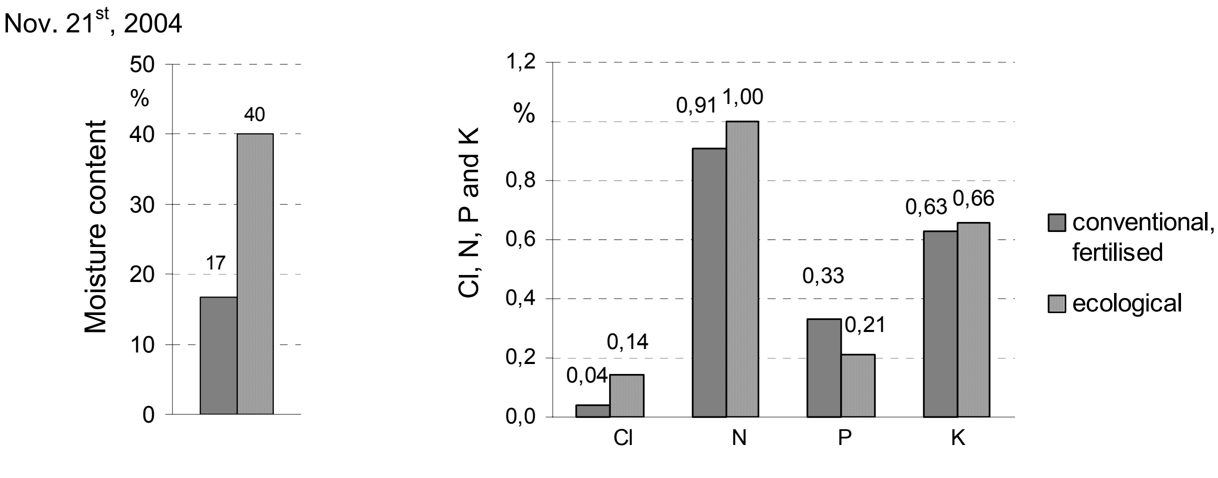

Figure 24: Biofuel properties of maize variety Clarica with conventional/fertilised and ecological cultivation. All values related to dry basis (d.b.), except moisture (w.b.)

4.3.2 Irrigation versus non-irrigation

For the irrigated crop the moisture effect is with more than twice as much unexpectedly high (see Figure 25). The difference was even apparent in the habit of the plants because in the not irrigated plot the leaves along the low stalk section were already died off at the time of sampling. Consequentially even a low irrigation quantity of 35 mm during a drought in the key time span of the vegetation period (see Chapter 3.5.2) can prevent the plant from early maturity. Irrigation is therefore a useful method for lowering the risk of crop failure, especially if applied between July and August, when the water demand of maize is highest. But in vegetation times or years with average precipitation irrigation can delay the stage of maturity which would consequently lead to a higher moisture content at the usual harvesting time.

Concerning the critical parameters, differences between irrigated and non-irrigated plants were again low, the irrigated maize contains slightly less nutrients. An explanation for this could be the fact, that the uninhibited growth had lead to a higher total production of the crop while the nutrient concentration did not increased in the same degree.

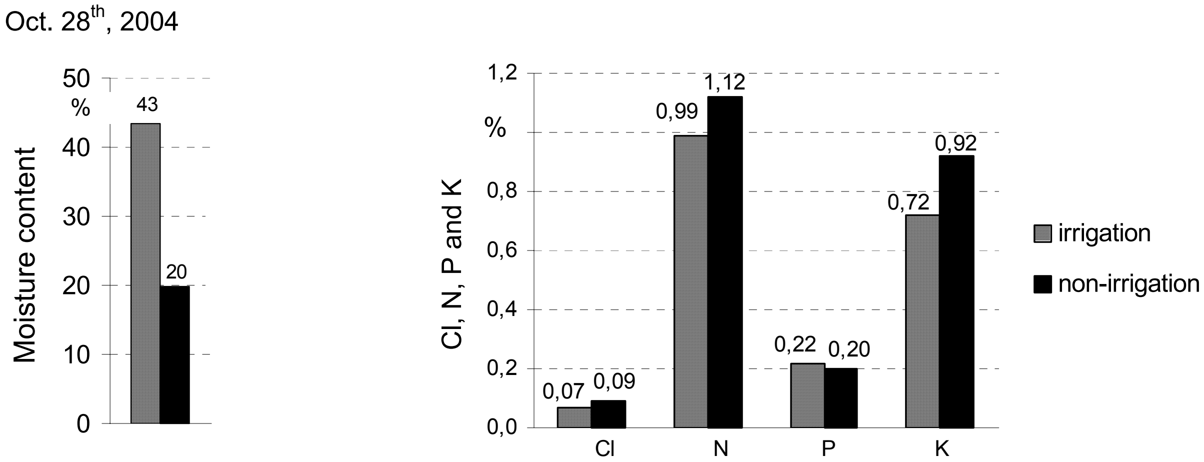

Figure 25: Biofuel properties of maize variety Clarica with irrigation and non-irrigation cultivation in 2004

So far, the results of crop characterisation, choice of variety and cultivation methods consistently show acceptable calorific values and relatively low ash contents. In terms of the critical chemical parameters slightly excessive values are recorded for nitrogen and potassium, while the chlorine content is always on a very low level compared to other herbaceous crops.

Chances for reducing the unfavourable element concentrations by a selective harvesting (e.g. ears and stalk separately) are low, because benefits for one parameter are compensated by disadvantages for the other. Also the choice of the maize variety or the way of cultivation does not bear a significant potential for fuel quality improvement. But most fuel characteristics are enhanced by a delayed harvesting, which is therefore an important factor. Overall, the moisture content is the limiting parameter because it limits the storing ability and consequently degrades the maize fuel quality.

4.4 Moisture content manipulation

As mentioned in the paragraph above moisture content is one of the most critical parameters for the provision of a high quality maize fuel. Therefore possible ways to manipulate this factor were investigated and are discussed in the following chapters.

4.4.1 Harvesting time

The trials of time series in 2003 and 2004 show, that moisture content is highly influenced by the harvesting time. During the progressing maturity the moisture content of whole maize plants is strongly reduced from 73 % in August to 17 % in November 2004 – a fact that has to be considered for choosing the proper harvesting time. Another fact is that the moisture content range within the plant is around 40 percentage points in August and decreases to only around 20 percentage points in November. These data show that the moisture content can strongly be manipulated by the choice of the harvesting time. For more details see Chapter 4.1.1 and 4.1.2.

4.4.2 Swath drying

The drying process of harvested maize in swaths compared to non-harvested growing maize is given in Figure 26. The moisture content decreases over the whole measured period from mid September to the end of October. However, whilst the decrease of the non-harvested plants is relatively consistent over the trial period, the gradient of the maize-swath declines especially in the first week and shows only small changes after that. Rainfall affects only the swath moisture causing a slight increase. At the end of the trial period the moisture content of the non-harvested maize amounts to 55 % while the swath reaches 45 %. These results indicate, that drying maize plants in the swath decreases the moisture content. But drying is not suitable for a late maturing crop variety as applied here. This is due to the fact that in the regarded area in Bavaria suitable climate conditions for swath drying of maize are not very likely in early autumn and they were also not given during the here reported observation period. Nevertheless, a final swath drying after harvesting can still be useful for an early maturing maize variety which reaches a relatively dry stage already in September.

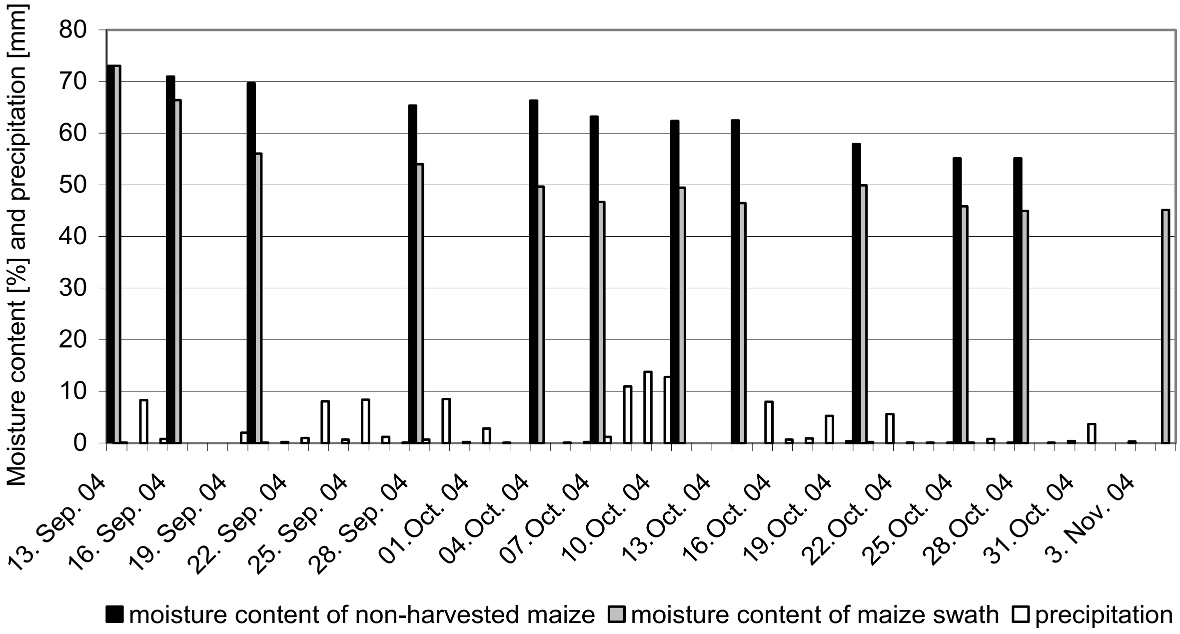

Figure 26: *Drying intensity of maize swaths in comparison to non-harvested growing maize in Pulling/Bavaria*

Figure 27 shows the results from the second swath drying trial which had already been set up one month earlier in Dürnkrut/Lower Austria. Because of the drier weather conditions in Lower Austria, a moisture content starting value of about 73 % is here already reached in August. The course of the observed moisture content over the harvesting season can be divided into three phases:

Phase 1: Between mid August and the beginning of September the moisture content decreases sharply from 73 % to 39 % in the non-harvested maize and to 32 % in the swath.

Phase 2: The difference between the two variants increases over time until the end of September, when it is about 22 % and 14 % respectively.

Phase 3: From the end of September the moisture content in the non-harvested maize hardly drops, while it slightly increases in the swath because of rainfall.

The second swath, which was cut on September 10^{th} on the same field, reached a moisture content level which was only marginally below the growing maize. The progression shows that it is possible to reach optimal storing conditions of below 15 % by swath drying if it starts early enough during the driest summer period. However, it is important to do the baling soon after the storing conditions are reached, so that rain does not affect the quality.

Generally the suitability of any swath drying is chiefly depending on a favourable combination of both, a variety with an early crop maturity and suitable drying conditions in the region. In any case the early cutting for swath drying is associated with a shortening of the vegetation period and thus leads to lower total crop yields.

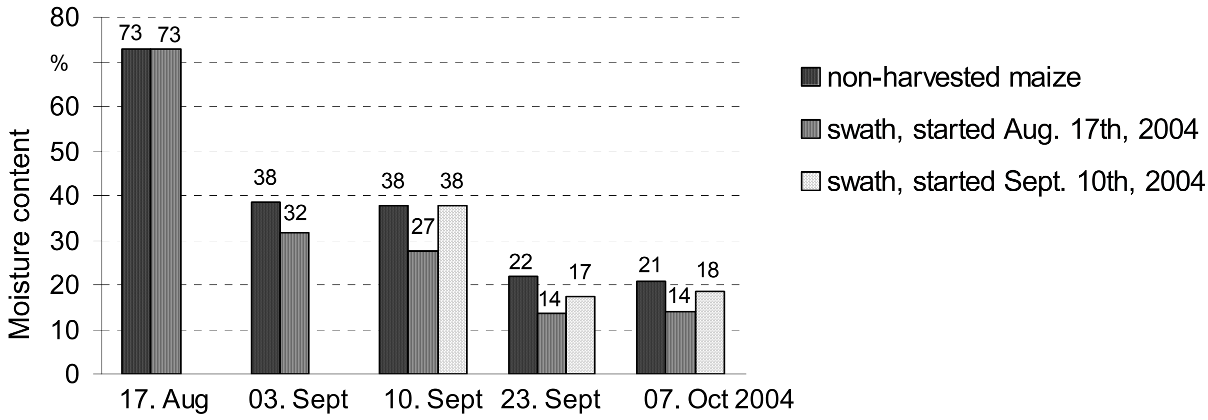

Figure 27: Drying intensity of maize swaths in comparison to non-harvested growing maize in Dürnkrut/Lower Austria

4.4.3 Storage

At the beginning of the storage trail the average moisture content was 23 % with a relatively wide range between 18 and 40 %. Figure 28 displays the moisture contents of the bales in the field depot at set-up time, after three and after six months. Except bale number 19 all core drill samples show higher moisture contents than the beginning determination. However, it is very unlikely that the moisture content had increased in the bales over the time, therefore the differences should rather be attributed to the different sampling methods which had to be applied here (sample collection from parallel swath during harvesting versus core drilling from maize bales during storage). Particularly for bales representative sampling is known to be critical, this is here furthermore complicated by the fact, that the material in the maize bale is inhomogeneous due to the mixture of ears and stalk which are usually unevenly wet.

Contrary to that the moisture content of the roof covered storage trial decreased from 23 to 15 % during eleven months.

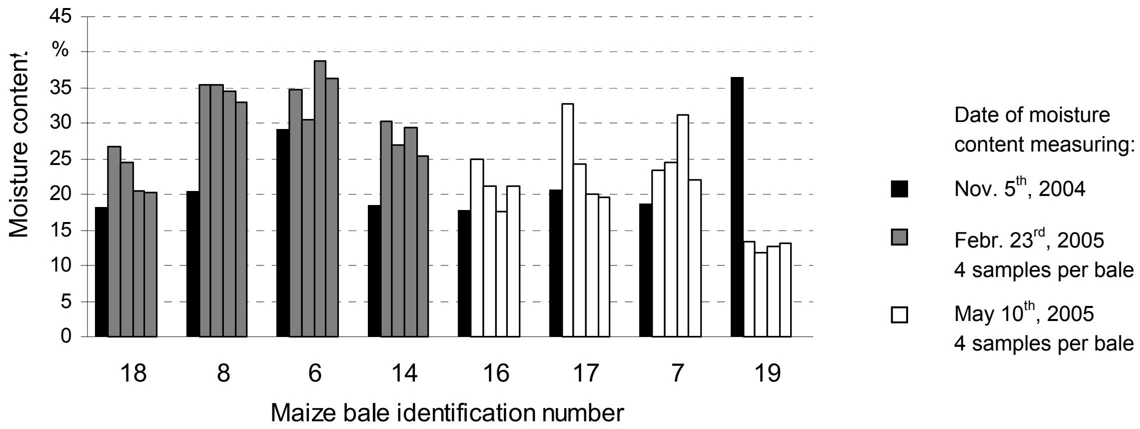

Figure 28: Drying intensity of baled maize under plastic covered storage conditions. The average moisture content at storage start was 23 %.

Assuming that loss of bale weight is being caused by both, the reduction of moisture content and by biochemical processes, the weight of bales were initially measured and the measurement was repeated in two intervals: after three and after six month. For the roof covered storage trial only a measuring period after eleven months was applied. As shown in Figure 29 (top) the weight of the plastic covered bales decreases during the first three months at an average of 15 %, which is a monthly rate of 5 %. After 6 month the decrease is about 23 %, which is a monthly rate of about 3,8 %. Thus the decrease in moisture content is slowing down over the time.

The results of the roof covered storage can be viewed in Figure 29 (bottom). The average mass loss of the fourteen test bales amounts to 16 % after eleven months, which is an average of 1,4 % per month. This decrease is rather low, but in practice it might not be easily achievable, because the bales would normally be placed on top of each other instead of being separated by EU-pallets between the bale layers (see Chapter 3.6.2). This separation had been required by the farmer, who owned the building, he feared the risk of self-ignition in the bale due to insufficient air access. Due to the varying sampling intervals and the fact, that the stacks had been set-up differently, the two storage trials are not easily comparable.

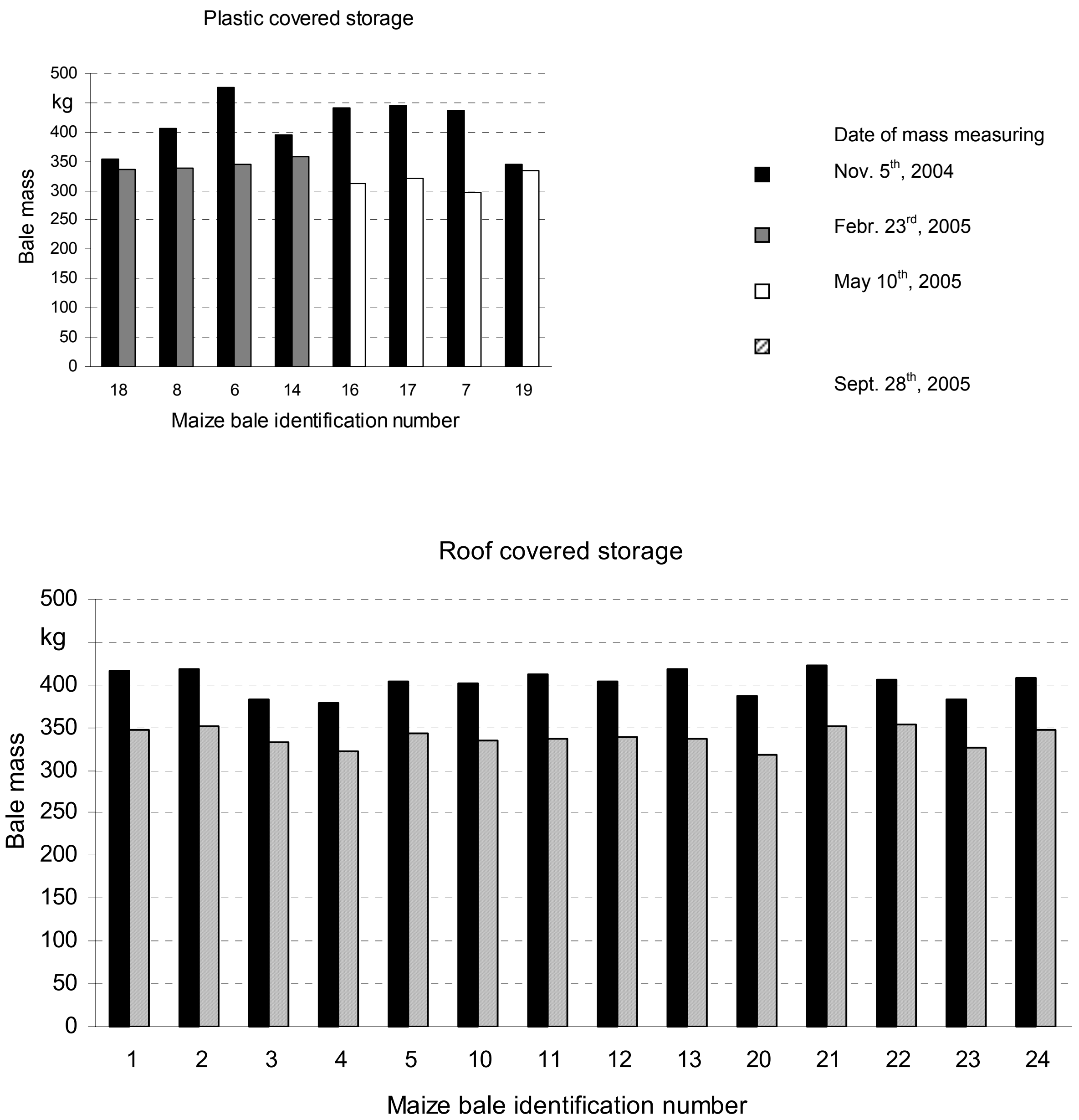

Figure 29: *Weight reduction of baled maize under plastic covered and under roof covered storage conditions. The average moisture content at investigation start was 23 %.*

As a summary of the results of Chapter 4.4 it can be concluded, that moisture content is strongly reduced with progressing maturity. It can also be influenced by harvesting time, irrigation and by the choice of variety. Swath drying and roof storage of maize bales are additional methods to decrease the moisture content.

4.5 Yield determination

The yields of the different maize varieties and row distances range between 15,5 and 25,2 t/ha dry basis with an average of 18,4 t/ha. While the varieties KX 5222 and Garbure show an increasing yield at higher row densities, for Gavott, KWS 2345 and Campesino the opposite is true, here the yield decreased with higher sowing density. Thus no general conclusion can be made about yield effects by variable row density. For the maturity properties of the varieties (see FAO-numbers in Table 5 in Chapter 3.7) the results show a correlation between ripening time and yield: the earlier the ripening time (low FAO-number) the lower is the yield.

Overall, the determined yields of the tested varieties and row distances are reasonable. For comparison: in Germany more than 20 t (d.b.) per hectare are considered as to a high yield, 15 t per hectare are easy to reach. However, these yield expectations are derived from practical scale production rather than from plot yield measurements.

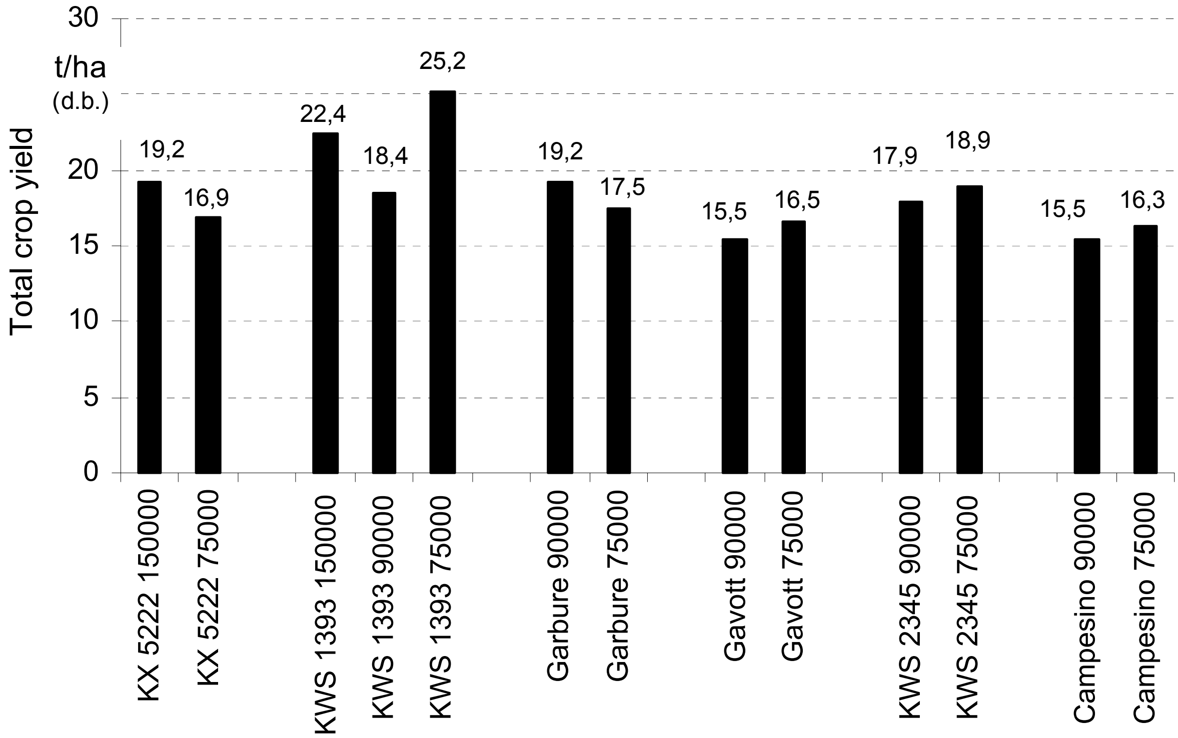

Figure 30: Yield determination of different maize varieties grown at different row distances in Dürnkrut in 2005

4.6 Moisture content determination of baled maize

A reasonable possibility is to take samples with the core drill and subsequently determine the moisture content in the compartment dryer. The advantage is that after sampling, the maize bales still keep their stability and can further on be used for combustion. However, a rapid moisture determination for maize bales is still missing.

4.7 Ash evaluation

In general, there is the possibility of using the ash of biofuel combustion as a fertiliser for crop cultivation. The ash content of fuel mainly contains nutrients and micro-elements; their concentrations determine the use as fertiliser or the necessary effort for disposal.

In Germany a fertiliser order has to be considered in order to assess the ash quality (DüMV) [1]. It only allows the use of fire bed ashes which were gained from a mono-combustion of untreated natural biomass while cyclone and flue-gas ashes are not permissible for fertiliser applications (DüMV Anlage 2 Tab. 10 Abs. 12 und Tab. 12 b Abs.14).

The sampling and the analyses of the here regarded ashes were done by the Technical University of Vienna in 2004. The ash content of more than 90 % indicates to a high energy yield and therefore a complete combustion of all combustible elements. As shown in Table 7 the highest concentrations are given by potassium (18,9 % K_2O) and phosphorus (16 % P_2O_5), consequently these elements represent the main fraction of the ash. Because of the high concentration of these two main plant nutrients a use as fertiliser on farmland seems advantageous. However, the third main nutrient – nitrogen – is completely missing because it is almost completely exhausts as N_2 and NO_x during combustion.

Also the nutrients calcium and magnesium show concentrations which suggest an application as fertiliser. For comparison, the commercial fertilisers "Nitrophoska" or "Vollkorn Plus" contain 8 % K_2O, 8 % P_2O_5 and 3 % MgO.

Table 7: Nutrients content in an ash sample from the combustion of maize whole plants in the NESSIE bale combustor collected from the grate (Data provided by University of Vienna)

	Nutrient concentrations in ash [mass-%]
K_2O	18,93
P_2O_5	15,95
MgO	3,89
CaO	4,42

The critical elements are supposed not to be higher than the given limit values of the DüMV [1] Annex 2 Table1. For the elements nickel, zinc and lead these limits are safely below the limitations and they can be seen as non-critical. Copper, on the other hand, is slightly elevated. On the basis of Swiss' researches [10] the determining parameters for the classification of naturally untreated fuels are zinc and lead. The here presented concentrations of these indicator elements highly under-run the limit values.

According to experience, variability of heavy metals is high and therefore it is necessary to take and analyse several ash samples over a period of time. For a comprehensive ash evaluation the complete set of all eight required elements should be analysed.

Table 8: Comparison of heavy metal concentrations in the ash from the combustion of whole maize plants and the limit values for fertilisers according to the German DüMV [1], Annex 2, Table 1

Heavy metal	Concentrations in the ash sample from whole maize plants [mg/kg d.b.]	Limit values in fertilisers, according to DüMV[a] [1] [mg/kg d.b.]
Arsenic (AS)	n.a.	40
Lead (PB)	21	150
Chromium (VI)	n.a.	2
Nickel (Ni)	47	80
Mercury (Hg)	n.a.	1
Thallium (Tl)	n.a.	1
Copper (Cu)	75	70
Zinc (Zn)	181	1000

[a] DüMV, Annex 2 Table 1 [1]
n.a. = no analysis

Overall, the here analysed ash sample can be used as a PK-fertiliser, because the given minimum nutrient content of 3 % P_2O_5 and 3 % K_2O is safely achieved. In order to avoid dust development and to assure a consistent distribution on the cultivation field, the ash has to be either grained or distributed as wet material. Beside the direct application as fertiliser the ash could also be added to an organic-mineral fertiliser with a maximum concentration of 50 % in the mixture.

5 Conclusions

The main conclusions of the here presented research can be compiled as follows:

- Due to its particular properties the use of maize as combustion fuel is practicable and in some concern it even shows better fuel properties than other annual agricultural crops or residues.
- The results of crop characterisation, choice of variety and cultivation methods consistently show acceptable calorific values and relatively low ash contents. In terms of the critical chemical parameters slightly excessive values are recorded for nitrogen and potassium, while the chlorine content is always on a very low level compared to other herbaceous crops. Within the baled whole plant the moisture content is unevenly distributed due to the different moisture in the cobs and the stalk, this can cause problems during storage and combustion.
- Chances for reducing unfavourable element concentrations by selective plant harvest (e.g. stalks only) or by higher crop cuttings are low, because benefits for one parameter are usually compensated by disadvantages for the other (e.g. nitrogen is mainly located in the ears, potassium in the stalks). Also the choice of variety does not significantly and reliably affect the fuel quality.
- Irrigation during a drought in the key time span of the vegetation period can prevent maize plants from early maturity, even if the irrigation depth is very low. Apart from that, the way of cultivation (fertilised, non-fertilised, irrigated, conventional, ecologically) seems not to bear a significant potential for fuel quality improvement at the given site.
- The analysed chemical parameters are obviously not influenced by climate or site conditions. Only the moisture content highly corresponds to the local precipitation and temperature conditions. Thus, the examined chemical elements are rather crop specific instead of being determined by variable site or climate conditions.
- Fuel quality can be enhanced by a delayed harvesting time: it leads to strongly reduced moisture and ash contents and to a slight descend of nitrogen, potassium and chlorine content. However, the calorific value remains relatively constant over the time.
- Swath drying before baling could decrease the moisture content, but it's applicability is difficult as it is chiefly depending on a favourable combination of both, a variety with an early crop maturity and suitable drying conditions in the region.
- In any case an early (for swath drying) or late (for full maturity) harvesting is associated with a reduced crop yield. For the choice of the optimum harvesting time a region specific yield determination is important in order to quantify the economic feasibility of maize cultivation for combustion..
- The moisture content is the limiting and most critical quality parameter of maize fuel crop production, this is due to the reduced storability and the consequently degrading maize fuel quality and quantity.
- Roof covered storage leads to a stronger decrease of moisture content in the maize bales than a plastic covered field depot.
- A suitable rapid moisture determination method for baled maize is still not available, however such a device would be useful for testing the storability and for fixing the proper fuel price.
- Influencing field crop quality for solid biofuel applications is a complex task with several counteracting variables.

6 Summary

The use of annual agricultural crops for combustion still suffers from several drawbacks which are associated with the particular fuel properties. Thus, in combustion there is an increased risk of excessive pollutant emissions and reduced useful plant life. It was therefore the aim of the here reported project to minimize such disadvantages by applying all useful agricultural methods for fuel quality enhancement.

The research focused on maize as an annual agricultural crop which is used as whole plant. Several aspects in the process chain were investigated. Main target parameters were the moisture content, calorific value, ash, nitrogen, potassium and chlorine content. Other fuel characteristics were also inconsistently determined, they were phosphorus, calcium, magnesium, sulphate, silicon and several heavy metals. Examinations were done for various maize varieties, plant sections, different maturity stages and sites. Furthermore several other influences such as fertilisation, harvesting time, swath drying and storage conditions were regarded.

The research was embedded in the NESSIE-project ("New small scale innovative energy transforming combustor based on baled biomass"), an EU-project which ended with the installation of a newly developed maize bale furnace at Dürnkrut, a small town in Lower Austria. The maize producing farmers are located in the region around the plant. Their cultivation techniques and local machine equipment were applied. The testing trials were part of the farmers lots and the trials were carried out over three consecutive years between 2003 and 2005.

Results show that more than half of the crop yield is usually provided by the ears (i.e. cobs + kernels) while the leaves contribute only 10 to 20 % and the stalk only 20 to 35 % of the total mass, depending on the harvesting time. The calorific values of the plant parts hardly differ; in average the net calorific value (dry base) of maize whole plants is around 17,5 MJ/kg with the highest values in the cobs (18,1 MJ/kg) and average variations of 0,5 MJ/ within the plant. During the vegetation period the calorific value remains relatively constant.

The ash content of whole maize plants is only around 4 %; peak values of up to 9 % occurred in the leaves, presumably due to dust and soil particle adhesions on the rough leaf surface. With the proceeding vegetation period the ash content decreases by almost 50 % to an average of only 2,3 % in November. This decline happens more or less consistently in all maize plant section (stalk sections, leaves, husk, tassel, cob or kernels). The total ash content reduction is also a result of the fact, that the higher ash containing leaves have partly been dropped in late autumn.

The moisture content (MC) is strongly reduced with progressing maturity, for example from 73 % in August to 16,7 % in November. But harvesting in November is problematic in most regions due to impassable ground or clammy plants. Therefore frost harvest or harvesting in early spring during dry weather conditions could be a possible alternative, however, a severe yield loss during the winter months (especially by falling leaves and by game animals which bite off the ears) has to be considered. With irrigation the risk of crop failure can be lowered in dry summers. But in an average precipitation year it can delay plant maturity; this means for example that moisture is still around 40 % while a non-irrigated crop has already reached 20 % in late October. Swath drying can decrease the moisture content, however, the availability of favourable drying conditions in late summer is hard to predict and a variety with an early crop maturity should be chosen, although this is associated with a lower total yield.

The critical element nitrogen averages between 0,9 % and 1,2 % in the maize whole plants. The absolute nitrogen content descends in every plant section especially during early autumn. This is due to a translocation of nitrogen mainly from the leaves into the kernels – a common procedure for annual plants. Therefore, again, a late harvesting is advantageous. Variety specific effects were also observed.

Contrary to nitrogen, potassium is mainly located in the stalk at up to three times higher concentrations than in the other plant sections. The ongoing descend even after entering the stage of physiological maturity can be explained by leaching effects through rainfall. Again, a late harvest can here be advantageous.

Due to its corrosive effects chlorine can reduce the useful life of a boiler and it can create harmful flue gas substances during combustion, therefore a lowest possible chlorine content in the crop is both a technical and an ecological aim. However, the usually high chlorine concentrations of annual herbaceous crops were here hardly ever reached in any maize plant section or in any other sample from a tested maize variety, harvesting season, cropping location or region. The here measured concentrations were rather low, they ranged from 0,02 to 0,15 % (in dry matter). Plant section analyses gave no indication that a variable cutting height could influence the chlorine content of the harvested crop. Neither was there any effect by fertilisation, which was either done by chlorine containing fertilisers or organically without chlorine content. Variety specific effects were also not observed; however, measures for fuel manipulation by a specific choice of variety are hardly useful at such low Cl-concentrations.

Between the tested sites (Lower Austria and Bavaria) no significant differences were found for either of the considered critical elements. This suggests, that the examined parameters are rather crop specific instead of being site specific. However, the moisture of maize is highly influenced by the local climate.

Bales were stored at an average moisture content of 23 % but at a large moisture variation between 18 and 40 %. A consistent and significant moisture decline was not visible in either the roof or plastic covered storage trials, this was mainly due to sampling problems which had proven to be particularly difficult for maize plants due to the inhomogeneous moisture distribution within the crop (ears and stalks are unevenly wet). However, the weight of the plastic covered bales decreased by around 15 % over the first three months and by 23 % over the full 6 month storage period. This loss is presumably caused by both, the reduction of moisture and by biochemical decomposition.

Generally it can be noticed that influencing field crop quality for solid biofuel applications is a complex task with several counteracting variables. Chances for actively minimising unfavourable fuel contents are generally low, because benefits for one parameter are usually compensated by disadvantages for the other.

7 References

[1] DüMV – Verordnung über das Inverkehrbringen von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln, Fassung vom 26. Nov. 2003

[2] Hartmann, H. (2001): Die energetische Nutzung von Stroh und strohähnlichen Brennstoffen in Kleinanlagen. In: Energetische Nutzung von Stroh, Ganzpflanzengetreide und weiterer halmgutartiger Biomasse. Gülzower Fachgespräche, Vol. 17. Fachagentur Nachwachsender Rohstoffe e.V. (ed.). Gülzow, Germany. p 62-84.

[3] Hartmann, H., T. Böhm, L. Maier (2000): Naturbelassene biogene Festbrennstoffe – umweltrelevante Eigenschaften und Einflussmöglichkeiten. Schriftenreihe „Umwelt & Entwicklung Bayern", Vol. 154. Bayerisches Staatsministerium für Landesentwicklung und Umweltfragen (StMLU) (ed.). Selbstverlag, München. 155 p.

[4] Hartmann, H.; Böhm, T. (2001): Rapid Moisture Content Determination of Wood Chips – Results from Comparative Trials. In: Proceedings 1st World Conference on Biomass for Energy and Industry, 5-9 June 2000 in Sevilla, James & James Ltd., London, pp. 571-574.

[5] Lewandowski, I. (1996): Einflussmöglichkeiten der Pflanzenproduktion auf die Brennstoffeigenschaften am Beispiel von Gräsern. In: "Eigenschaften fester Bioenergieträger" - Internationale Tagung in Stuttgart im Mai 1996. Schriftenreihe "Nachwachsende Rohstoffe" (6), Fachagentur Nachwachsende Rohstoffe (ed.), Landwirtschaftsverlag Münster, S. 32-48.

[6] Sander, B. (1996): Fuel Data for Danish Biofuels and Improvement of the Quality of Straw and Whole Crops. In: Biomass for Energy and the Environment (Vol. 3). Proceedings of the 9th European Conference on Bioenergy in Copenhagen, June 1996, Elsevier Science Ltd., Oxford, England, pp 490-495.

[7] Strehler, A., W. Stützle, D. Bludau (1987): Zuckerhirse – Technische Vorschläge zur Gewinnung von Zucker, Futtermitteln und Ethanol aus Zuckerhirse in Bezug auf die Verfahrensschritte von Anbau bis zum Endprodukt unter besonderer Beachtung der Wirtschaftlichkeit. Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten (ed.). Selbstverlag, München. 128 p.

[8] Thrän, D. und M. Kaltschmitt (2001): Stroh als biogener Festbrennstoff in Europa. In: Energetische Nutzung von Stroh, Ganzpflanzengetreide und weiterer halmgutartiger Biomasse. Gülzower Fachgespräche, Vol. 17. Fachagentur Nachwachsender Rohstoffe e.V. (ed.). Gülzow, Germany. p 85-102.

[9] Zschetzsche, A., W. Hantsch-Linhart, A. Schmidt (1993): Analysen von biogenen Brennstoffen. Bericht für das Bundesministerium für Wissenschaft und Forschung (eds.). Vienna, Austria. 44 p.

[10] Kaltschmitt, M., H. Hartmann (eds.) (2001): Energie aus Biomasse – Grundlagen, Techniken und Verfahren. Springer Verlag, Berlin, 259 p.

Berichte im Rahmen dieser Schriftenreihe

Berichte aus dem TFZ:

1	Qualitätssicherung bei der dezentralen Pflanzenölerzeugung für den Nicht-Nahrungsbereich Projektphase 1: Erhebung der Ölqualität und Umfrage in der Praxis
2	Erprobung der Brennwerttechnik bei häuslichen Holzhackschnitzelheizungen mit Sekundärwärmetauscher
3	Daten und Fakten zur dezentralen Ölgewinnung in Deutschland
4	Untersuchungen zum Feinstaubausstoß von Holzzentralheizungsanlagen kleiner Leistung
5	Qualität von kaltgepresstem Rapsöl als Speiseöl und Festlegung eines Qualitätsstandards
6	Entwicklung einer Prüfmethode zur Bestimmung der Cetanzahl von Rapsölkraftstoff
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