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The impacts of genotype and harvest time on dry matter, biogas and methane yields of maize (*Zea mays* L.).

Dissertation

A Thesis Submitted in partial fulfilment of the requirements for the degree of Doctor of Agricultural Science (Dr. Agr.) to the Faculty of Agricultural Sciences, Nutritional and Environmental Management

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To my Mum, Anna Koyen, Rev Fr. Tatab H. Mbuy and Gen Ivo D. Yenwo

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Abbreviations and definitions used in this thesis.

ADF	Acid Detergent Fibres
BBCH	Biologische Bundesanstalt, Bundessortenamt and CHemical industry
CCM	Corn Cob Mix
CF	Crude fibres
CP	Crude protein
DMC	Dry Matter Content
DMY	Dry Matter Yield
EEG	Erneuerbare Energie Gesetz
ELOS	Enzyme soluble substances
GDD	Growing Degree Day
GG	Gross-Gerau
GI	Giessen
LAI	Leaf Area Index
LSD	Least significant difference
ML	Milk line
NDF	Neutral Detergent Fibres
NIRS	Near infra red reflectance spectroscopy
PAR	Photosynthetically Active Radiation
VFA	Volatile fatty acids
VS	Volatile solids

1 Introduction

Anaerobic digestion is a natural process that converts biomass to biogas which contains basically methane (CH₄) and carbon dioxide (CO₂). Both gases are reputed for their potentials to cause global warming and methane is known to have more of this potential than CO₂ (IPCC 2001). For this reason using methane from anaerobic digestion is presently seen as an important way to curb global warming as well as increase energy supply in the century threatened by unending increasing petrol prices. Because anaerobic digestion treats biomass which is a renewable and carbon neutral resource, energy farming is increasingly becoming an important part of agriculture. The crops produced under this concept are referred to as energy crops. They are judged according to energy needed and their energy balance at the end of the whole process from planting, harvesting, storing up to the transformation to the required energy stage.

Just as important as these economic factors is also the ability to produce high yields of high quality (including digestibility) whole plant silage maize. High yielding potentials and quality are functions of genotype and maturity at harvest. Hence while farmers have responded by dedicating more land for whole plant silage maize production, scientist are still in search of the best hybrids and harvest maturity that will provide maximum dry matter yield, biogas and methane productivity.

Maize (*Zea mays L*) as a C₄ plant, has the potential to produce higher biomass yields compared to most grass crops (family Poaceae) common in German agriculture. Maize's efficient nutrient and water usage, excellent ensilability, and the fact that maize cultivation, harvesting and storage techniques are well established in Germany, has made maize the most cost effective energy crop to cultivate. The cost effectiveness of producing corn as compared to other forages has been reported by Roth et al. (1995). The comparatively high biogas yields and a positive energy balance (output/input) in producing biogas from maize, has further increased this image and silage maize is presently seen as the most competitive energy crop for anaerobic production of biogas not only in Germany but in the wider European Union (Amon et al. 2003, Von Felde 2007).

When growing maize for whole plant silage, critical factors which influence optimum harvest timing includes whole plant dry matter content (DMC), total dry matter yield (DMY) and dry matter chemical composition. Higher per hectare DMY ensures substrate's sustainability while DMC and chemical composition dictates preservability and biogas and methane productive potentials respectively.

Many years of research on the suitability of whole plant silage maize as feed for dairy animals revealed starch as an inevitable component of dry matter. Since then whole plant silage maize varieties have been selected and bred on the basis of their grain productivity (Mahanna, 2005; Shaver et al. 2003; Coors, 1996). The grain milk line (indicating the degree of starch fill) has since then been the main orientation in timing harvest for best quality feed (Crookston 1984; Hunter et al. 1991; TeKrony et al. 1994; Bal et al. 1997; Johnson et al. 2002). Half milk line of maize grains has been

found to correspond to 30% dry matter content for whole plant silage maize. This dry matter content is considered not only optimal for storage in Bunker silos that are very common in German farms but is also the stage at which the whole maize plant would have accumulated most of its dry matter quantitative as well as qualitative.

The recent switch to use whole plant silage maize as a substrate for the production of methane via anaerobic digestion suggests new challenges to maize breeders who are determined to create new maize varieties solely intended for this purpose. Just as is the case in the breeding of whole plant silage maize for feed, maximising yield and digestibility are presently the primary research concern of these breeders.

Yield and chemical composition (that strongly influence digestibility) are primarily influenced by genotype (Hunt et al. 1992; Carter et al. 1991. Barrier et al. 1995; Coors et al. 1994) as well as by genotype x environmental interactions (Evans and Fischer, 1999; Allen et al. 1991). All these factors can add as well as subtract optimum yield and quality of any crop depending on the phenological stage of the plant. Maturity at harvest and genotype both have significant effects on yield quality of whole plant maize silage (Johnson et al. 1999a) and subsequently on products made from them. Choosing the right variety might be easier with the help of a breeder but the choice of the right harvest time is only possible with enough knowledge on maize phenology.

The aims of the experiments described in this thesis were to pinpoint the best time to harvest each of the 13 maize cultivars planted for maximum dry matter yield (DMY), optimum dry matter content (DMC) and maximum biogas and methane productivity via anaerobic digestion. In doing so the following hypothesis were put forward:

1. Dry matter yield, biogas and methane productivity of maize is affected by genotype, maturity at harvest and experimental location.
2. Delaying harvest increases dry matter yield, biogas and methane productivity for each genotype.
3. Higher biogas volumes equally contain higher methane volumes.

2 Literature

2.1 Agricultural bio energy resources

The ability of biomass to meet today's global energy demands will depend on the efficiency of technologies used as well as on a sustainable availability of biomass resources. Traditionally the role of agriculture has been the production of biomass for food and feed purposes. However being an energy intensive activity, many farmers have used agricultural waste from both animals and crops to supplement fossil fuels. The use of biomass as an energy feedstock is hence not a novelty in agriculture. What is new is the huge scale of demand for bio energy resources that has developed over the past few years. In an attempt to satisfy these demands farmers have reverted to the cultivation of crops primarily intended for energy production purposes. Crops produced with this primary intention have been termed energy crops.

Energy crops, are defined as any plant material used to produce bio energy, but those grown specifically for the purpose are characterized by their capacity to produce large volumes of biomass, with high energy densities (for this work methane density) per unit amounts (kg VS of silage maize) of biomass, as well as their ability to adapt to any marginal and crop lands (Lemus and Lal 2005).

The cultivation of energy crops is presently very common in the developed world and includes food and feed crops like maize (*Zea mays L.*), rape seeds (*Brassica napus L.*), soy bean (*Glycine max L.*), and sugar cane (*Saccharum officinarum L.*). The fact that these are all conventional food or feed crops is one among many reasons why energy crops are presently heavily criticised. There are many ongoing researches therefore to cultivate none food crops like jatropha (*Jatropha curcas L.*), Miscanthus (*Miscanthus sinensis or Giganteus*), switchgrass (*Panicum virgatum*) and many others to replace these controversial food crops.

In economic terms, the success of an energy crop highly depends on its energy balance (output/input). Bioenergy balances allow the analyses and understanding of all the operation and process units of biofuel cycles from production up to the use of energy generated with them (FAO 2004).

When compared with petroleum energy crops appear relatively expensive and again call for more criticism. This is due to the very low energy balance of petroleum, which actually comes from the fact that unlike energy crops, petroleum and other fossil resources do not have to be cultivated. However when compared in terms of renewability, environmental compatibility and the ability to curb rural poverty, energy crops again become more attractive. The suitability of any energy crop is presently studied only from the energy balance point of view. The impact on land for food and feed production is very often ignored. Supporters of energy crops believe that most of the high cost seen with bioenergy production occurs at the transformation level and that improvement in the efficiency of transformation technologies will reduce this

cost and make bioenergy competitive with petroleum and other fossil fuels in a very near future (FAO 2004).

The Brazilian sugar cane ethanol is regarded by many as the most successful bio-energy scheme in the world. It is therefore seen as a world bioenergy model (Tatsuji 2003). The successes of most bioenergy projects are hence usually judged by comparing their energy balances to this Brazilian model. Energy balances for biogas and biodiesel production in Germany have been calculated by the main maize breeding company- KWS and compared with the Brazilian ethanol model. These calculations are presented in table 2.1 and 2.2 below.

Table 2.1: Energy balances of producing bioethanol from different biomass types in different regions of the Globe (KWS 2007)

Region	Biomass type	Yield (dt/ ha)	Gross ethanol(l/ha)	Net ethanol (l/ha)	Energy balance
Germany	Wheat	80	2800	1527	1,2
Germany	Sugar beet	600	5833	3821	1,9
USA	Grain maize	100	3600	2034	1,3
Brazil	Sugar cane	850	7100	6265	8,3

Table 2.2: Energy balances of producing biogas from maize, beet and sorghum and biodiesel from rape seeds in Germany (KWS 2007) 4

energy form	Biomass type	Yield (dt/ ha)	Gross energy (l/ha)	Net energy (l/ha)	Energy balance
Biogas	Maize/Beet /sorghum	55 / 70 / 760	8000-10000	7058-8823	7,5
Biodiesel	Rape seed	45	1600	838	1,1

The preference of maize as an energy crop by the Germans can be depicted from the rapid increase in land area cultivated with maize compared to other potential energy crops in Germany from 2004 the year the German renewable energy policy was renewed to 2006 (Infer table 2.3 below).

Table 2.3: Relative land area cultivated with energy crops in Germany in 2004 2005 and 2006 (FNR 2007)

Type	Set aside land (hectare)			Land area with energy bonus		
	2004	2005	2006	2004	2005	2006
Cereals	82	3.613	7440	446	4.094	13.589
Silage maize	2.765	21.410	36.955	7.863	45.578	119.351
Sorghum	107	214	117	19	144	332

2.2 Maize

Cultivated maize (*Zea mays* L) is worldwide an important agricultural crop (Morris, 1998) of the Maydeae tribe of the family, Poaceae. It is a robust, herbaceous monoecious annual plant with an unclear ancestry and therefore requires the help of humans to disperse its seeds for its propagation and survival. Maize is hence a cultigen. It is both phenotypically and genetically so highly diverse that its molecular diversity has been found to be roughly 2 to 5 fold higher than that of other domesticated grass crops (Buckler et al. 2001). The tremendous genetic variability of maize will certainly continue to provide opportunities that will make maize the most adapted agricultural crop worldwide (Doebley 1990; Kellogg and Birchler 1993) both ecologically as well as socioeconomically. Today maize is cultivated under extreme conditions of humidity, sunshine, altitude and temperature from the equator up to latitude 50°N and about 48°S and as high as 3000m above sea level. One genetic factor of maize that is highly regarded by energy crop producers is its C₄ photosynthesis, which enables maize to avoid photorespiration and to efficiently convert photosynthetically active radiation (PAR) and nutrients into useful biomass under conditions that will limit the productivity of many C₃ crops.

Added to genetic diversity, developments in genetic engineering that allows the introduction of foreign genes into the genome of maize are already providing new methods that can improve maize resistance to many biotic and abiotic factors and boost yields in traditional as well as in marginal ecosystems like the dry savannas and cold temperate climates. Despite the controversial view of the European Union towards genetically transformed maize, the total area put to its cultivation is increasing worldwide especially in the USA.

2.2.1 Origin and taxonomy of maize

Knowledge on the origin of cultivated maize like any agricultural crop is an important tool for future breeding and biodiversity considerations. For these reasons breeders and botanists continues to search for the true botanical and cultural origin of cultivated maize. The great wealth of maize genetic diversity found in central south America together with fossil discoveries have convinced researchers to declare this region especially today's Mexico as the true original centre where maize cultivation began (Mangelsdorf, 1974; McClintock et al. 1981; Doebley et al. 2002).

Despite the unanimous agreement on the geographical origin, the botanical heritage of cultivated maize (*Zea mays* L) is still controversial. Four main hypotheses have been put forward to explain maize true ancestors. Of the four hypotheses, only the teosinte hypothesis has appreciable acceptance. The teosinte hypothesis put forward by Ascherson in 1895 (Mangelsdorf and Reeves 1939) claims that cultivated maize originated by human selection from a wild Mexican grass called teosinte (*Zea mays* spp. *mexicana*) (Beadle 1986; Doebley 1990; Doebley and Stec 1991). The reason why the teosinte hypothesis has attracted so much appreciation lies in observations that teosinte can naturally and freely hybridise with cultivated maize. The tripartite

hypothesis, the common ancestry hypothesis (Randolf 1959) and the catastrophic sexual transmutation hypothesis (Iltis 1983) could not attract much appreciation.

2.2.2 World maize production and usage

Maize, rice and wheat are three most important food crops worldwide but unlike rice and wheat, maize none food uses seem to increase year in year out. Besides providing food for humans and feed for animals, maize is a basic raw material for many extractive industries producing products like starch and starch derivatives, oil, proteins and protein derivatives, alcoholic beverages, food sweeteners and, more recently energy in the form of ethanol and biogas. This increase diversity in maize usage has boosted the demand for maize worldwide especially in India, China, the USA and the European Union (EU) countries. The incentive to produce more maize as a way to meet demand is increasing worldwide. This can be inferred from the increasing cultivated land (fig 2.1) which is aimed at increasing productivity (fig 2.2).

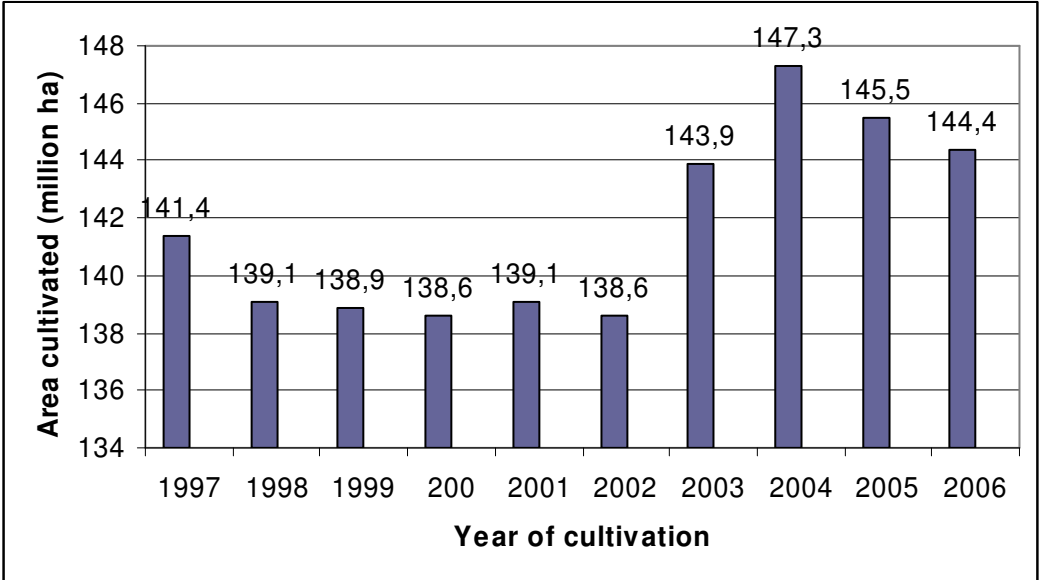


Fig. 2.1: World maize cultivated land (million hectares) from 1997 to 2006 (FAO STAT 2008)

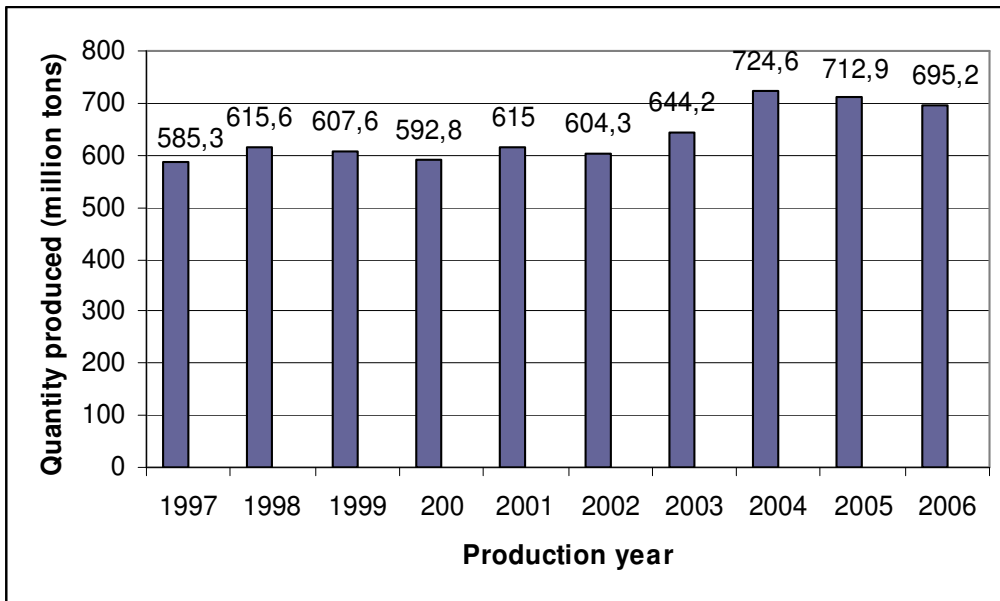


Fig. 2.2: World maize production (million tons) from 1997 to 2006 (FAO STAT 2008)

Despite the increasing attempts to produce maize worldwide china and the USA still account together for more than 50% of world maize production.(see figure 2.3 below).The reason why the European Union is not represented is because this productivity is related only to grain maize.

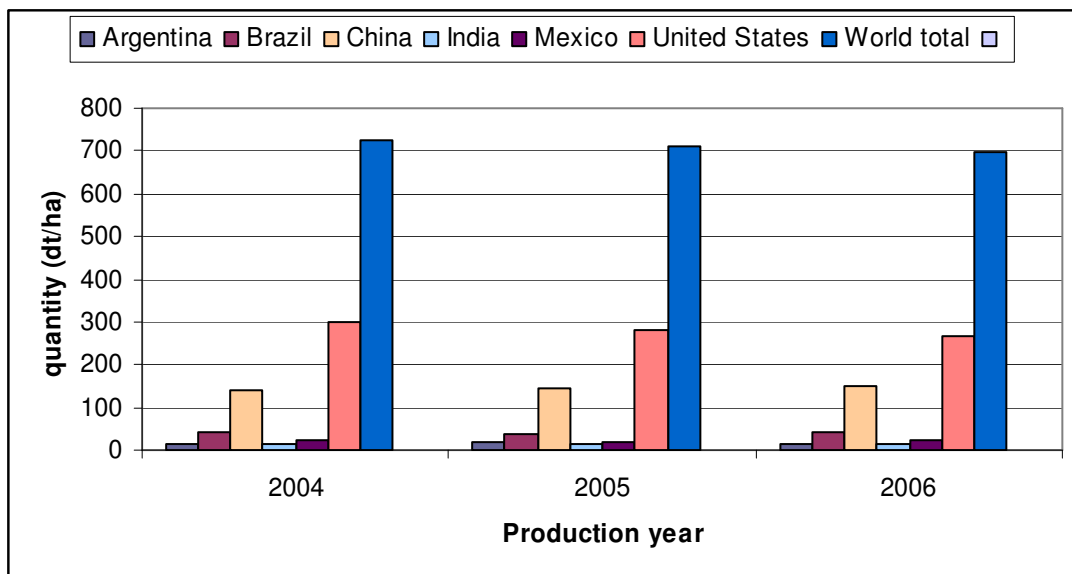


Fig. 2.3: World maize production in the top producer countries from 2002 to 2006 (DMK 2008)

Due to climatic reasons maize in the European Union is mainly produced in form of whole plant silage .In Germany maize production has also been increasing but more in the form of whole plant silage maize which now is a highly valued substrate for biogas production. From figure 2.4 below the surface area used for silage and grain maize production in Germany between 2004 and 2006 can be compared.

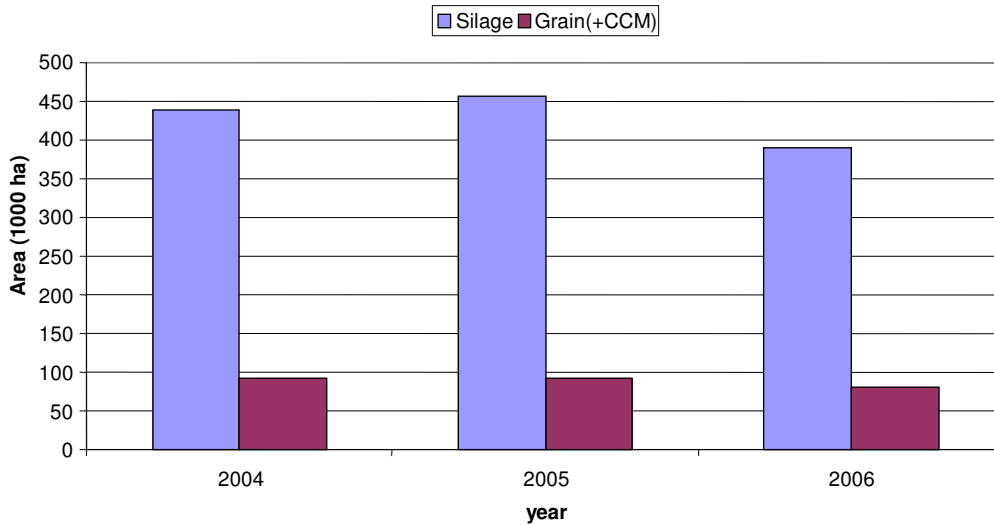


Fig. 2.4: Cultivated area for silage and grain maize in Germany from 1998 to 2006

Because silage maize has become such an important substrate for biogas production in Germany, the observed increase in silage maize cultivated area can also be reflected by the increasing number of biogas digesters. Most biogas digesters in Germany today use whole plant silage maize either as co material in the normal wet digestion or alone in the dry digestion.

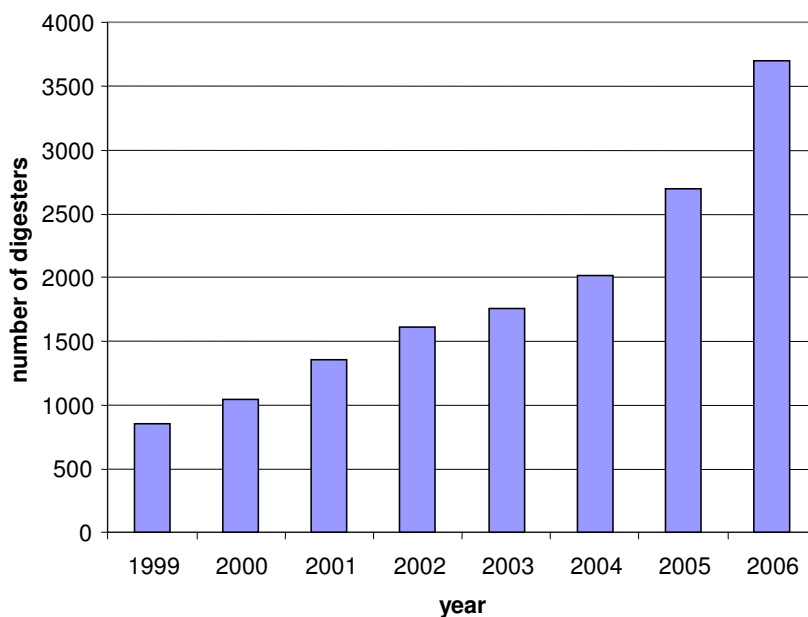


Fig. 2.5: Number of biogas digesters in Germany from 1999 to 2006 (DMK 2008)

Increasing diversity of maize usage poses new challenges regarding agronomic and plant breeding methods that must be adopted to produce the required yields and

yield qualities that are appropriate to the use for which the maize is intended. This means selecting and breeding appropriate varieties, adapting tillage methods, fertilizer applications, pest and disease control, and harvest timing. According to Amon et al. (2003), maize that is to be used for biogas production acquires most of its methane production potentials already at field.

2.2.3 General factors in maize cultivation

High seed quality, appropriate plant protection, fertilizer (and manure) applications, harvesting techniques, transportation and storage techniques are vital factors determining the sustainability of maize production. Each of the above-mentioned factors must be appropriate to the ecosystem in which they are to be cultivated. Put together they determined the input (economically calculated as energy input) which is vital in calculating the energy balance at the end when the crop has been harvested and transformed into the energy envisaged and the output (also calculated as energy) is already known.

Quality factors of an ecosystem used to judge its suitability for maize cultivation are primarily temperature and water availability. Although day-length and soil factors (moisture, nutrients) have an influence, the development of a maize plant from emergence, through tasseling, silking, and grain filling, to physiological maturity follows closely the amount of accumulated heat (temperature units or growing degree day - GDD) over the growing season. Maize is a cold sensitive plant requiring a temperature of at least 10°C for germination alone. Knowledge on temperature regime and drought potentials is hence vital when choosing maize varieties for any given region. Because both temperature and water availability affects seed germination, maize sowing dates are highly determined by these two factors. Regions with high vulnerability to drought and cold temperatures are hence regarded as marginal locations for maize cultivation. Besides pest and disease resistance, drought and cold tolerance are also vital breeding factors aimed at increasing maize yield world wide. When choosing varieties it is important that their maturity ratings matches the length of the growing season and that the variety is well adapted to the biotic and abiotic factors prevailing in the region in question.

Temperature sums (growing degree days - GDD) decide very much the sowing as well as harvesting dates of a maize plant. This is because each variety has a particular temperature sum requirements to complete all stages of growth necessary to achieve physiological maturity. The differences in the rate of maturation observed when different maize genotypes are simultaneously sown together under the same conditions are due to the facts that different varieties requires different temperature sum to complete each phenological stage. To be able to cultivate maize successfully therefore a farmers must know his environments well to be able to choose appropriate genotypes. He also needs to understand maize phenology and its significance on cultivation factors like pest and disease scouting, pesticides, herbicides and fertilizer requirements not withstanding harvest timing.

Maize cultivation in Germany

Temperature is the major limiting factor to Maize cultivation in Germany. The average specific temperature sum over the Federal Republic of Germany has been calculated using a base temperature of 8°C (DMK 1994). According to these calculations the warmest regions in Germany are those located in the “Oberrheinische” lowland with an average temperature sums of >1600°C (DMK 1994). Gross-Gerau, which is one of the experimental fields used in the experiments described in this thesis, is located here. The same calculations also showed a unit rise in altitude (+1°N) to result in a unit fall (-1°C) in temperature sum. The experimental field Giessen also used for the experiments of this thesis differ from Gross-Gerau in altitude as well as latitude.

The potential growing season for maize in Germany is the period from mid April to about mid November depending on latitude and altitude. Early and late frost are the major adverse factors every farmer tries to avoid. The ultimately result which is mainly poor total harvest yield is usually avoided by choosing genotypes with the right maturity class for the different regions of Germany. Maize breeders have advisers at all regions to help farmers on this. Sowing dates are usually decided by the climatic conditions of the year in question.

Maturity ratings of maize varieties worldwide usually employ the FAO classification. However because this classification best applies to grain maize production than silage, the use specific maturity classification was introduced in Germany in 1998 to account for silage maize harvest maturity as this is the major form for which maize is cultivated here. Because some regions do produce grain maize, the letters S and K are put before the maturity class numbers of maize to indicate their specific usages. K indicates grain maturity and is derived from the German term Körner (English grain) and S refers to silage maturity. Maturity classes for dual-purpose varieties usually carry both letters. Table 2.4 below gives an overview of the use specific classification for maize common in Germany.

Table 2.4: Maturity classification of maize varieties used in Germany since 1998 (DMK 2008)

Maturity group	Maturity number range	Average daily temperature requirements (May-Sept)
Early	S/ K 170-220	14,0-15,0 °C
Middle early	S/ K 230-250	15,0-15,5 °C
Middle late	S/ K 260-290	15,6-16,4 °C
Late	S/ K 300-350	16,5-17,4 °C

From the table 2.4, it can be seen that lower maturity classes requires less temperature sum than higher maturity classes. Hence lower maturity classes are suitable for cooler regions like Giessen and higher maturity classes are suitable for warmer regions like Gross-Gerau.

Tillage methods for maize production in Germany.

Soil preparatory activities for maize production in Germany usually involves ploughing the land in autumn and preparing a suitable seed bed in spring. The ploughing (primary tillage) and seed bed preparations (secondary tillage) activities are usually carried out using a moldboard plough and various types of harrows respectively. The intensity of the seedbed preparation depends on the soil type and the effects of winter on the autumns tilt. Apart from giving the soil a good aeration and water circulation potentials, all these tillage activities also enables soil to quickly warm up.

Sowing methods of maize

With a good seedbed, farmers in Germany usually will start sowing between mid April and early May depending on latitude, altitude and weather conditions. Conventionally corn is sown in Germany using either a precision row crop planter or an air drill (pneumatic drill). There are no special prescriptions and the choice tool and their combinations depend on the farmer preference. Sowing density is also a free choice and depends on the farmer's experience.

The time taken from sowing to germination and emergence usually varies also depending on latitude, altitude and weather conditions over the region in question. Upon emergence farmer scout for weeds, pest and diseases as well as providing the young plant with sufficient and balance nutrients. The efficiency of doing this depends on the farmer's knowledge on maize phenology.

Fertilizer applications on maize

Whether silage or grain, maize productivity depends strongly on fertilizer applications. Fertilizer applications are calculated based on known nutrients requirements (kg/ha) of maize, the efficiency in providing the nutrient(s) by the fertilizer form used and the natural potentials of the soil to provide the same nutrient(s). In Germany, calculated results can be obtained at various soil analysis laboratories. Pre knowledge on N_{\min} and P_2O_5 potentials of the soil organic matter is usually recommended.

As any other crop, maize requires ample supplies of the basic elements nitrogen (N) phosphorus (P), potassium (K) and other nutrients depending on soil analysis results and the phenological stage considered. Generally, the first N application is recommended together with P and K at seedbed preparations. A second N application becomes necessary at about the forth leaf stage and the third about 10-15 days prior to tasseling.

Maize phosphorus requirements

Phosphorus usually supplied in form of phosphate (P_2O_5) is part of the energy carrier adenosine triphosphate (ATP). Phosphorus therefore is vital in many metabolic processes involved in the life cycle of maize from the juvenile stages through

flowering, ear formation right up to grain filling stages. The period of highest P requirements however have been calculated to occur during the phenological stages closer to and after tasseling. A maize plant will on average extract 11kg of P_2O_5 for every metric ton of dry matter produced. In Germany this is ensured by applying about 90-120 kg P_2O_5 ha. Phosphorus deficiency can reduce yield by causing kernel abortion or kernel deformities.

Maize Nitrogen (N) requirements

The highest demand of nitrogen by maize is known to correspond to the stage of the highest dry matter accumulation. Like phosphorus, this is usually the period close to tasseling and about four weeks after tasseling. On average a maize crop will extract about 25kg N for every metric ton of dry matter produced. The need to calculate soil N mineralization before applications is highly demanded in Germany for environmental purposes (Nitrate pollution of ground water pollution). In Germany N fertilisers are usually applied at the rate of 180-200 kg N/ha, after considering the organic matter mineralization potentials of the soil. Maize nitrogen supplies are mostly achieved by applying either an ammonium or a nitrate fertilizer. Nitrogen fertilization of maize has the tendency to increase the length of the vegetative stages (hence maize height and number of leaves). In this way N fertilization can increase the ratio of stover in the final yield. Equally, the increase in leaf area index can also increase the degree of photosynthesis with potential positive effects on grain yield but negative from the point of view of NDF concentrations.

Maize Potassium (K) requirements

Potassium is known to promote the formation of carbohydrates. Maize being a starch producing plant will therefore require a lot of K especially if intended for grain production. Maize average K extraction rate is about 23kg per metric ton of dry matter produced. This is usually ensured by applying 170-300kg K/ha. Besides favouring carbohydrates formation K is also known to improve maize's water uptake thereby increasing its potentials to resist droughts. By enhancing maize ability to resist diseases K equally ensures a normal growth and hence possibly good yield.

Apart from the main elements NPK, maize requires little supplies of magnesium. Calculations shows grain maize to require 30kg MgO / ha compared to 70kg MgO for silage maize. Traces of the elements zinc (Zn), iron (Fe) and manganese (Mn) are also required as cofactors and catalyst for many metabolic processes like photosynthesis.

Water requirements of maize

Compared with other agricultural crops in Germany maize as a C_4 plant has a relatively low transpiration coefficient of 220 - 300 (Ehlers, 1997, Greenwood et al. 2005). Despite this, the relatively high yielding potential of maize can only be achieved with sufficient water supply. In Germany, this usually occurs in June and July when the maize is at the stem elongation or flowering stages. Although water is not usually a

limiting factor in Germany, farmers in the warmer regions never forget to include irrigation in the maize cultivation planning. The experiments carried out in Gross-Gerau for this thesis always included irrigation.

Plant protection of maize

Applications of pesticides on maize in Germany are only done at an extensive level. In fact fungicides applications are not allowed. A report from DMK refers to a research carried out by the “Biologische Bundestanstalt für Land-und Forstwirtschaft” according to which maize was isolated out of ten cultivated crops to have the least requirements for pesticides applications. This reduces the cost of producing maize and explains why its energy balance is seen as favourable compared with the other potential energy crops.

The major activities under plant protection involve weed prevention and prevention against the European stem borer (*Ostrinia nubilalis*). While weed preventions is the most intensive plant protection activity German wide, the fight against the stem borer is only important in the warmer regions where. The use of genetically transformed maize is still very controversial in Germany so that many farmers are still afraid to try out the potentials of Bt maize as a remedy against stem borers. This also applies to many herbicides tolerant maize varieties presently used in the USA and some countries around the globe.

The fourth to the eighth leaf stage is considered the most appropriate stage to control weeds in maize. This is usually done using herbicides even though there are farmers (especially those doing organic agriculture) who prefer the mechanical methods. The number of active substances against weeds is so much that the best way out is to seek the advice of plant pathologist first.

Harvest methods used for maize

The method use to harvest maize is determined by the use for which it is destined. All over the world, maize is harvested as either grains or silage for food and feed purposes. Even the new use of maize as an energy feedstock has not changed these two harvest methods. Maize used for ethanol production is harvested as grain and maize for biogas production is harvested as whole plant silage. While grain maize is best harvested at a moisture content of 20% to 30%, silage maize is best harvested at about 70% to 65% moisture. The moisture contents in both cases are functions of environmental conditions and genotype (maturity class effects). Both are harvested using combined harvesters with harvesting heads adapted for chopping whole plant as well as threshing the grains from the cobs.

2.2.4 Effects of phenology on maize quality for anaerobic digestion

The first and foremost factors considered when planning anaerobic production of biogas are availability and suitability of feedstock. Feedstock availability depends on crop yield and suitability refers to yield quality (chemical composition). In producing

biogas anaerobically feedstock digestibility is the primary quality factor affecting biogas productivity. Methane content of the biogas produced on the other hand depends on quality factors like crude proteins (CP), crude fibre (CF), sugars and starch that have been termed methanogenic substances by Amon et al. (2003). The choice of the right harvest time is hence a harmonization process that seeks to pinpoint a phenological stage at which maize yield and quality optimally coexist.

Maize phenology refers to the developments, differentiation and initiation of organs (Hodges et al. 1991) and phenological stages describes the time lapse necessary for different maize organs to come into view or become fully developed. Due to the wide distribution of maize species and their vulnerability to climate stress, numerous models have been developed to study maize developments and yield. Even though most are designed to predict the response of maize grain yield to environment, they all differ in terms of the biological processes considered. Some only consider the effects of temperature alone but others like the CERES maize combine the effects of both temperature and photoperiod at the same time. However, all the models recognise the fact that for any organ to appear a certain temperature sum (specific to each maturity group) must first have accumulated over the growing environments. The different intervals between the emergence of the different organs and processes can be summed up into a scale like the widely applied BBCH scale.

The BBCH scale was developed in Germany and today finds applications all over the world in identifying the phenological developments of different crops and weed plants. There are a series of them developed for specific crops. That developed for maize divides maize phenology into 8 major growth stages each with its characteristic subdivisions.

1. Germination,
2. Leaf development,
3. Stem elongation,
4. Inflorescence emergence (tasseling),
5. Flowering (Anthesis),
6. Kernel (fruit) development,
7. Ripening,
8. Senescence.

Figure 2.6 illustrate a simplified method of evaluating maize phenology. It simply divides maize growth cycle into two major phases: vegetative (V) and reproductive (R). VE to VT and R₁ to R₆ are the corresponding subdivisions of the vegetative and reproductive phases respectively.

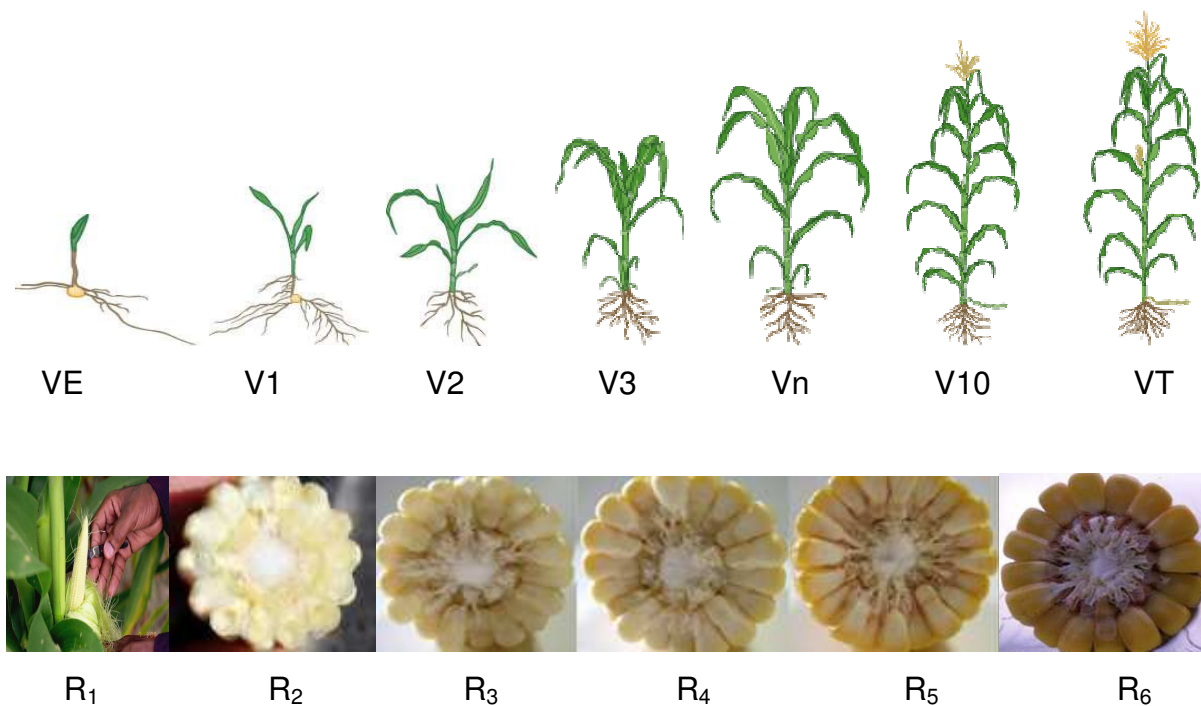


Fig. 2.6: Vegetative stages (V) and reproductive stages (R) of maize
(www.agronext.iastate.edu/corn/)

The main components of a maize plant that determine yield and yield quality are stem, leaves and ear. Because they are fully developed at different stages of maize growth cycle the quantity and quality of yield depends highly on the maturity at which the whole silage maize is harvested. This explains why timing harvest is such an inevitable factor in maize production for any use possible.

The vegetative phase is the first major stage and is characterised by leaf formation stages, stem elongation stages and terminate with the appearance of a male flower (the tassel). The biomass components formed at all the vegetative stages are jointly referred to as stover (leave plus stem). Maize stem is an erect unbranched organ dissected into internodes by joints called nodes. Maize stem contributes between 42 and 44% to total plant weight early in the growing season, against 18% at the end of it (Wilman et al. 1996c; Boon et al. 2005). Stem in vitro digestibility is also known to be relatively low and variable (Deinum & Struik, 1989) and declines as the growing season advances (Struik, 1983). The height of a maize plant that is also a yield determination factor depends on the number and sum of length of individual internodes. Every maize node bears a lanceolate leaf and the leaves are arranged alternately along the stem. The total surface area of leaves (leaf area index) depends on total number of leaves (hence number of nodes) and the individual sizes of the leaves. Maize has a determinate growth that ends a few days after tasseling. Depending on cultivar, the ratio of leaf can decline rapidly (quick dry down varieties) or slowly (stay green varieties) after tasseling. Tillering which is a very common characteristic of cereals like wheat exist in maize also. This characteristic however is presently not very significant in maize breeding.

The reproductive phase begins a few days after tasseling and is characterised by appearance and developments in the ear. During the vegetative phase buds can be observed at every leaf axil. Each of these buds has the potential to develop into a maize ear. Multicobing is a situation where two or more buds develop into true ears with cobs grains and husks. It is a valuable yield determination factor used by many maize breeding companies. Potential maize ears are most commonly formed from buds located half way along the length of the main stem. Tassel ears are also known to exist in maize but no relevant information exist on their importance in improving yield.

A maize ear can be seen as a female plant in symbiosis with the male (vegetative) plant. The ear biomass consists of a shank, cob, husks and grains each developed at the different reproductive stages and differs from each other in chemical composition hence digestibility. The shank develops from an axillary bud as a side stem which attaches the ear to the main stem (Culm). The shank is dissected into internodes by nodes and from each node leaves known as husks arises. The number of husks depends on the number of internodes on the shank. The husks cover the grains and thereby prevent maize from self-propagation by shattering. The last internode of the shank develops into a female inflorescence (spike) usually referred to as cob. The spike consists of several spikelets each with an ovary destined to become a grain given a successful fertilization. Each ovary bears a long style that all protrudes out at the tip of a maize ear forming a turf structure usually called silk. This enables the pollen falling from the tassel to be trapped and conveyed into the ovary for fertilization after which the style dries away.

Knowledge on phenology is hence such a vital factor in crop production that without it many agronomic activities and physiological processes necessary to optimise crop productivity both quantitative and qualitative cannot be accurately planned or executed. The digestibility of whole plant silage maize is highly determined by cell wall (NDF) which is mainly concentrated in the stover especially the stem (Hofmann et al 2003). The quantity (total yield) and quality (chemical composition) of Whole plant maize silage harvested at any of the phenological stages therefore depends largely on the stover to ear ratio (stover:ear). Biomass quality factors usually considered in forage laboratories includes Cell wall components, cell content and moisture content depending on envisaged usage.

Moisture content at harvest is the main established factor used to judge the optimal harvest time for maize. Research shows that at a moisture content of 65 % (which is equivalent to 35% DMC), maize would have accumulated its maximum dry matter yield and as well as attained optimum quality (Darby and Lauer, 2002, Schwab and Shaver, 2001, Lewis et al. 2004). Optimum dry matter content at harvest like other chemical composition also depends on the intended use or methods of conservation planned. Dry matter content in the range 28-35% has been established as optimum for maize that is to be ensiled using bunker silos. Most producers of silage maize in Germany use the bunker silo to preserve silage maize for biogas production or animal feed purposes. The dry matter content of maize can be determined in the laboratory by oven drying maize samples to a constant weight. Another but less

reliable method used mostly by farmers in the USA is to observe maize kernel milk line (ML). According to this method 1/2ML corresponds to the optimum dry matter range established for bunker silo preservation (Wiersma et al. 1993).

Digestion is a catabolic process and leads to a complete break down of a plant chemical components into some final products depending on conditions at which the digestion took place. In anaerobic digestion the wishful end product is biogas with maximum methane gas concentrations.

The digestibility of a plant material depends on the ability of digesting factor (e.g. enzymes) to gain access to the digestible matter. Unlike animal cells, plant cells consist of a cell wall containing polymers like lignin, cellulose and hemicelluloses among others. In forage analysis they are referred to as cell wall components or fibers. While these fibers are indigestible to most organisms, some microorganisms like those found in the rumen of ruminant animals or in some fungi and termites have the potentials to digest these fibers with the exception of lignin. Because anaerobic digestion makes use of such fiber digesting microorganisms, the degree of lignification is likely to be the major hindrance to the digestibility of substrate used.

Lignin confers rigidity to plant and so increases as a maize plant maturity advances and its content, composition and localization are genetically determined, but can be influenced by environmental factors such as temperature (Boon et al. 2005).

Lignification is also known to have plant protection properties besides ensuring rigidity (Joachim and Jung 1997). For this reason scientist are faced with a tough decision as to how maize digestibility should be improved to enhance anaerobic digestion. Lodging is and remains a yield decreasing factor in maize production and lignification helps prevents this. There have been controversial discussions as to which role the Bt gene in transgenic maize plays in preventing stem borer. Besides the maturity dependent lignification maize mutant carrying a brown mid rib gene (Bmr) are known to possess a natural reduction in the degree of lignification. That has given them a natural digestibility higher than in conventional silage maize. Research also shows this brown mid rib maize mutants to increase milk productivity in dairy animals compared with conventional silage (Oba and Allen 1999).

Determining cell wall lignification has always proven difficult and many cell wall digestibility determination methods have been developed over the decades to help in predicting the degree of lignification and hence cell wall digestibility (Joachim and Jung 1997). In the past cell wall digestibility has been simply determined by determining the crude fiber contents. With the coming of Van Soest in the sixties, the division of cell wall into acid detergent fibers (ADF) and neutral detergent fibers (NDF) has become the basis of characterizing cell wall. NDF consist of all the components of the cell wall and is also called total cell wall by some authors (Hofmann et al. 2003, Joachim and Jung 1997). ADF fraction on the other hand only refers to cellulose and lignin. NDF digestibility is for this reason a more reliable method of predicting cell wall digestibility. It is important to observe the direction of change (increasing or decreasing) taken by both ADF and NDF as maize maturity advances.

The most common observation is that as forage matures, leaf-to-stem ratio declines (more stem, fewer leaves) and as a result NDF digestibility declines because a greater portion of the total NDF is NDF associated with stem tissue. Corn silage is unique in defining maturity effects on NDF digestibility because leaf-to-stem ratio is not greatly altered across normal harvest maturity stages. It is actually common to observe a decline in total NDF content in corn silage as the corn plant matures. This is because the corn ear is filling with grain, which dilutes the total forage NDF content. Despite this illusionary maturity effect, the NDF digestibility of the corn plant still declines with advancing maturity (Hofmann et al. 2003).

The cell wall enclosed a cytoplasm containing mainly digestible components like the sugars, starch, proteins and lipids. These components are collectively referred to as cell contents. Unlike cell wall contents the cell contents are digestible at all stages of developments. Cell wall digestibility therefore remains the most important factor limiting digestion of all plants including maize. One of the methods used to determine cell wall digestibility is the use of fungi cellulase in a process called enzyme soluble organic substances. In this thesis cell wall digestibility is presented as ELOS (derived from the German “**E**nzyme **L**ösliche **O**rganische **S**ubstanzen). The degree to which these enzymes hydrolyses the cellulose and other cellulase digestible substances present in the cell wall gives a clue on the degree of lignification and can therefore predict cell wall digestibility. Both cell wall and cell contents including ELOS can be characterised using the near infrared reflectance spectroscopy (NIRS) common in forage laboratories today.

2.3 Biomass energy technologies

Biomass is mankind’s oldest form of energy and different societies have used different techniques to harness the energy in biomass to meet their daily energy needs. Techniques like direct combustion, pyrolysis (and gasification), anaerobic digestion and alcoholic fermentation have been developed and continue to be improved for efficient energy production. Each technique has particular demands on the quality of the biomass employed and this explains the importance of carefully choosing genotype and maturity to harvest. This thesis considers anaerobic digestion and the suitability of whole plant silage maize as a substrate for anaerobic digestion aimed at producing commercially useful biogas with high methane concentrations.

2.3.1 Anaerobic digestion

Anaerobic digestion is a purely natural process and has been employed by humans for centuries to treat waste and improve sanitation in living communities. For centuries it has been used to provide some exciting possibilities and solutions to such global concerns as alternative energy production, handling human, animal, municipal and industrial wastes safely, and providing fertilizer substitutes for farmers (Marchaim 1992). In the face of global energy crises, many none oil producing societies like Germany see the employment of anaerobic digestion as a means to convert waste and energy crops into methane which can then reduce their dependency on imported petroleum and natural gas.

Anaerobic digestion is a process that takes place in the presence of biodegradable biomass (substrate), anaerobic micro-organisms (facultative as well as obligatory), and a milieu (digester) free of molecular oxygen (O₂). The process converts the energy in biomass into energy in a gaseous mixture otherwise known as biogas. The principal gases in biogas are methane (CH₄) and carbon dioxide (CO₂) together with small to minute concentrations of other gases. This composition depends on substrate quality, conditions of digestion environment and the type of microorganisms involve.

Biogas is not only produce using anaerobic digestion. The process of gasification that is a thermal transformation process can also be used. Biogas is also produced at sewage disposal locations and many countries see tapping this also as a potential to increase home made energy methane. The qualities of biogas produced however vary according to method used. Table 2.5 shows average composition and energy value of biogas usually associated with anaerobic digestion processes and table 2.6 compares the composition of biogas produced using anaerobic digestion in different environments to that produced via gasification.

Table 2.5: Average composition and energy value of biogas (Tandon and Roy 2004)

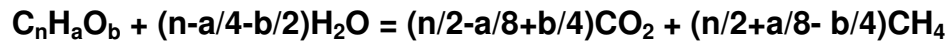
Composition	Formula	Content (%)
Methane	CH ₄	50-60
Carbon dioxide	CO ₂	30-40
Hydrogen	H ₂	5-10
Nitrogen	N ₂	1-2
Hydrogen sulphide	H ₂ S	traces
Calorific value	4700-6000 kCal/m ³ or 20-24 MJ/m ³	

Table 2.6: Typical composition of raw biogas produced using different technologies. (Hofbauer 2002)

Component	Wood gas		Sewage biogas	Landfill biogas	Biogas production range
	Way of gasification				
	Air	Vapour			
CH ₄	3-6%	9-11%	60-75%	45-55%	50-75%
CO ₂	12-16%	20-25%	30-40%	30-40%	25-45%
H ₂ O			saturated	saturated	saturated
H ₂ S			<1%	50-300ppm	0-1%
H ₂	11-16%	33-40%	traces		0-1%
CO	13-18%	25-30%	Traces		

2.3.2 Substrate quality for anaerobic digestion

In a study on the biochemistry of anaerobic digestion Buswell found a relationship between the biogas productivity and the chemical composition of the substrate digested. He summarised this into a formula generally referred to as the theoretical gas equation.



Even though the calculated results of this formula do not always agree with practical yields, many biogas laboratories today still use it to predict biogas and methane yield potentials of different biomass types. The cultivation of oil crops like sunflower and Maize in a mix cropping system for biogas production is aimed at maximising biogas and methane productivity based on knowledge of theoretical gas equations. The theoretical gas equation only consider the biogas productivity of the major cell contents (fats, proteins and carbohydrates) and makes no mention of cell wall and digestibility problems. The results shown in table 2.7 below have been calculated by Canadian renewable energy technology incorporation (RENTEC).

Table 2.7: Theoretical biogas potentials (liters/kg) of carbohydrates, proteins and lipids (RENTEC 2004)

Organic component	Theoretical biogas potentials(l/kg)	% Vol of biogas	
		CH ₄	CO ₂
Carbohydrates	790	50	50
Lipids	1250	68	32
Proteins	700	71	29

Many years of research on biogas has accumulated enough empirical data that allows the determination of actual biogas yields expressed in litres as a function of organic matter content {volatile solids (VS)}. Volatile solid is a general name for the fraction of substrate's dry matter on which anaerobic digesting agents (micro-organisms) actually act. The differences in biogas yields and methane contents of different substrates therefore are because of differences in contents and quality of the volatile solids. All these factors vary depending on biomass type, specie, phenological stage at which the species is digested and treatments applied to them prior to digestion. Specific biogas productivity of any biomass including silage maize is calculated on the bases of their volatile solid contents. From the specific biogas, total per hectare biogas can be calculated from the total volatile solids content which is a percentage of total dry matter yield (DMY). Table 2.8 below gives average biogas yields and methane contents of different crop types and crop residues as estimated by the German international cooperation enterprise for sustainable development (Gesellschaft für Technische Zusammenarbeit GmbH (GTZ)).

Table 2.8: Biogas yields of different substrates (GATE (GTZ) 1996).

Substrate	Gas yields liters/kgVS	Methane content (%)
Wheat straw	200-300	50-60
Rye straw	200-300	59
Barley straw	250-300	59
Oats straw	290-310	59
Corn straw	380-460	59
Rape straw	200	-
Rice straw	170-280	-
Rice seed coat	105	-
Flax	360	59
Hemp	360	59
Grass	280-550	70
Elephant grass	430-560	60
Cane trash(bagasse)	165	--
Broom	405	-
Reed	170	-
Clover	430-490	-
Vegetable residue	330-360	-
Potato tops(greens)	280-490	-
Field/Sugar beet greens	400-500	-
Sun flower leaves	300	59
Agricultural waste	310-430	60-70
seeds	620	
Pea nut shells	365	-
Fallen leaves	210-290	58
Water hyacinth	375	-
Algae	420-500	63
Sea wage sludge	310-740	-

Because serious research on energy crops as substrate for biogas production has only just begun, there are presently no concrete facts as to which chemical substances needs to be promoted so as to improve biogas and methane productivity of these crops. Besides relying on the theoretical gas equation, most producers of bio-gas from energy maize are still very reliable on quality parameters that have been established for use to improve milk and meat productivity in dairy and beef animals. In doing so, they try to take advantage of the similarity between ruminant digestion and digester digestion. Both the rumen and the digester harbour cellulose digesting micro-organisms. This similarity is even much closer with mesophilic digesters as this also is the operating temperature range for the rumen. However, unlike in the rumen where methane production is seen as an energy wasting process, the digester is constructed to produce as much methane as possible. In breeding maize for animal feed much was done to avoid methane production as possible. Maize for biogas production on the other hand is expected to produce as much methane as possible. These contradictory aims indicate that substrates quality considerations for feed

purposes can not exactly be the same with those vital for methane production. Good forage maize therefore must not directly be good for biogas production. High substrate digestibility however is one important factor required by both production systems.

Maize digestibility depends on phenology in the same way as does most crops. The two main factors that must be considered when evaluating maize digestibility are, type of kernel endosperm (Philippeau and Michalet-Doureau 1997), and the degree of cell wall lignification at the time of harvest (Hofmann et al., 2003, Oba and Allen., 1999). Philippeau and Michalet-Doureau (1997) observed that increased kernel vitreousness was associated with decreased rumen starch degradation. Vitreous starch, is the predominant starch in flint maize kernels and the flint texture is known to come as a result of starch granules being embedded in a dense protein matrix as the grains matures (Holland and Kezar 1999). Kernel vitreousness might therefore also be a factor to consider in anaerobic digestion.

Besides digestibility, the moisture content of substrate is also very important as microorganisms require water for proper functioning. Besides determining optimum yield and quality according to Wiersma et al (1993), the moisture content and digestibility of substrate together with digester temperature are very important parameters used when determining the loading rate (substrate input) and the retention time (time taken for the substrate to be completely digested) of an anaerobic digestion process. Retention times and loading rates are also known to depend on digester design (Sasse et al. 1991).

2.3.3 Digestion environment

Anaerobic digestion as the name suggest takes place in a molecular oxygen free environments. Such environments can be natural such as in swamps or they can be man made as in landfills and commercial anaerobic digesters.

Commercial anaerobic digesters are created to trap biogas for further processing (scrubbing) into commercially useful methane. They can be any shape and can be made from any material available provided the reaction milieu (temperature, pH, moisture etc) is conducive to the proper activity of the micro-organism consortium involved. Biogas digesters are classified based on loading schedule, flow patterns and temperature requirements during the digestion process. Based on loading schedule three types of biogas digesters are usually distinguished: Batch digesters, Continuous digesters and Semi batch digesters

Batch digesters

These are digesters that can take biomass with a wide rage of moisture contents. The most important thing is to calculate the retention time and the appropriate digester volume. The digester is operated by repeatedly feeding and emptying after the calculated retention time. The concept of loading rate is hence very appropriate to

batch digesters than any other type. Batch digesters are disadvantageous in that the gas productivity is either not enough or is erratically produced.

Continuous digesters

Continuous digesters as the name imply are fed and emptied continuously. They can be fed automatically as well as manually but the emptying occurs automatically due to the ability to push out the effluents by the pressure that develops within the digester. Unlike batch digesters biomass for continuous digestion must be of high moisture content (very low DMC) and homogenous. Gas production is continuous and more in volume than in the batch digestion systems. For this reason nearly all biogas digesters today are operated in the continuous mode.

Semi batch digesters

Semi batch digesters are those that co digest substrate with normal retention time with cellulosic or lignified biomass having extreme retention time of about six months. The one with normal retention time can be fed and emptied as allowed by the retention time without disturbing the other.

All types of digesters must function at a constant temperature that depends on the microorganisms used. Basically microorganisms in the digester fall into groups requiring temperatures in the ranges $<20^{\circ}\text{C}$, $25\text{-}40^{\circ}\text{C}$, and $>45^{\circ}\text{C}$. Those requiring $25\text{-}40^{\circ}\text{C}$ are termed mesophilic, those requiring $>45^{\circ}\text{C}$ are thermophilic and those requiring $<20^{\circ}\text{C}$ are psychrophilic. Temperature requirements of digesters are usually used in combination with the name of the digester type in the classification of digesters. A mesophilic batch digester for instant is one that is fed in batches and operated at a constant temperature in the range $25\text{-}40^{\circ}\text{C}$. The majority of modern biogas digesters are operated at the mesophilic range and at optimum pH 7-8.

Digester design

According to Marchaim (1992) and ISAT(1996) the floating dome (fig 2.7) and the fixed dome (fig 2.8) are the most frequently used digester designs among the many designs known world wide. Given the increasing interest in anaerobic digestion as a renewable energy technology today, several newer processes that offer more efficient treatment, and stabilization of biomass, are likely to be developed.

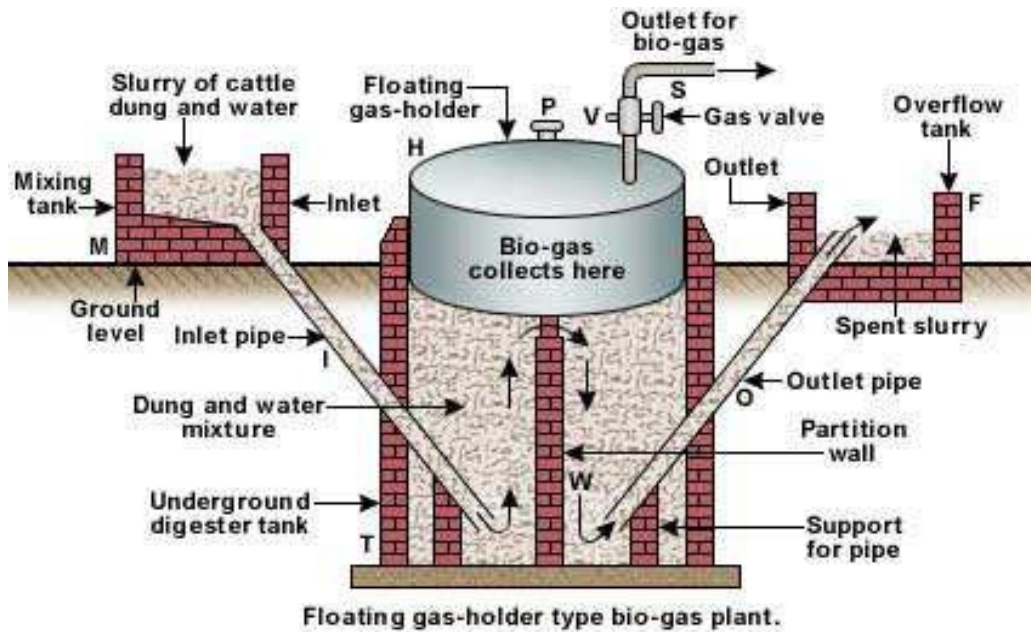


Fig 2.7: Floating cover digester (Source:home.att.net/~cat6a/fuels-II)

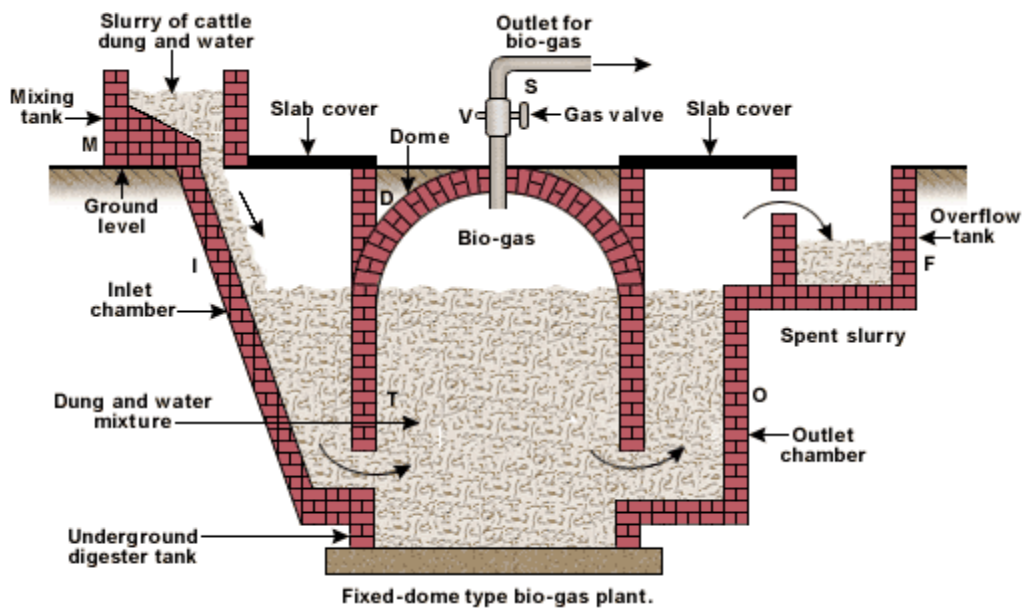


Fig 2.8: Fixed dome digester (Source:home.att.net/~ cat6a/fuels-II)

2.3.4 Digester parameters and gas productivity

The size (volume) of a biogas digester is usually determined based on the amount of substrate (digester load) that must be digested at a time as well as the quality of the substrate (dry matter content). This is because both affects the retention time (**RT**) and the loading rate (**L_r**). Hence if **V_d** is the digester volume needed then:

$$V_d = L_r \times RT \quad (m^3 = m^3/\text{day} \times \text{number of days})$$

Because **RT** also depends on temperature it is necessary to consider this also especially in regions with no possibilities to artificially heat the digester. The loading

rate also depends on the moisture content (dry matter content) of the substrate. Knowing all these factors enables daily biogas production to be calculated if the volatile solid (**VS**) content and the specific biogas productivity (**Sg**) of the VS is known. Hence if **G** is the expected daily biogas produced, **Sg** the specific gas productivity per kilogram of volatile solid (**VS**) then:

$$\mathbf{G} = \mathbf{VS} \times \mathbf{Sg} \text{ (solids) (m}^3/\text{d} = \text{kg} \times \text{m}^3/(\text{d} \times \text{kg})$$

It was mentioned above that gas productivity also is affected by retention time (**RT**) and digester temperature (**T**). Including them in the daily gas productivity increases the accuracy of results.

$$\mathbf{Sg} (\mathbf{T}, \mathbf{RT}) = m\mathbf{Sg} \times f(\mathbf{T}, \mathbf{RT})$$

Sg (T, RT) = gas yield as a function of digester temperature and retention time.

m Sg = average specific gas yield e.g. l/kg VS

f (T, RT) = multiplier for the gas yield as a function of digester temperature **T** and retention time **RT**.

More and more digester parameters can be added so that even the specific digester gas productivity (i.e. the daily gas production per m³ digester volume) can also be calculated. If **Vd** is the total digester volume, **Gp** the expected digester specific gas productivity and **G** the daily specific gas per kilogram **VS** then:

$$\mathbf{Gp} = \mathbf{G} / \mathbf{Vd} \{(\text{m}^3/\text{d})/\text{m}^3\}$$

All the digester conditions mentioned above affect microbial reactions so that anaerobic digesters are bound to have different demand on substrate used. The growth rate of micro-organisms depends on the substrates nutritive value relative to the organism, and so will affect the time taken for a given amount of substrate to digest (digester retention time). The suitability of a substrate for anaerobic digestion is therefore usually represented by its C/N ratio. C represents the energy supplying molecules like carbohydrates and fats and the N represents the proteins necessary as building blocks for bacterial growth and multiplication.

2.3.4 Process microbiology and biochemistry

Years of studies on anaerobic digestion revealed it as a complex process involving wide ranges of micro-organisms. Although some fungi and protozoa can be found in anaerobic digesters, bacteria are undoubtedly the dominant micro-organisms (Marchaim, 1992), The whole process involves four categories of obligatory and facultative anaerobic bacteria operating in a synergistic relationship whereby the products of each reaction functions as the reactants of the preceding. There are those responsible for hydrolysis, acidogenesis, acetogenesis and methanogenesis reactions. The final and most important product is methane gas. Some authors put hydrolysis and acidogenesis into one stage but most others usually separate the four stages.

Stage 1 Hydrolysis reactions.

This is the first reaction of the whole process involving the original substrate e.g. silage maize fed into the digester. Consortia of anaerobic bacteria excrete extra-cellular enzymes such as cellulases, proteases, and lipases and these breaks down complex organic molecules (proteins, cellulose, lignin, and lipids) into soluble monomers such as amino acids, glucose, fatty acids, and glycerol. The monomers are directly available to the next group of bacteria. Hydrolysis appears to be relatively slow and can be the rate limiting stage in anaerobic digestion especially when the organic matter contains high proportions of lignin and cellulose. According to Pavlostathis and Giraldo-Gomez (1991), Angelidaki et al (1995), lipids hydrolysis at a much faster rate than proteins and carbohydrates. Beccari et al. 1996, Rinzema et al. 1993 and Hanaki et al. 1987 dismissed this and claimed lipid hydrolysis to be the slowest and hence rate limiting reaction of hydrolysis.

Stage 2 Acidogenesis

The microorganisms involved in hydrolysis are usually the same that carries out acidogenesis. Usually hydrolysis and acidogenesis are jointly referred to as fermentation reactions. Species of the genera *Bacteriodes*, *Clostridium*, *Butyrivibrio*, *Eubacterium*, *Bifidobacterium* and *Lactobacillus* are known to dominate the fermentation reactions (McDonald et al 1991). These microorganisms convert the products of hydrolysis into organic acids usually termed volatile fatty acids (VFA). The major VFA formed are acetic, propionic, formic, lactic, butyric, or succinic acids. Acetic acid is the main product of carbohydrate fermentation. Alcohols and ketones (e.g., ethanol, methanol, glycerol, and acetone), CO₂, and H₂ are also formed. According to Batstone (2000), Only the glycerol and the amino acids and sugars undergo acidogenesis. The long chain fatty acids according to his observation degrade only at the acetogenesis as they need an external acceptor for oxidation. Glycerol on the other hand produces acetate, lactate and 1,3 propandiol. The products of acidogenesis are usually converted into acetate, hydrogen and carbon dioxide which are potential methanogenic substrates.

Stage 3: Acetogenesis

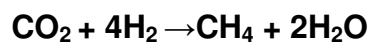
This stage involves the action of acetogenic bacteria that convert the volatile fatty acids and alcohols formed during acidogenesis into acetate, hydrogen, and carbon dioxide. Two groups of acetogenic bacteria have been isolated and studied. These are the hydrogen and acetate producers (McInerney et al.1981; Boone et al.1980).

Because acetogens and methanogens are sensitive to higher hydrogen concentrations (pH acidic), it is necessary to closely monitor the hydrogen concentrations during the anaerobic digestion process. Under relatively high H₂ partial pressure, acetate formation has been observed to decrease in favour of propionic acid, butyric acid and ethanol formation. While the formation of acetate indicates good potentials for methane formation, the production of butyrate and propionate are deemed as disturbances. The hydrogen producing forms have been found to have the potentials of breaking down propionate and other organic acids into

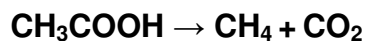
acetate and hydrogen (Boone et al. 1980). This is seen as important as it prevents the accumulation of propionate which otherwise would have antimicrobial effects on vital microorganisms especially the methanogens. Knowledge on acetogens has increased in the past few years with the help of biochemical and molecular techniques (Hansen et al. 1999 and Zhao et al. 1993).

Methanogenesis

Methanogenesis is the last but most important as it is the reaction that produces the wanted methane. Its microbiology is for this reason the most studied of all the stages involved in anaerobic digestion. Methanogenesis reactions are known to involve a complex none bacteria group of micro-organisms referred to as archaea (Woese et al. 1990). Barker was the first person to classify Archaea (methanogens) in his study of anaerobic digestions. He put them all into the family Methanobacteriaceae and subdivided the family into four generas; *Methanobacterium*, *Methanosarcina*, *Methanococcus* and *Methanospirillum*. However using observed structural differences in the rRNA of the organisms, Balch et al. (1979) introduced a new taxonomy. Metabolically Methanogens are known to utilize a limited number of substrates, and Acetate, H₂ CO₂ and formate are the most important (Zinder 1993). Methanogens are hence classified as Hydrogenotrophic, Acetotrophic or methylothrophic depending on whether hydrogen, acetate or formate is used. The hydrogenotrophic methanogens converts hydrogen as well as formic acids into methane by reducing CO₂.



Acetoclastic methanogens on the other hand converts acetate into methane and carbondioxide.



Acetoclastic methanogens are known to grow slowly and to be very sensitive to milieu changes. The most studied genera to use acetate are : *Methanosarcina*, and *Methanotherix* / *Methanosaeta*. Methanogens are known to function optimal at the pH range 6,5-8. because they are the most wanted organisms in the production of methane digesters are best operated at this range for optimum methane productivity.

Experience shows the acetate pathway to be responsible for about two thirds and the H₂ / CO₂ and formate pathway for about one third of the methane produced (Conrad 1999, Boone et al. 1989). This suggest the methane productive potentials of any substrates to depend on the total acetate produced in the four reactions involved in anaerobic digestion. Crude proteins, crude fats and carbohydrates, that have been termed methanogenic components by Amon et al. 2003 surely fulfil this function via conversion into acetate. Addition of substrates with high acetate potentials (e.g. silage) and promotion of conditions favouring acetotrophic methanogens might therefore be methods that can be used to improve the methane concentrations of a biogas. It is hence not surprising that silage maize has been chosen as the most potential substrate for anaerobic production of biogas.

The process of ensiling is known to produce acetic acid (Zubr 1986, Egg et al. 1993, Madhukara et al. 1993) and ensiled crops have also been reported to have higher methane potentials than their corresponding fresh samples (Heiermann et al. 2002, Rani & Nand 2004, Woodard et al. 1991, Chynoweth et al. 1993, Madhukara et al. 1997, Pouech et al. 1998). Acetic acid production can also be enhanced by adding inoculants. Addition of inoculants and amylases in silage maize however has not been able to affect methane productivity (Neureiter et al. 2005).

3. MATERIALS AND METHOD

This chapter describes the materials and the methodologies used to evaluate maize yields, yield quality, biogas and methane productivity. Even though there were inbred lines used in all the experiments, the word cultivar has been adopted for the sake of convenience to describe all the maize planted in all the experimental years. Before going into the descriptions of the materials and methods themselves an overview is presented below.

3.1 Field experiments

The effects of genotype and harvest time on total dry matter yield (DMY) and dry matter content (DMC) of thirteen maize cultivars differing mainly in maturity class were planted in Giessen and Gross-Gerau that both differ in climate and soil conditions. From the thirteen cultivars four were simultaneously planted in 2004, five in 2005 and six in 2006. The same cultivars were used for both locations in 2004 and 2005. In 2006 each location had two cultivars that were not the same. The cultivars were planted in a two factorial randomised complete block designs with four replications and four harvest times. An overview of the general experimental design used for all the experiments is illustrated in fig 3.1 below and overviews of treatments, cultivars used and measurements made during the field experiments are respectively presented in tables 3.1, 3.2 and 3.3 below.

3.1.1 Overview of field experiments

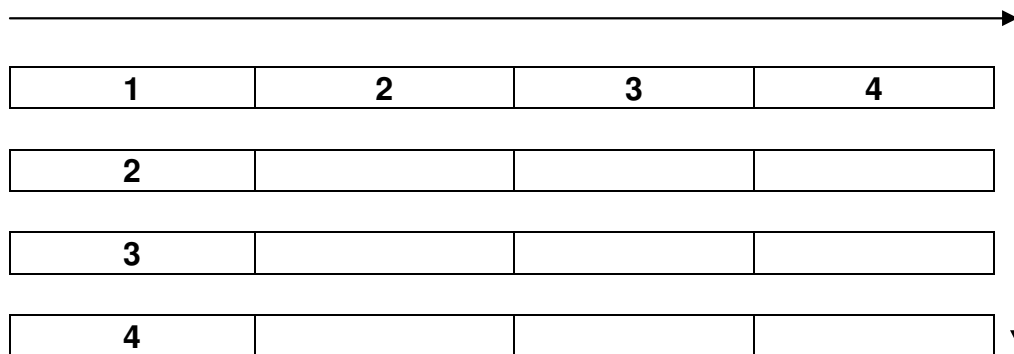


Fig. 3.1: General experimental design used for all field experiments.

The file pointing downward (↓) indicates the experimental blocks and that pointing from left (→) to right represent replications.

Table 3.1: Treatments according to experimental year and experimental station

Year	Giessen		Gross-Gerau	
	No. cultivars	No. of harvest times	No. cultivars	No. of HT times
2004	4	4	4	4
2005	5	4	5	4
2006	6	4	6	4

No. = Number of ; HT = harvest time

Table 3.2: Overview of Cultivars used

Gi / GG 2004	Gi /GG 2005	Gi 2006	GG 2006
Gavott (S 250)	Gavott (S 250)	Gavott (S 250)	Gavott (S 250)
KX2352(S 270)	KXA5226 (S 260)	KXA5233 (S 270)	KXA5233 (S 270)
Vitalina (S 280)	KXA5233 (S 270)	KXA5243 (S 290)	KXA5243 (S 290)
Doge(FAO 700)	KXA5243 (S 290)	Atletico (S 280)	Atletico (S 280)
	Mikado (FAO 500)	Magitop (S 240)	Fiacre (S 350)
		Beatus (S 260)	Baxter (S 300)

GI –Giessen; GG –Gross-Gerau

Measurements during field experiments

Maize heights (stem lengths) were measured in Giessen in 2004, 2005 and 2006 and in Gross-Gerau only in 2004 and 2006. Maize leaf area indexes (LAI) on the other hand were measure only in Giessen and only in 2005 and 2006. Maize dry matter yields (DMY) and dry matter contents (DMC) were measured immediately after harvest at both experimental stations and in all the experiments.

Table 3.3: Measurements made during field experiments Giessen and Gross-Gerau, 2004, 2005 and 2006

Parameter	Method	Materials
Leaf area index	Digitalised	Delta T Sun Scan canopy analysis system SS1
Maize height in centimetres	Manually	Bricklayer ruler
Dry matter yield	Drying and gravimetry	Laboratory drying oven

3.1.2 Laboratory analysis

Samples from both experimental fields were analysed for chemical composition, biogas and methane productivity at respective laboratories in Giessen. Table 3.4 gives an overview of the materials and methods used for these analyses.

Table 3.4: Overview of laboratory analysis, 2004, 2005 and 2006

Parameter	Method	Materials
Chemical composition	Near infrared reflectance spectroscopy (NIRS)	FOSS NIRS Systems model 6500
Volatile solids (VS)content	Ignition and gravimetry	Muffle furnace and laboratory balance
Biogas production	Mesophilic anaerobic digestion	Desk top batch digester
Biogas volumes	Volumetry by displacement	Wet Ritter gas meter
Methane concentrations	Volumetry by absorption	ORSAT gas analyzer

3.2 Description of the experimental locations

Maize was grown in two locations (Giessen and Gross-Gerau) which differed both in soil as well as climatic conditions. For these reasons the two locations are separately described in the proceeding paragraphs below.

3.2.1 Experimental station Giessen

The experimental station Giessen (50°°35'N,8°°40'E) is located in the valley of the Lahn river. With about 1° 12' northward displacement, the experimental station Giessen is relatively cooler compared with Gross-Gerau. This delays sowing and consequently harvest time by at most a week in Giessen relative to Gross-Gerau. Topographically the station is generally even with homogenous soils rich in clay. These mainly fluvogenic (river side) soils are best described as having a Silty clay consistency. Despite high levels of clay, the soils are characterised by lower available field capacity with high dead water contents (around 202mm / 100cm).

Table 3.5: General characteristics of the experimental station Giessen

Factor	Value
Soil specie	Silty clay
Clay content	28-33%
Available field capacity (100cm)	123mm
Height above NN	158m
Long term average Air temperature	9,0°C
Long term average precipitation	650mm/year

NN= Normal null (the German standard for measuring height above sea level).

The experimental field used in 2004 was previously sown with winter Vetch (*Vicia villosa*) and that used in 2005 and 2006 were previously sown with winter wheat (*Triticum aestivum*).

Soil conditions and fertilization

Prior to each experiment a soil analysis was carried out to help in planning fertilizer applications. Soil nutrient contents were evaluated from top soil to 90 cm deep. The results are presented in table 3.6 and 3.7 below.

Table 3.6: Results of soil analysis Giessen 2005

Nutrient	Results(mg/100g soil)
P ₂ O ₅	21
K ₂ O	17
MgO	18,6
Soil reactions were slightly acidic (pH 6,1)	

Table 3.7: Results of mineralised Nitrogen at different soil depths

Soil depth analyse	N _{min} (mgNO ₃)/100g soil
0 – 30 cm	12,65
30 – 60 cm	13,5
60 – 90 cm	15
Total	41,15

Based on this soil analysis results, fertilizer applications were executed at the seed bed preparation stage of each experiment: The application dosages can be inferred in table 3.8 below.

Table 3.8: Fertilizer applied at the seed bed preparation stage in Giessen in 2004, 2005 and 2006

Fertilizer type	Nutrients	% Nutrients content	Applications (kg/ha)
Nitrophoska	N	16	110
	P ₂ O ₅	16	110
	K ₂ O	16	110

At the fourth leaf stage a second N – fertilization of 60 kgN/ha was applied using potassium ammonium sulphate fertilizer containing 27% nitrogen.

Weather and climate conditions in 2004

In order to access the effects of weather on the performances of the maize cultivars used, meteorological results of each experimental year were compared with the known long term averages for Giessen. The results are illustrated in figures 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7 below.

Results of precipitation in 2004 shown in fig 3.2 below shows May to have been the wettest month as indicated by its very high rainfall compared with long term average. In June precipitation was below long term average.

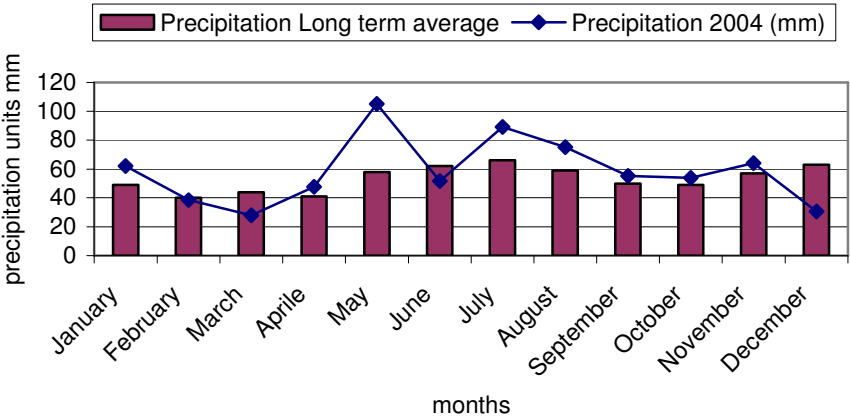


Fig. 3.2: Developments in precipitation over Giessen in 2004 compared with respective long term averages (ppt = precipitation; lta = long term average)

This was the period of stem elongation for the maize cultivars. Apart from these two abnormalities the growing season (April to October) was generally favourable in Giessen.

Fig. 3.3 shows results of temperature regime over Giessen in 2004. According to this illustration Giessen was normally warm as temperatures were very close to long term averages at all months especially during the growing season.

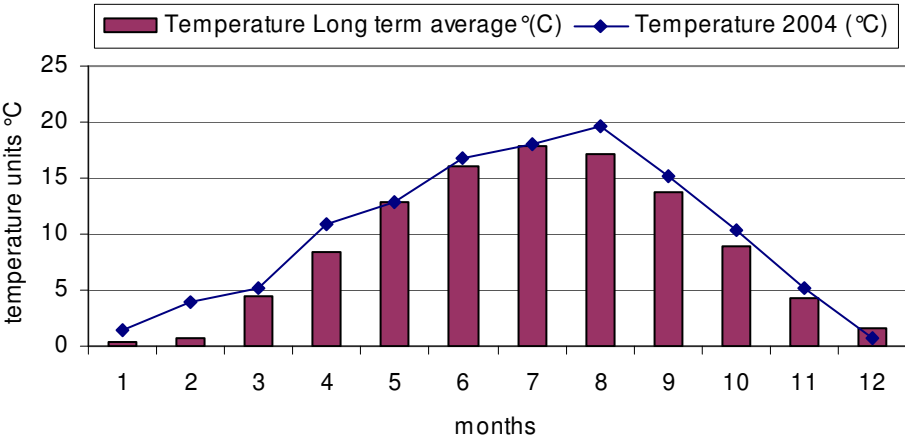


Fig. 3.3: Developments in atmospheric temperature over Giessen in 2004 compared with respective long term averages ;(temp=temperature; lta = long term average)

Temperatures in mid April were above 10°C suggesting good potentials for germination. A higher than long term value in August also suggests good dry down potentials for maize especially the early maturing cultivars.

Weather and climate conditions in 2005

Results of precipitations as shown in figure 3.4 indicate a wetter growing season (April to October) compared with the long term averages as well as with 2004.

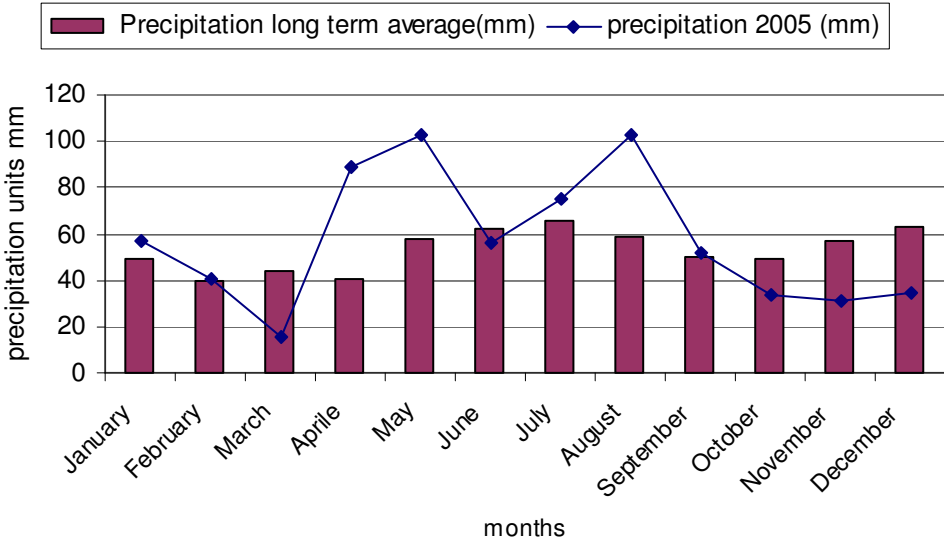


Fig. 3.4: Developments in precipitation over Giessen in 2005 compared with respective long term averages (Ppt = precipitation; Ita = long term average)

Like in 2004 may was the wettest month and June the driest. However unlike in 2004, the drier June was equivalent to observations made from long term averages. The growing season was also normal even though wetter than 2004.

Results of average temperatures over Giessen in 2005 are compared with long term averages in figure 3.5. It can be observed that temperatures were above long term averages for all the months within the growing season except in August where temperatures were same as the long term average.

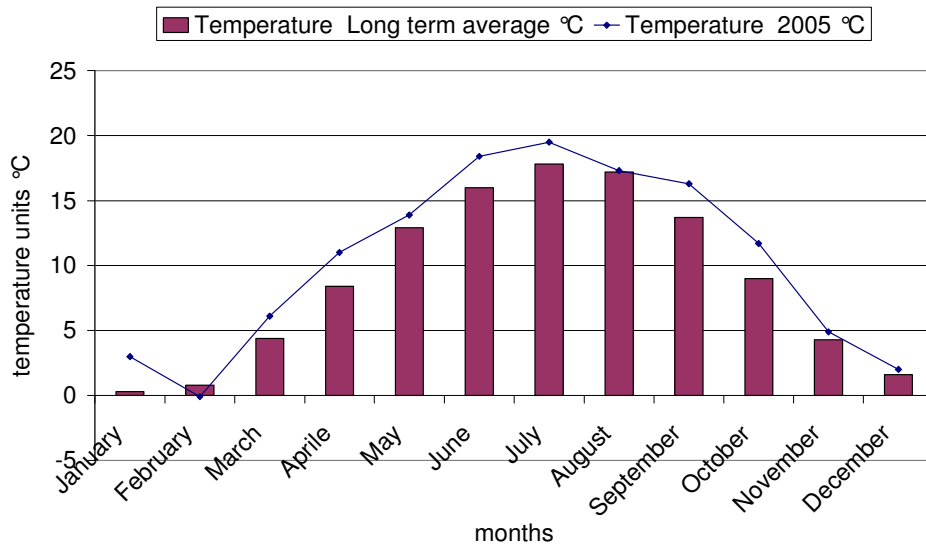


Fig. 3.5: Developments in atmospheric temperature over Giessen in 2005 compared with respective long term averages (temp=temperature; Ita = long term average)

The temperature above 10°C observed in mid April was a favourable sign for good germination potentials as is known for maize.

Weather and climate conditions in 2006

Figure 3.6 shows 2006 to be a very problematic year as compared with 2004 and 2005. March and mid August were the wettest months and April was even drier than long term average.

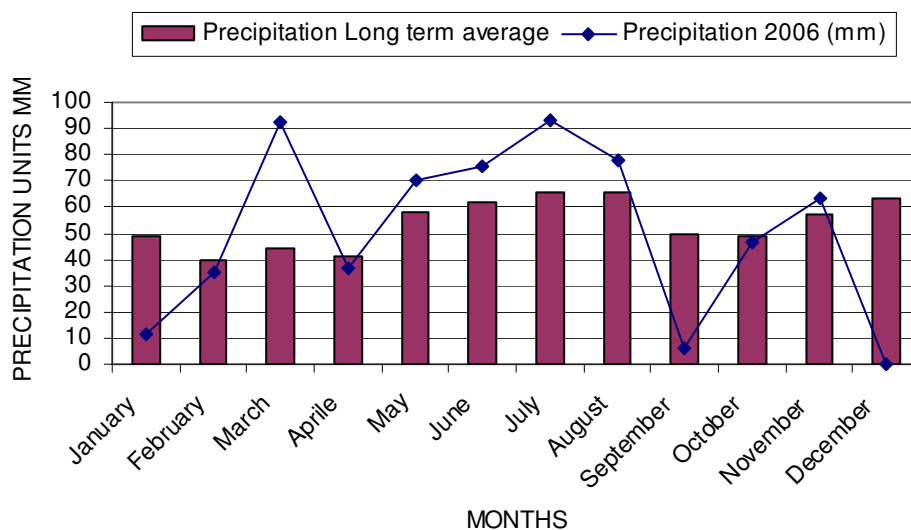


Fig. 3.6: Developments in precipitation over Giessen in 2006 compared with respective long term averages (Ppt = precipitation; Ita = long term average)

The growing season (April to October) can be seen to be drier than 2004 and 2005. July was the hottest month and corresponded with the period of Anthesis in the middle late and late maize cultivars as well as grain filling stages for the early and middle early cultivars. This Couple with the cooler April and may explain the reason why 2006 is described as problematic.

Figure 3.7 shows the temperature distribution over Giessen in 2006 and compares it with long term averages of each month. The growing season (April to October) can be seen to be drier than 2004 and 2005. July was the hottest month and corresponded with the period of Anthesis in the middle late and late maize cultivars as well as grain filling stages for the early and middle early cultivars. This Couple with the cooler April and may explain the reason why 2006 is described as problematic.

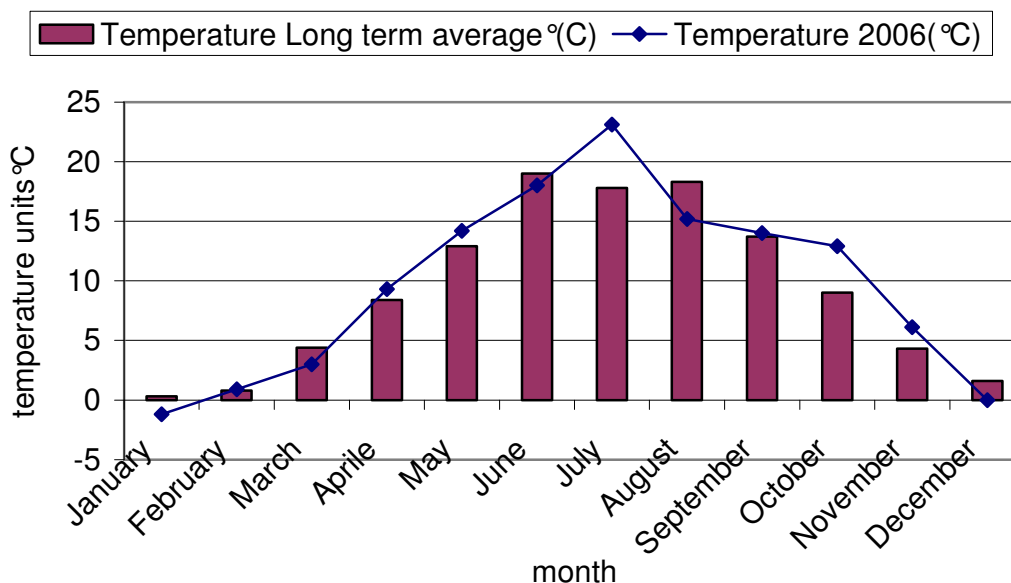


Fig. 3.7: Developments in atmospheric temperature over Giessen in 2006 compared with respective long term averages (temp=temperature; lta = long term average)

3.2.2 Experimental station Gross-Gerau

Gross-Gerau (49°55'N 8°28'E) is located in the upper Rhine valley with the river Main to the north, the river Rhine to the west and the Odenwal mountains to the east. With elevations ranging from 83.2 m to 145 m above sea level, this location is generally low lying. The soils are mainly alluvial with a predominantly sandy but also loamy texture. The soils are hence best described as having a slightly loamy to loamy sand consistency. While the low lying topography has given Gross-Gerau a generally warmer climate compared to Giessen, its sandy soils reduces its water retention capacity thereby limiting crop cultivation. Irrigation was hence an inevitable component of the experimental planning in Gross-Gerau during all the three field experiments carried out in 2004, 2005 and 2006. General characteristics of Gross-Gerau are presented in table 3.9 below.

Table 3.9: General characteristics of the experimental station Gross Gerau

Factor	Value
Soil specie	sandy loam
Clay content	<5%
Available field capacity (100cm)	<100mm
Height above NN	91m
Long term average Air temperature	8,0°C
Long term average precipitation	590mm/year

NN= Normal null (the German standard for measuring height above sea level)

The experimental field used for maize cultivation in 2004, was previously sown with sun flower in 2002 and pea in 2003. That used for the 2005 experiments had sun flower in 2003 and pea in 2004 as pre crops. For the 2006 experiments the field used was pre-sown with winter rye in 2004 and pea in 2005.

Soil conditions and fertilization

Soil nutrient contents were analysed from top soil to 90 cm deep and the results were used in planning any necessary fertilizer or manure applications. The results of soil analysis for the experiments of 2004 are presented in tables 3.10 and 3.11 and those for the 2005 and 2006 experiments can be found in tables 3.12 and 3.13 below.

Table 3.10: Results of soil analysis (depth 0-90 cm) for the 2004 experiments

Nutrient	Content (mg/100g soil)
P ₂ O ₅	23
K ₂ O	12
MgO	5
B	0,2
Soil reaction (pH value) 6,6	

Table 3.11: Results of mineralised Nitrogen at different soil depths

Soil depth analyse	N_{min} (mgNO₃)/100g soil
0 – 30 cm	6
30 – 60 cm	6
60 – 90 cm	10
Total =	22

Table 3.12: Results of soil (depth 0-90 cm) analysis for the 2005 and 2006 experiments

Nutrient and soil reactions	mg Nutrient /100g soil
P ₂ O ₅	24
K ₂ O	11
MgO	4
B	0,2
Soil reaction were slightly acidic (pH 6,1)	

Table 3.13: Results of mineralised Nitrogen at different soil depths

Soil depth analyse	N _{min} (mgNO ₃)/100g soil
0 – 30 cm	0,14
30 – 60 cm	0,30
60 – 90 cm	-
Total =	0,44

Table 3.14 shows fertilizer applications made in 2004, 2005 and 2006 following soil analysis results.

Table 3.14: Fertilizer applied at the seed bed preparation stage in Giessen in 2004, 2005 and 2006

Type of fertilize	Application(kg / ha)	
Thomaskali [®]	P	K
	70	210

Type of fertilize	Application(kg/ha)
Ammonium nitrate(NH ₄ NO ₃)	N
	60kg/ha

At the fourth leaf stage a second N – fertilization of 40 kg N / ha was carried out using the same Ammonium nitrate (NH₄NO₃) fertilizer containing 27% nitrogen.

In all the experimental years, the same types of herbicides were applied during the fourth leaf stage to ensure a healthy maize crop stand.

Table 3.15: Herbicides used in 2004, 2005 and 2006

Plant protection	Type	Trade mark	Quantity l/ha
	Herbicide	Gardo Gold	2,0 l/ha
	Herbicide	Mikado	1,0 l/ha
	Herbicide	Certrol B	0,5 l/ha

Weather and Climate conditions

Just as in Giessen, the effects of weather on the performances of the maize cultivars were also assessed by comparing meteorological results of each experimental year with the known long term averages for Gross-Gerau. The results are illustrated in figures 3.8, 3.9, 3.10, 3.11, 3.12, and 3.13 below.

Weather and climate conditions in 2004

Figure 3.8 below illustrates precipitations over Gross-Gerau in 2004 and compares it with long term averages. Precipitations during the growing season in 2004 were less than the long term averages except August.

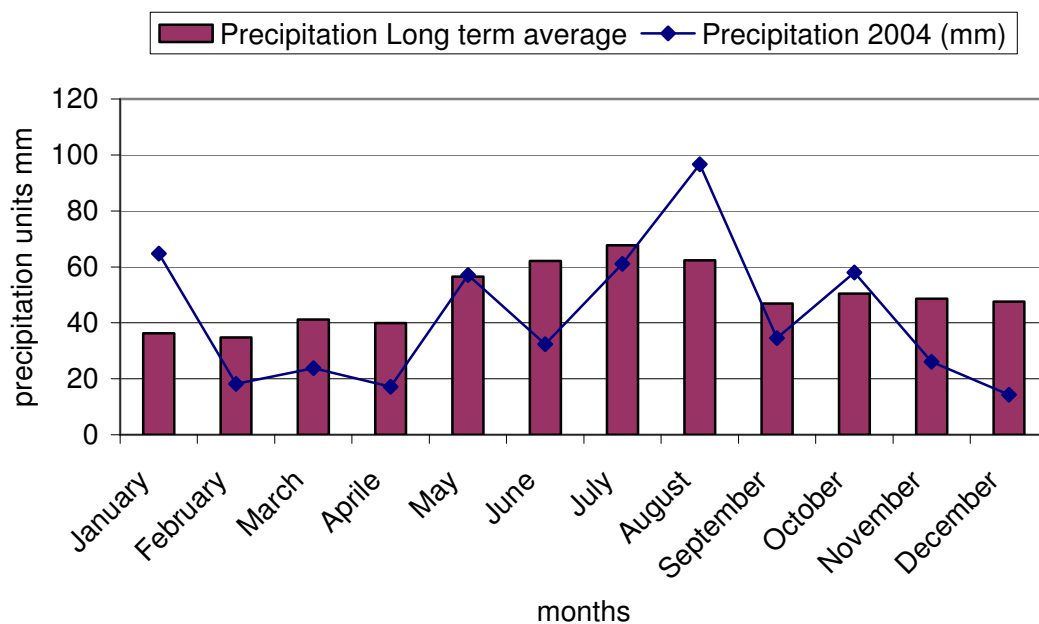


Fig. 3.8: Developments in precipitation over Gross-Gerau in 2004 compared with respective long term averages (Ppt = precipitation; lta = long term average)

This is indicative of the drier climate of Gross-Gerau as compared with Giessen.

Results of temperature conditions over Gross-Gerau in 2004 are compared with the respective long term averages in figure 3.9 below.

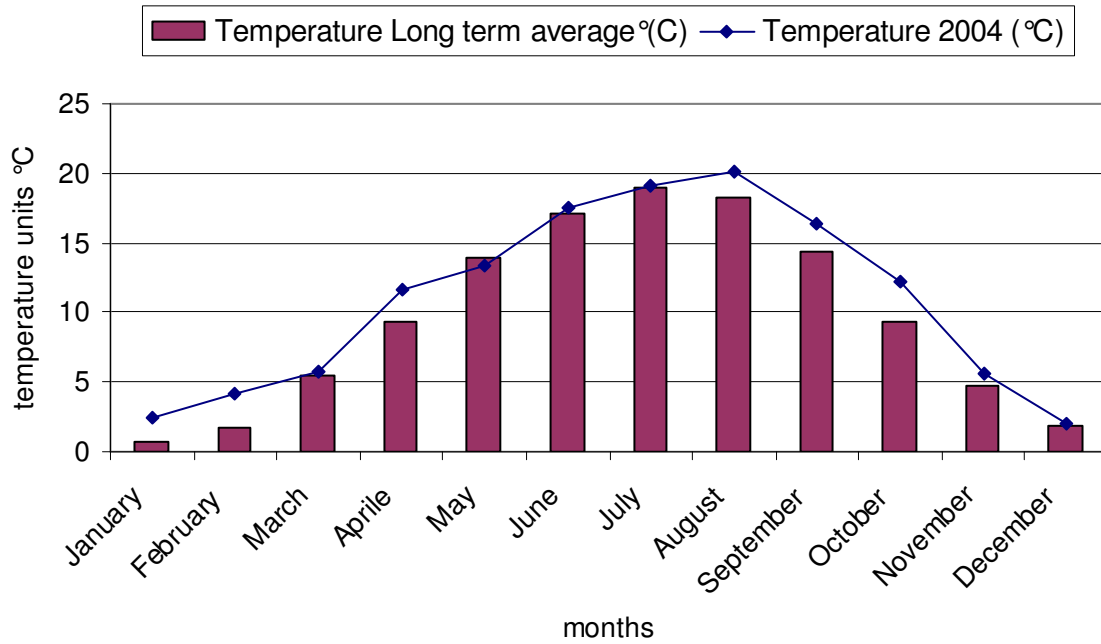


Fig. 3.9: Developments in atmospheric temperature over Gross-Gerau in 2004 compared with respective long term averages (temp=temperature; lta = long term average)

Generally conditions were warmer with favourable temperatures ($\geq 10^{\circ}\text{C}$) for Germination in mid April.

Weather and climate conditions in 2005

Fig. 3.10 shows a very wet April and May and dry July and August in Gross-Gerau.

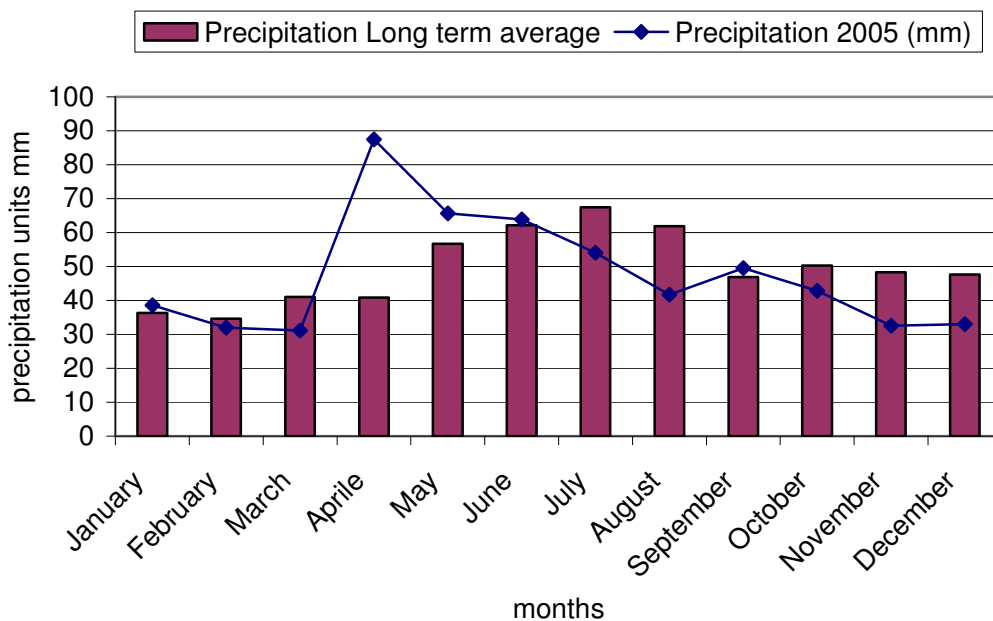


Fig. 3.10: Developments in precipitation over Gross-Gerau in 2005 compared with respective long term averages (Ppt = precipitation; lta = long term average)

As has already been pointed at the beginning Gross-Gerau is a region prone to sporadic droughts. Hence irrigation was always included in the experimental planning.

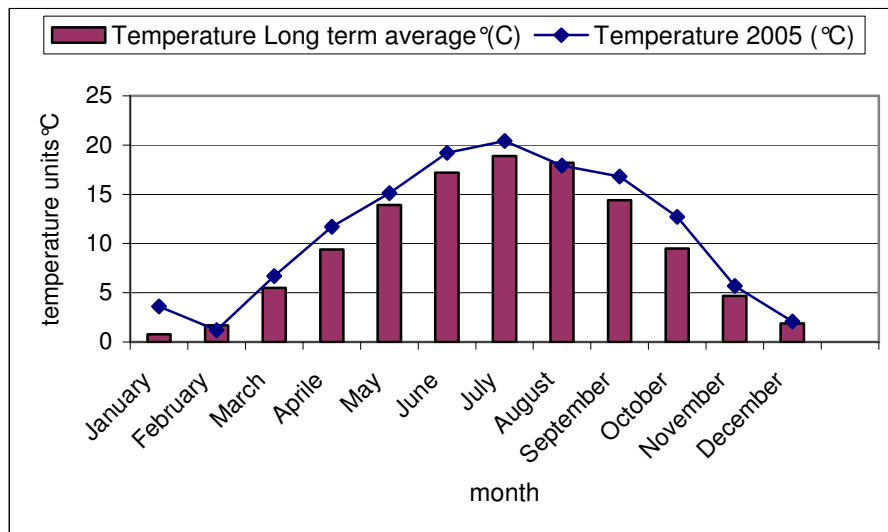


Fig. 3.11: Developments in atmospheric temperature over Gross-Gerau in 2005 compared with respective long term averages (temp=temperature; Ita = long term average)

It can be observed that 2005 was warmer as the temperatures of each month are above their respective long term averages. Temperatures were therefore favourable at all months.

Weather and climate conditions in 2006

A comparison of monthly precipitations with their respective long term averages over Giessen in 2006 is illustrated in figure 3.12 below.

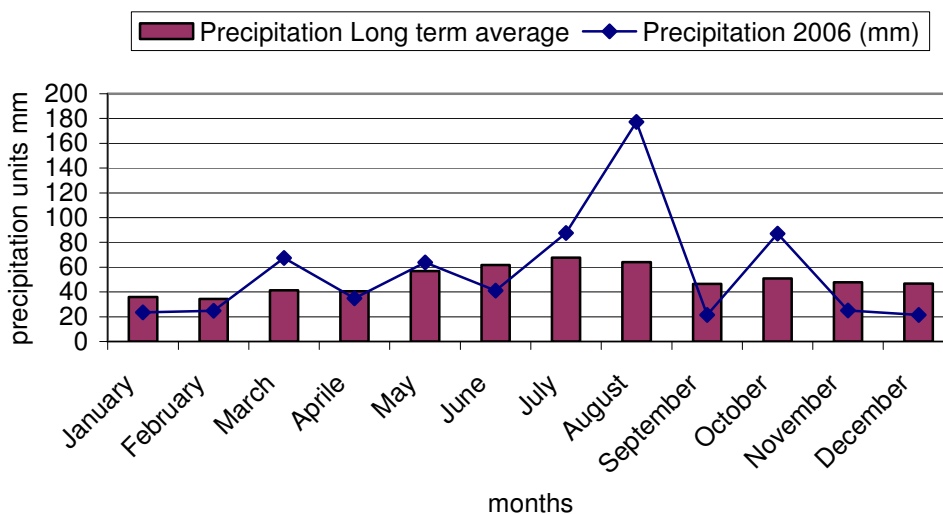


Fig. 3.12: Developments in precipitation over Gross-Gerau in 2006 compared with respective long term averages (Ppt = precipitation; Ita = long term average)

April, June and September were drier but September was much drier. Since September was the harvesting period this could be a problem in controlling the moisture contents of whole plant silage maize.

Figure 3.13 shows the results of monthly temperatures over Gross-Gerau as compared with their respective long term averages. The trend is equal to that observed in 2005 but the individual values are higher compared with 2004, 2005 and long term averages.

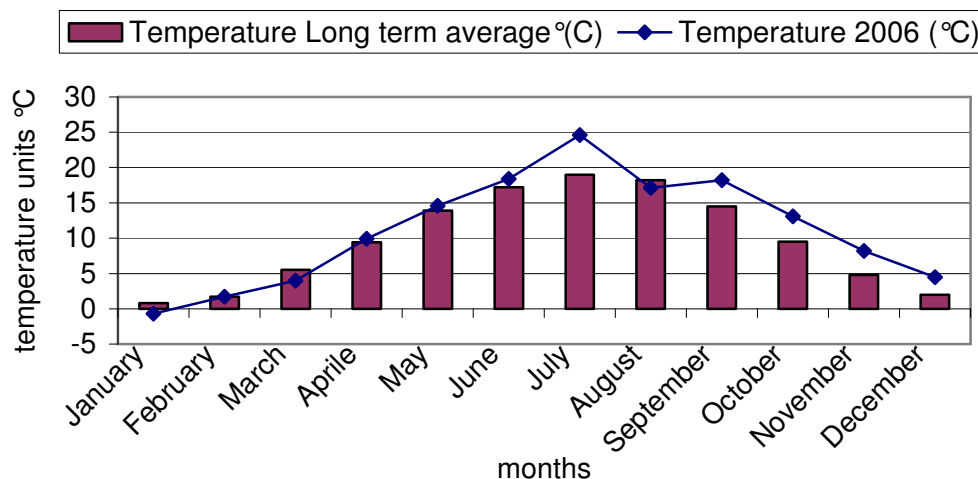


Fig. 3.13: Developments in atmospheric temperature over Gross-Gerau in 2006 compared with respective long term averages (temp=temperature; lta = long term average)

This also indicates 2006 to be the warmest of all the experimental years as was also observed in Giessen. The lower values of temperature in April also indicates cooler than normal conditions for Gross-Gerau. Like in Giessen 2006 in Gross-Gerau was characterised by late frost and droughts at Anthesis and grain filling stages.

3.3 Description of the experiments and analysis

This section describes in details the materials and procedures used in the fields experiments and in the laboratory analysis.

3.3.1 Descriptions of field experiments

All the field experiments were carried out using the same design for both Giessen and Gross-Gerau. Maize dry matter yield (DMY) and dry matter contents (DMC) were measured in both locations and in all the experiments. Added to these maize heights were measured in Giessen at each harvest in all the experiments. In Gross-Gerau plant lengths were measured only in 2004 and 2006. Maize leaf area indexes were also measured but only in Giessen and only in 2005 and 2006.

Experimental design

A randomised complete block design was used for all the experimental years and locations. This was done by dividing the experimental fields into four blocks lying side by side to each other. Each of the four blocks represented a harvest date and was subdivided into four replications (see fig.3.1). Each replication was subdivided into a number of plots each measuring 6m x 3m (18 m²) at sowing and spaced 0.75m from each other. The numbers of plots per block were equal to the number of cultivars chosen for the experimental year in question (four in 2004, five in 2005 and six in 2006). Each cultivar was planted in four rows on each plot. During harvest only the two inner rows of each plot were sampled (making an area of only 1.5m x 6m = 9m² out of the original 18 m²) while the two outer rows were considered edges.

Measurements of Leaf area indexes (LAI)

LAI were measured using a pre-calibrated Sun Scan canopy analysis system from Delta T Company. SunScan measures and analyses incident and transmitted photosynthetically active radiations (PAR) in crop canopies. This provides valuable information about LAI and biomass production. It provides an opportunity to quickly sample vast areas of land. The advantage of using SunScan lies in its ability to function in both steady as well as changing light conditions.

The system consists of a probe, a beam fraction sensor (BFS), and a data collection terminal (also called a Psion or Workabout) containing Sundata software for programming the system.



Fig. 3.14: SunScan probe (left) and workabout (right on the white file)



Fig. 3.15: Beam fraction sensor (BFS) mounted on a tripod

The BFS contain two photodiodes, one of which could be shaded from the direct solar beam by the shade ring. This allowed the direct and diffuse components of PAR to be separated. BFS therefore measured the actual solar light incident on the canopy.

The SunScan probe is a 1 meter long light sensitive rectangular rod containing 64 photodiodes equally spaced along the 1m length. It ends in a handle containing batteries and ports to which the workabout and BFS are connected. It also contains electronics that function in converting the photodiode output from the “Wand „into digital PAR readings. The readings are then sent to the data collection terminal (Psion Workabout) via an RS232 link (cables).In this experiments these readings directly represented the true leaf area indexes of plants of the different maize cultivars.

Procedure

LAI measurements procedures constituted mounting the beam fraction sensor to a tripod and connecting to the probe via cables .From the probe the workabout was connected via the RS232 link. By positioning the BFS in an unshaded position and inserting the probe beneath the canopy shadow of plants of the targeted maize variety, the leaf area index of the variety was then gotten by directly reading the values displayed by the workabout.

Measurements of maize heights

The same day that maize leaves area indices were measured, maize lengths were also measured using a normal two meter bricklayer ruler. Heights of maize plants from each cultivar were measured from the soil surface to the tip of the tassel. From each replication six plants from each cultivar were measured and the average calculated. Results were recorded in centimetres.

Measurements of the dry matter yields of the different maize cultivars

Maize was harvested using a Silage plot harvester driven by the power take off shaft of a tractor.



Fig. 3.16: Maize harvesting and sampling

The harvesting was done plot for plot across the block from replication one to replication four until the whole experimental block (corresponding to a harvest time) was completely harvested. The same harvesting and sampling methods were used in all the experimental years, stations and harvest times.

At first edges were harvested and thrown away onto the field as manure. This was followed by the second pass by which the two inner rows were harvested and sampled for further analysis and processing. The samples taken were to be used for dry matter yield and moisture content determinations, maize silage chemical composition analysis and for anaerobic digestion to produce biogas.

For each variety, samples for dry matter yield and moisture content determinations and those for chemical composition analysis were collected replication for replication while those for biogas production were collected as mixed samples from all the four replications. All the samplings were done manually by some workers of the experimental stations.

Immediately after each harvest dry matter and moisture content of samples were determine. Samples intended for NIRS analysis of maize chemical composition were dried, finely grounded, packaged into dry paper sachets and stored in a moisture free condition. Those for biogas production were immediately deep-frozen at -20 °C.

Measurements of total dry matter yield and dry matter content

One hundred grams each of the samples were weighted out and put into a laboratory drying oven set at a constant temperature of 105°C. The samples were intended to dry over a period of 48 hours. At intervals samples were taken out and weighted until no weight change was observed between consecutive intervals. Water was considered to be the only volatile substance present and so the constant weight indicated a complete evaporation of water. This was therefore recorded down as the dry matter content (DMC). By subtracting this final constant weight (DMC) from the weight of the sample originally put into the drying oven, the moisture content of each sample was also calculated.

$$\text{Sample mass (g)} = \text{Sample dried mass (g)} + \text{Moisture (g)}$$

$$\text{Moisture (g)} = \text{Sample mass (g)} - \text{Sample dried mass (g)}$$

The results are usually expressed as percentages of the sample masses

$$\text{Moisture Content [\%]} = \frac{(\text{sample mass [g]} - \text{dried mass [g]})}{\text{sample mass [g]}} \times 100$$

$$\text{Dry matter Content [\%]} = \frac{\text{dried mass [g]}}{\text{sample mass [g]}} \times 100$$

3.3.2 Descriptions of Laboratory analysis

Laboratory analysis constituted determining the chemical composition of maize dry matter by means of a near infra red reflectance spectroscopy (NIRS), anaerobically digesting maize samples using a table top laboratory scale batch digester, measuring the total biogas volumes produced by means of a wet Ritter gas meter and characterising the resulting biogases using an ORSAT gas analyser.

Anaerobic digestion of maize samples

In all the experiments samples for biogas production were deep frozen at -20°C for at least two months. Bearing in mind that only the organic portion of the dry matter is digestible and that specific biogases and methane productivity are calculated on the bases of organic matter (volatile solids), it was necessary to determine the organic matter content of each maize sample before digestion. Because the freezing had the potential to alter maize dry matter contents, the DMCs determined at harvest were not more very valid. Volatile solids could therefore only be calculated from the as received dry matter contents which were determined as described below.

Determination of dry matter content

The determinations of maize dry matter content was done gravimetrically in conformity with the prescriptions in section two of the German industrial standard

(DIN 38 414 Teil 2). The samples which had been subjected to a constant temperature of -20°C since the day of harvest were chopped up 60 seconds long using a Thermomix operating at 12.000 revolutions per minute. Fifty grams of the chopped samples were then weighted out and oven dried until a constant weight was attained.

Procedure

Dry porcelain crucibles (2 for each sample) were weighted out using a laboratory balance and individual weights of the crucibles were noted. Fifty grams (50g) each of the selected chopped maize samples were weighted out into the porcelain crucibles and inserted into a laboratory drying oven operating at a constant temperature of 150°C . Sample were taken out at regular intervals and weighted. When the weight from two consecutive intervals could not differ (or differed negligibly), the porcelain containing the samples were taken out of the oven, cooled in a desiccator and finally weighted out to determined the “as received” dry matter weights. This was done by subtracting the known weights of the crucible from the sum weight of crucible and sample originally put into the oven. When this weight is expressed as a percentage (%) of the fresh weight it is called the dry matter content (DMC). The calculations were done in the same way as in field experiments.



Fig. 3.17: Experimental set up for determining maize dry matter “as received”
Maize samples (left) in crucibles; drying Oven (middle); desiccator and
Balance (right)

Determination of volatile solids contents

Volatile solids are easily oxidised (combustible or digestible) as compared with the mineral solids. Hence by burning the total dry matter (total solids) of a given biomass all the organic matter present will be burnt away and the residues (representing the mineral solids) can be directly measured. This allows an easy calculation of both fractions by simple subtraction .The experiments described in this thesis all used this procedure to separate the Volatile solids from the inorganic (mineral) solids (ash).This was done in accordance with the prescriptions in section three of the German industrial standards (DIN 38 414 Teil 3)

Sample preparation

Sample preparation and weighting procedures were the same as for total solids determination described above. In this case however known weights of maize samples in crucibles of known weights were inserted into a laboratory muffle furnace operating at a constant temperature of 500°C and allowed to burn completely to ashes.



Fig. 3.18: Experimental set up for determining maize Volatile solids content
Samples in crucibles (left) Muffle furnace (middle) Desiccator and
Balance (right)

The burning led to a loss in the organic components due to volatilization. For this reason this portion is referred to as the volatile solids (VS). As soon as the combustion process was over, the crucibles containing the ashes were removed cooled in a desiccator and then weighted out. By subtracting the known weight of each crucible from the combined weight of crucible and ash, the remainder weight was equal to the weight of the ash in the crucible in question. By further subtracting the amount of ash produced from the amount of sample initially put into the furnace, the volatile solids could be determined. Just as dry matter, volatile solids can also be expressed in grams as well as percentages (volatile solid contents) of the corresponding sample masses.

$$\text{Volatile solids content (\%VS)} = \frac{(\text{mass of TS [g]} - \text{mass of ashes [g]}) \times 100}{\text{mass of TS [g]}}$$

Batch anaerobic digestion of maize samples

The anaerobic digestion of chosen maize samples from particular harvest times and corresponding experimental years were carried out in the mesophilic range (20-40°C) using a plastic laboratory scale desk top batch digester. The digester had a filling and an emptying outlet, an automatic electric stirrer and a gas out let via which the gas collecting sacs were connected. The digesters were kept at constant temperature by standing them in a constant temperature (38°C) water bath. The temperature regulation was achieved by a thermostat attached to the bath. The source of micro-organism used for the digestion was the active sewage sludge taken from the

sewage treatment plant in Giessen. The digester layout diagram and picture are illustrated in figures 3.19 and 3.20 below.

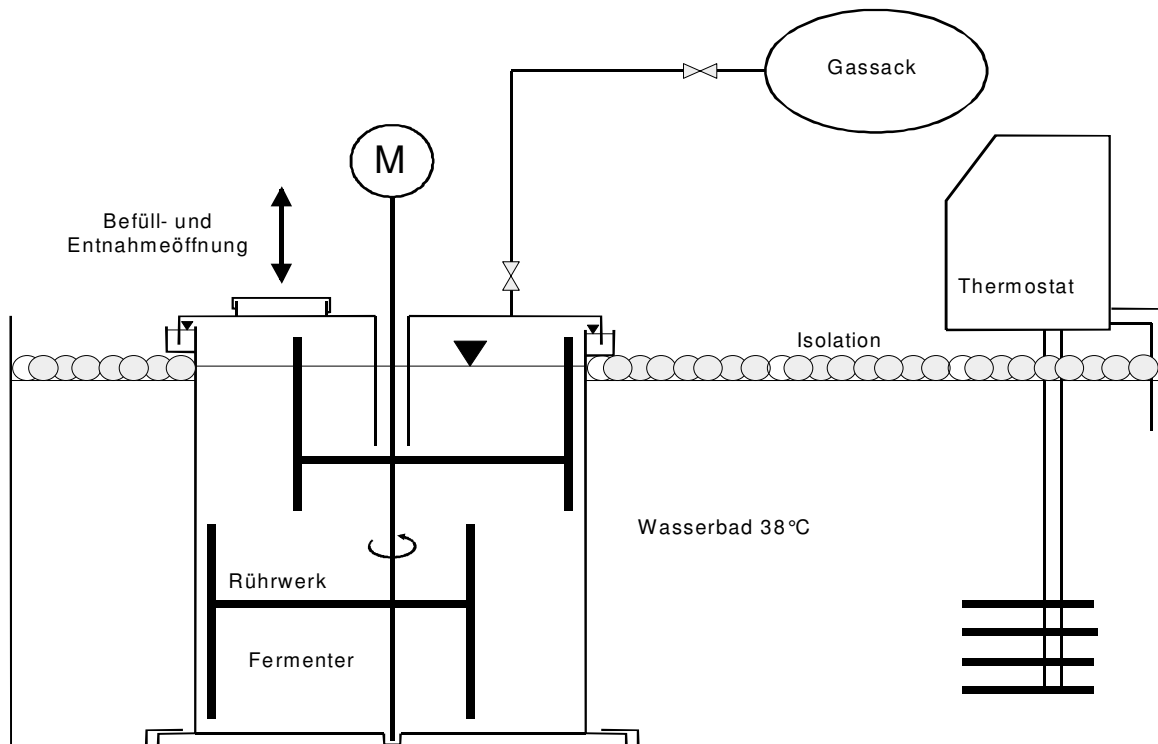


Fig. 3.19: Layout of the batch Digester

Fermenter = Digester;

Rührwerk = Stirrer;

Wasserbad = water bath;

Gas sack = gas sac,

Befüll und Entnahmeöffnung = filling and emptying outlets.



Fig. 3.20: Photo of batch digester system showing attached gas sacs

Procedure

A week before the actual digestion, the digesters were fed with the active sewage sludge and allowed to “gas out” over a period of eight days. This ensured that all the oxygen was consumed thereby creating anaerobic conditions within the digesters as required. In order to ensure a constant pH within the digester, the digester pH was constantly measured according to prescriptions in section five of the German industrial standards (DIN 38 414 Teil 5).



Fig. 3.21: A gas sac filled with biogas

A batch of about 150g each of the samples were put into different digesters and allowed to digest over a predetermined retention time of 21 days. The produced biogases were collected in the attached gas sacs. The gases were then further measured and characterised volumetrically using a wet Ritter gas meter and an ORSAT gas analyser respectively. Within the twenty one days retention time, biogases of each samples were measured and characterised every working day for the first week and every three or five working days for the second and third week depending on the gas productive potentials of the sample.

Biogas measurements with a Ritter Wet Gas Meter

A Ritter wet gas meter consists of a multi-chamber rotary measuring drum containing water. The drum is attached to a counting mechanism consisting of scales and needle-dials. It functions upon the principle of positive displacement. It contains an inlet and outlet for connecting the gas sac and expelling the measured gas respectively.

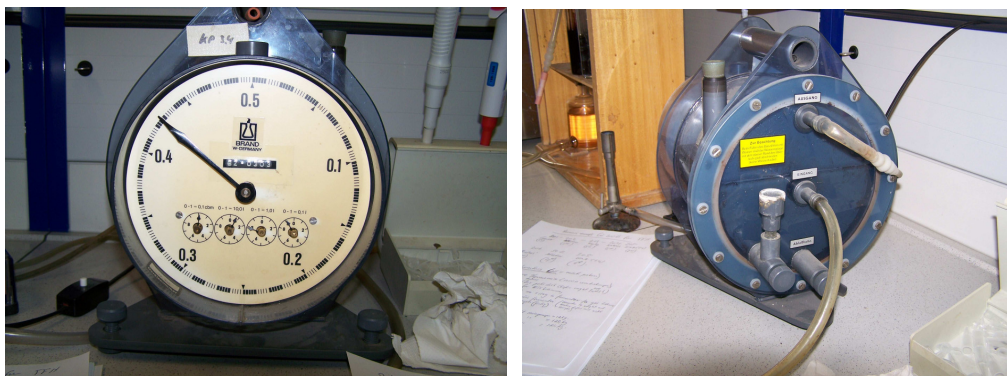


Fig. 3.22: A Ritter Wet Gas Meter(front view left, back view right)

Procedure

The meter was connected to a Bunsen burner and gas sac by means of a PVC tube so that the sampled biogas flew from the sac through the meter chambers and out into the Bunsen burner where it was burned away. As biogas flew from one chamber of the drum to the other, the drum rotated. This rotated the needle-dials clock wise around the scales so that the positions of the needles on the scales were read directly as the volume of gas that has flown through the meter. The larger needle on the larger scale gave full volumes and the smaller needles on the smaller scales gave fractions of the volumes. By combining the readings of the two scales the total biogas volumes produced by digesting 150g of each maize sample was calculated. Using the calculated volatile solids the specific biogas (biogas / kg VS) of the corresponding maize samples could be calculated.

Characterization of biogas

Biogas consist mainly of methane and carbon dioxide together with minute to traces of other gases. There are many types of gas analyser that can be used to characterise biogas. In these experiments biogas samples of all the maize samples were characterised using an ORSAT gas analyzer illustrated in fig 3.23 above.

Descriptions of ORSAT analyzer

An ORSAT analyzer works by the principle of gas absorption whereby the unwanted gases are absorbed and the wanted gas is measured at the end of the system. An ORSAT analyzer therefore consists of a volumetric measuring burette , absorption pipettes, U-tube, two cocks (one closing the access to gas sac via the U-tubing and the other closing access of the last pipette to the volumetric burette) and the bottle.

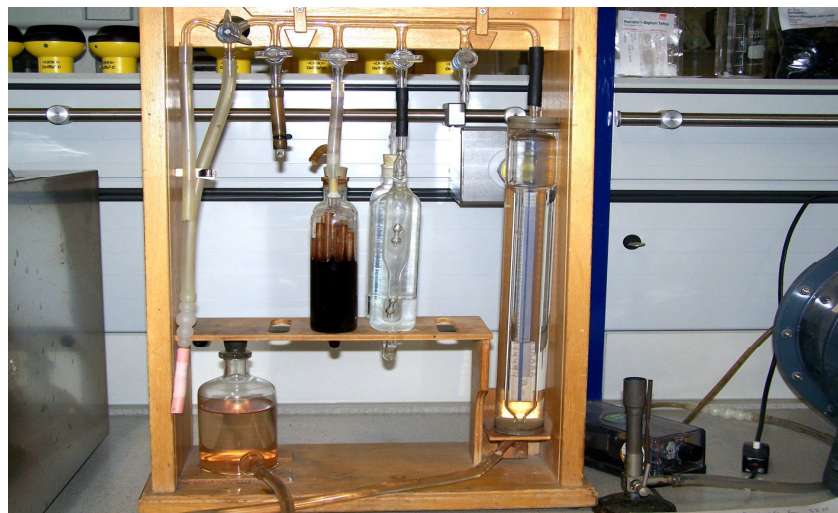


Fig. 3.23: An ORSAT gas analyzer

The volumetric measuring burette is graduated in cubic centimeters up to 100, and is surrounded by a water jacket to prevent any change in temperature from affecting the density of the gas (e.g. methane) being analyzed. The analysis made by the ORSAT apparatus is volumetric. Therefore if the analysis by weight is required, it can be found from the volumetric values by conversion.

An ORSAT usually has four absorption pipettes. The first contains a solution of sodium hydroxide (NaOH) for the absorption of carbon dioxide, the second an alkaline solution of pyrogallol (phenol got by heating gallic acid) for the absorption of oxygen. The remaining absorption pipettes contain an acid solution of cuprous chloride for absorbing the carbon monoxide. Each pipette contains a number of glass tubes, to which some of the solution clings, thereby increasing the surface area for the absorption of the gas. In the tubes of the last two pipettes, copper wire is usually placed to re-energize the solution as it becomes weakened. The rear half of each pipette is fitted with a rubber bag, to protect the solution from getting any contact with the air. The solution in each pipette should be drawn up to the mark on the capillary tube. To ensure accuracy the apparatus should be carefully tested for any leakage possible. This is usually done by closing the cock and placing the bottle on top of the frame for a short time and again bringing it to the zero mark. If the level of the water in the burette is above the zero mark, a leak is indicated.

Using an ORSAT gas analyzer

The gas is drawn into the burette through the U-tube which is connected to the gas sac and filled with spun glass, or similar material, to clean the gas. To discharge any air or gas in the apparatus, the cock is opened to the air and the bottle is raised until the water in the burette reaches the 100 cubic centimeters mark. The cock is then turned so as to close the air opening and allow gas to be drawn through the U-tube. The bottle needs to be lowered during this action.

The gas is drawn into the burette to a point below the zero mark, the cock then being opened to the air and the excess gas expelled until the level of the water in the bottle and in the burette are at the zero mark. This operation is necessary in order to obtain the zero reading at atmospheric pressure.

The final gas sample for analysis is taken by first filling the burette with gas and emptying once or twice. This ensures that all the apparatus is filled with the gas to be characterized. The first cock is then closed and the cock in the last pipette is opened and the gas driven over into it by raising the bottle. When the solution in this last burette has reached the mark in the capillary tube, the cock leading to the burette is closed and a reading is taken on the burette.

In all the experiments described in this thesis the biogases produced by all the maize cultivars were considered to consist of only methane and carbon dioxide. For this reason only one absorption pipette containing sodium hydroxide (NaOH) was used to absorb the carbon dioxide. The remaining gas was then considered to contain only

methane and was measured volumetrically and further back calculated as specific methane(methane/kg VS) using the calculated volatile solids of each sample.

During each gas measurements the room temperature, pressure and humidity were also measured and converted into standard conditions (101,325kPa and 0°C) as prescribed in DIN 1343.This conversion made it possible to apply Avogadro’s hypothesis to calculated biogas and methane volumes in a manner that allows international comparison. Avogadro’s hypothesis states: “*Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules*”. From this hypothesis a universal gas equation has been derived for use to calculate gas volumes commercially every where on earth.

$$PV = nRT$$

Where: **P** is the absolute pressure (Pa); **V** is the volume (m³) of the vessel (digester) containing **n** moles of gas; **R** is the gas constant whose value depends on the units used for pressure. The standard condition used for these experiments were those stated by DIN where **P** = 101325 Pa (101,325 kPa), and **T** = 273 K (0°C).Under this conditions R = 8.314472.

Hence by inserting the biogas and methane volumes measured together with the corresponding standard pressures and temperatures the norm (Standard) volumes of the biogas samples together with their corresponding methane concentrations were calculated. In all the experiments the volumes were expressed as norm litres (nL). From this values could also be converted into norm cubic meters (Nm³).

A norm Nm³ is defined as the quantity of gas contained in one cubic meter (1m³) at a pressure of 101.325kpa and a temperature of 273 K (0°C)(DIN 1343) or15°C(ISO 2533) . table 3.16 below shows the differences between the normal conditions as defined by the German industrial norms and that defined by the international standards organisation (ISO)

Table 3.16: Standard conditions as defined by DIN and ISO

	Pressure	Humidity	Temperature
<u>DIN</u> 1343	101,325 bar	0%	0°C
ISO 2533	101,325 bar	0%	15°C

Near infra red reflectance spectroscopy (NIRS) analysis

The chemical composition of maize dry matter were analysed spectroscopically by measuring the ability of components to reflect wave lengths in the near infra red region of the light.

Near-infrared radiation is the region of the electromagnetic spectrum between the visible and the infrared region. (Sheppard, 2002). By convention it is characterized as the region containing the wavelengths (λ) from 780 to 2500 nm (Workman and

Shenk, 2004). That biological materials interact with near infrared radiation (NIR) has been known for a long time. The near infrared reflectance spectroscopy (NIRS) technology exploits the ability of chemical components of biomass to absorb and reflect specific wavelengths over the infrared range (750 to 2500 nm).

Scientists found out that for a substance to absorb wavelengths, the radiation of the wavelength must match the vibration or rotational frequency of the chemical bond within a particular substance. This technology therefore enables information about the physical-optical and chemical composition of biological matter to be obtained. Samples are generally supplied in the dried and ground form but liquids and fresh material can also be used. Infrared wavelengths are known to be particularly absorbed by:

- C-H bonds; common in carbohydrates
- N-H bonds; common in proteins, amides, and amino acids
- O-H bonds; common in water, alcohols, organic acids etc.

Experts use statistical procedures to correlate the reflectance of one or more specific wavelengths to the true level of a chemical entity (Molecules, free radicals etc) as would be measured by wet laboratory methods. From this they develop a regression equation that estimates the quantity of a chemical entity based on the entity's strength to reflect infrared wavelengths. This equation forms the calibration equation for the material containing such chemical entities. It is then entered into the computer software for use by NIRS on future samples where wet laboratory analysis will not be conducted (Carrow, 2000). In Germany these experts are at the "Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten(VDLUFA)".

The chemical composition of all the maize samples from all the harvest times and corresponding experimental years described in this thesis were characterized using a FOSS NIRS Systems Model 6500 (see figure 3.22 below) containing software for silage maize developed by the VDLUFA.



Fig. 3.24: A FOSS NIRS Systems model 6500 (left) and sample ring cup (right)

Sample preparation

The samples were prepared by drying maize biomass for 48hrs, at 40°C in an oven with forced ventilation. The dried samples were later grounded to a size of ca 1 mm. The finely grounded materials were then put into dried sachets and further analysed for starch, sugar, crude protein (CP), crude fibre (CF), neutral detergent fibre (NDF), acid detergent fibre (ADF) and enzymes soluble substances (ELOS). The values of each of these parameters were expressed as percentages (%) of the dry matter content.

Analytical procedure

Fixed amounts of the grounded samples were measured out as required by the size of the sample ring cups (Cuvettes). The sample ring cups with the known amount of samples were inserted into the NIRS system operating at the reflectance module. The samples were scanned from 400 to 2500 nm in a computer controlled NIRS system, model 6500 scanning monochromator. The results of the calculations were displayed on an attached computer screen and printed out by a writer attached to the computer system.

3.2.3 Statistical analysis

The significance of the experimental data from all the experimental years and locations were evaluated using the statistical program SPSS version 5.11. After proving data to be normally distributed sample mean values were calculated and their standard deviations and least significant differences (LSD) were calculated using the standard deviation equations and the t-Table respectively. The significance of mean differences were measured at the probability level of 5% ($P=0.05$).

4 Results

4.1 Giessen 2004

4.1.1 Field experiment results

During field experiment , dry matter yield (DMY), dry matter content (DMC) and heights of all the cultivars were measured at each of the four harvest times. The cultivars even though exposed to the same growing conditions, differed mainly in maturity classifications. Gavott (S 250), whose milk stage was used as standard to begin the first harvest for itself and all the other cultivars, was the a middle early cultivar. Vitalina (280) and KX2352 (270) were middle late and Doge (FAO 700) was the latest cultivar of this experiment.

Maize dry matter yield (DMY)

Table 4.1 below shows every delay in harvest to have increased the dry matter content of all the maize cultivars. Doge produced the highest (144,4 dt /ha) DMY at par with Vitalina (139,7dt /ha) and KX2352 (137.5 dt /ha) when they were harvested at the fourth harvest time. The lowest yields (62,9 dt /ha) were measured in Gavott when it was harvested at the first harvest time.

Table 4.1: Maize dry matter yield (dt / ha) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	62,9	69,1	90,7	122,3
KX2352	75,4	88,6	108,7	137,5
Vitalina	69,7	80,0	106,4	139,7
Doge	66,9	88,0	114,6	144,4
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		12,0	12,0	23,9

A significant ($p = 0,000$) cultivar x harvest time interaction ($LSD = 23,9$) occurred probably at the third harvest when Doge (FAO 700) as the late maturing cultivar outperformed KX2352 in dry matter accumulation. Before the third harvest KX2352 was the leading cultivar in dry matter accumulation.

Maize dry matter content (DMC)

According to studies of scientist like Johnson et al (2002), whole plant silage maize should best be harvested for maximum dry matter yield and dry matter quality (chemical composition) when it is at a dry matter content in the range 28-35%

From table 4.2 below it can be inferred that delaying harvest increase the DMC for all cultivars and that this range was only possible at the fourth harvest time for the middle late and middle early cultivars but not at all for the very late cultivar Doge. A significant ($p = 0,000$) interaction ($LSD = 1,7$) between cultivar and harvest time was also observed.

Table 4.2: Maize dry matter content (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	18,2	24,7	26,7	31,0
KX2352	17,0	23,0	25,8	29,9
Vitalina	16,5	22,4	25,1	29,7
Doge	14,0	17,1	18,1	19,0
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	0,9	0,9	1,7

The highest dry matter contents which also were within the optimum range were measured in Gavott (31%) at par with KX2352 (29,9%) and Vitalina (29,7 %) when they were harvested at the fourth harvest time. Doge could not attain optimum DMC at any of the four harvest times and as expected the lowest(14,0%) DMC was also measured in Doge when it was harvested at the first harvest time.

Maize heights

Maize plant heights were measured manually using a normal bricklayer ruler. Statistical evaluations and figure 4.1 below shows that maize heights differed significantly among the cultivars ($p = 0,000$) as well as between the harvest times ($p = 0,020$). A significant ($p = 0,000$) interaction between cultivar and harvest time was observed certainly due to Doge as its height increase faster than that of the other cultivars from the second to the fourth harvest time. Heights of the other cultivars were observed to decrease at the same second harvest.

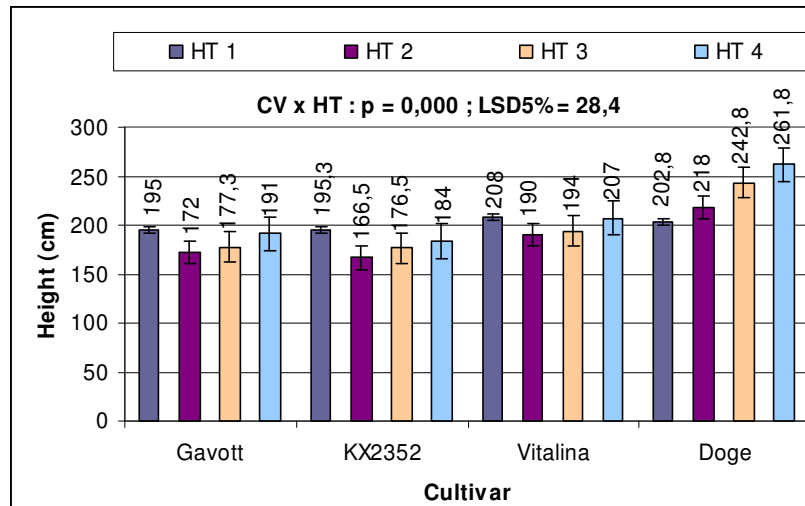


Fig. 4.1: Maize heights according to cultivar and harvest times, Giessen 2004

Doge had the tallest (261,8 cm) plants when it was harvested at the fourth harvest time and the shortest (166,5 cm) plants were measured in KX2352 when it was harvested at the second harvest time.

4.1.2 NIRS analysis results

Maize samples taken from each cultivar at four different harvest times were analysed for crude proteins (CP) contents, Crude fibre (CF) contents, acid detergent fibre (ADF) contents, neutral detergent fibre (NDF) contents; sugar contents, starch contents and enzymes soluble organic substances (ELOS)

Maize crude protein (CP)

Table 4.3 below shows each delay in harvest to have a decreasing effect on the crude protein contents of all the maize cultivars in accordance with Wiersma et al (1993) or Darby and Lauer (2002). A hard to explain but significant ($p = 0,000$) cultivar harvest time interaction ($LSD = 0,9$) was observed .

Table 4.3: Maize crude protein content (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	11,3	9,8	8,4	7,5
KX2352	11,0	10,0	8,3	7,3
Vitalina	11,1	10,1	8,3	7,3
Doge	12,6	11,7	8,9	7,6
		CV	HT	CV*HT
		0,000	0,000	0,000
		LSD (5%)	0,4	0,9

The highest CP content (12,6%) were measured in Doge when it was harvested at the first harvest time and the lowest (7,3%) was measured in KX2352 and Vitalina when they were harvested at the fourth harvest time. The mean values were also in the range observed by Darby and Lauer (2002).

Maize crude fibre (CF)

Table 4.4 below shows every delay in harvest to also have had a decreasing effect on maize CF contents of all cultivars. A significant ($p = 0,000$) interaction ($LSD = 1,5$) between cultivar and harvest time was also observed.

Table 4.4: Maize crude fibre contents (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	30,2	22,6	17,2	15,5
KX2352	30,2	25,6	19,2	16,2
Vitalina	30,9	26,1	19,4	17,5
Doge	31,1	29,3	27,6	24,0
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	0,8	0,8	1,5

The highest (31,1%) CF were measured in Doge at par with Vitalina when both were harvested at the first harvest time and the lowest was measured in Gavott (15,5 %) at par with KX2352 (16,2%) when they were harvested at the fourth harvest time.

Maize neutral detergent fibres (NDF)

Maize NDF contents as shown in table 4.5 below also decreased for each delay in harvest. A significant cultivar interaction also occurred. There were no significant differences in the NDF contents among the cultivars at the first harvest but at the second third and fourth harvest differences were observable especially compared with Doge. There was a significant cultivar harvest time interaction.

Table 4.5: Maize neutral detergent fibres content (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
	68,0	51,9	41,5	37,7
	68,4	57,7	44,5	38,9
	69,2	58,6	45,2	41,2
	69,8	65,5	59,0	52,6
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		1,1	1,1	2,2

The highest NDF contents (69,8%) were measured in Doge at par with the rest of the cultivars when they were harvested at the first harvest time. The lowest NDF (37.7) was found in Gavott when it was harvested at the fourth harvest time. All the cultivars had NDF far above the range observed by Thomas et al (2001) and the values depended on the maturity classification as can be seen from the facts that KX2352 and Vitalina as middle late maturing cultivars produced very similar values while the Values of Gavott as middle early cultivar and Doge as a late cultivar were uniquely different.

Maize acid detergent fibres (ADF)

According to table 4.6 below, maize ADF contents also decreased with delay in harvest for all cultivars with a significant interaction between cultivar and harvest time. Like NDF no significant differences were observed in ADF during the first harvest but during the second, third and fourth. The cultivars however differed in NDF contents in accordance with Barriere et al (2003) who established genetic differences in cell wall of different maize genotypes.

Table 4.6: Maize acid detergent fibres content (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	36,6	26,5	20,6	18,4
KX2352	36,7	30,1	23,0	19,2
Vitalina	37,7	37,7	23,4	20,8
Doge	39,4	36,7	33,4	29,0
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,8	0,3	1,7

Doge produced the highest ADF (39,4 %) at par with the rest of the cultivars when they were harvested at the first harvest time. The lowest ADF content was measured in Gavott (18,4 %) at par with KX2352 (19,2 %) when they were harvested at the fourth harvest time. The cause of the cultivar harvest time interactions observed with ADF might be due to Vitalina outperforming Doge in ADF concentration at the second harvest.

Enzyme soluble organic substances (ELOS)

Table 4.8 shows maize ELOS increasing with every delay in harvest time for all cultivars. Like NDF and ADF, ELOS values did not differ significantly at the first harvest time for all cultivars but the different cultivars differed in ELOS content in accordance with Barriere et al. (2003) who observed maize cell wall digestibility to be dependent on genotype. Gavott produced the highest ELOS (73,5 %) at par with KX2352 (73,4 %) and Vitalina (71,3 %) when they were harvested at the fourth harvest time. Doge did not only produced the lowest ELOS at par with the rest of the cultivars when they were harvested at the first harvest time but also expectedly had the lowest ELOS at all the four harvest times. ELOS contents in the range 46.2 – 73.5 have also been observed by De Boever et al. (1993) with whole plant silage maize.

Table 4.7: Maize enzyme soluble organic substances (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	48,6	63,3	71,9	73,5
KX2352	48,7	58,3	69,8	73,4
Vitalina	48,1	58,0	69,6	71,3
Doge	46,2	50,8	57,2	64,2
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		1,2	1,2	2,4

A significant ($p = 0,000$) cultivar harvest time interaction occurred for ELOS may be due to Gavott's sudden increase in ELOS at the second harvest relative to its two competing cultivars (KX2352 and Vitalina). Decreasing cell wall digestibility however contradicts observations of Darby and Lauer (2002) by which cell wall digestibility should decrease with delay in harvest due to increasing lignification.

Maize sugar contents(S)

From Table 4.8 below, a complex effect of delaying harvest on maize sugar content can be observed. However a genotype effects based on maturity class are observable as the middle early Gavott produces lower sugar contents at all the harvest times. KX2352 and Vitalina as middle late cultivars produced similar values and Doge

the latest of all the cultivars produced a far higher value than the rest of the cultivars. A significant cultivar x harvest (CV*HT) interaction observed might have come from the sharp increase in sugar content shown by Doge at the fourth harvest.

Table 4.8: Maize sugar content (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	10,2	8,7	8,7	9,7
KX2352	11,5	9,7	11,6	10,6
Vitalina	11,1	9,2	11,7	11,2
Doge	14,4	11,6	14,4	20,2
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,7	0,7	1,5

Delaying harvest neither increase nor decreased maize sugar content in a uniform manner like it did on CP, CF, ADF, NDF and ELOS. The only effect demonstrated by all cultivars was that they all had very low sugar contents at the second harvest time. The highest sugar content (20,2 %) was measured in Doge at the fourth harvest time and the lowest (8,7 %) in Gavott at the second and third harvest times.

Maize starch contents Giessen 2004

Table 4.9 below shows delaying harvest to produce an increase in the starch contents of Gavott, KX2352 and Vitalina. Doge's starch content showed a different response to delaying harvest by increasing from first to second harvest and decreasing continuously from second to fourth harvest. The increases and decreases were however not significant compared with the increases observed in the other cultivars.

Table 4.9: Maize starch content (%) according to cultivar and harvest time, Giessen 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	5,5	22,5	32,9	36,5
KX2352	4,2	13,9	25,2	34,5
Vitalina	4,1	13,8	25,1	30,7
Doge	6,5	9,2	5,2	3,2
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		1,2	1,2	2,4

An interaction between cultivar and harvest time was observed for starch content probably as a result of the very low starch content (3,2) produced by Doge at the fourth harvest time. The highest starch content (36,5 %) was measured in Gavott when it was harvested at the fourth harvest time and the lowest (3,2%) in Doge when it was also harvested at the fourth harvest time.

4.2 Giessen 2005

In 2005 one field experiment and two laboratory analysis were also carried out using a germplasm of two maize cultivars (Gavott and Mikado) and three inbred lines (KXA5226, KXA5233 and KXA5243). For convenience all are also referred to in this thesis as cultivars.

4.2.1 Field experiment results

During field experiment , dry matter yield (DMY), dry matter content (DMC) heights and leaf area indexes (LAI) were measured at every harvest time for all the four cultivars used. Like in 2004, the cultivars were exposed to the same growing conditions and differed mainly in maturity classifications. The cultivars were the middle early Gavott (S 250), the middle late KXA5226 (S 260), KX5233 (S 270) and KXA5243 (S 290) and the very late Mikado (FAO 500). The first harvest date for all the cultivars was also based on the date of Gavott attaining the milk stage.

Maize dry matter yield (DMY)

Table 4.10 below shows KXA5226 (183,4 dt/ha) to have produced the highest DMY at par with KXA5233 (183,1 dt /ha) and KXA5243 (181,8 dt/ha) when maize were harvested at the fourth harvest time. Mikado (97,5 dt/ha) produced the lowest yields at the first harvest. An interaction between cultivar and harvest time existed probably as a result of the sharp increase in dry matter yield of the late maturing Mikado at the second harvest time.

Table 4.10: Maize dry matter yield (dt / ha) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	109,0	143,7	152,8	147,9
KXA5226	114,4	147,7	173,2	183,4
KXA5233	120,3	163,2	176,8	183,1
KXA5243	108,0	149,1	173,2	181,8
Mikado	97,5	144,3	169,8	169,9
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		6,9	6,2	13,8

During the first harvest Mikado influenced total average yield negatively because unlike the early maturing Gavott (S250) and the middle late KXA5226 (S 260), KXA5233 (S 270) and KXA5243 (S 290) Mikado was just at the flowering stage while the rest of the cultivars were already at one milk stage or the other.

Maize dry matter content (DMC)

As table 4.11 shows, delaying harvest increased the DMC of all the cultivars but at different rates that reflected their maturity classifications. Gavott (S 250) the earliest and KXA5226 (S 260) attained optimum DMC (28%) already at the second harvest time. KXA5233 (S 270) produced its first optimum DMC (29,6%) at the third harvest time and the middle late cultivar KXA5243 (S 290) could only achieve optimum (31,8%) DMC at the fourth harvest time. An interaction (LSD = 1,6) between cultivar and harvest time was observed .

Table 4.11: Maize dry matter content (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	19,0	28,0	33,4	40,6
KXA5226	16,9	28,0	33,4	40,6
KXA5233	17,1	24,3	29,6	36,7
KXA5243	16,0	21,0	24,5	31,8
Mikado	16,0	19,4	21,8	25,3
		CV	HT	CV*HT
		0,000	0,000	0,000
		LSD (5%)	0,7	1,6

The latest cultivar Mikado (FAO 500) did not attain optimum DMC at any of the four harvest times. The highest DMC (40,6 %) of the experiment was measured in Gavott and KXA5226 when both were harvested at the fourth harvest time. Mikado and KXA5243 produced the lowest DMC (16 %) of this experiment when they were harvested at the first harvest time.

Maize Heights

Figure 4.2 below shows delay in harvest to have no significant ($p = 0,890$) influence on heights of the different maize cultivars. However, the maize cultivars differed significant ($p = 0,000$) in heights among themselves A significant ($p = 0,000$) interaction (LSD = 13,6) between cultivar and harvest was also observed

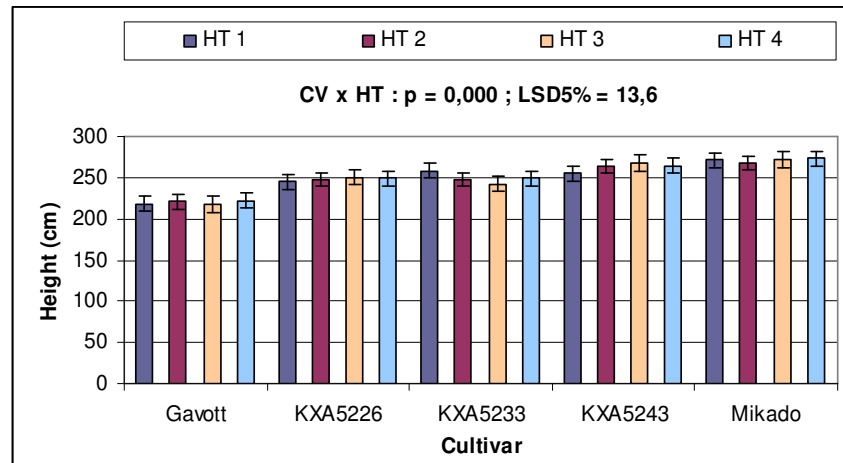


Fig. 4.2: Maize heights according to cultivar and harvest time, Giessen 2005

Mikado produced the tallest (272 cm) plants at par with KXA5243 (264,3 cm) when they were harvested at the fourth harvest time and Gavott had the shortest(216,8 cm) when it was harvested at the third harvest time.

Maize leaf Area index (LAI)

Figure 4.3 shows delaying harvest to have had no significant ($p = 0,300$) effect on the leaf area indexes of the different maize cultivars. The LAIs of the individual cultivars however did differ significantly ($p = 0,000$) from each other.

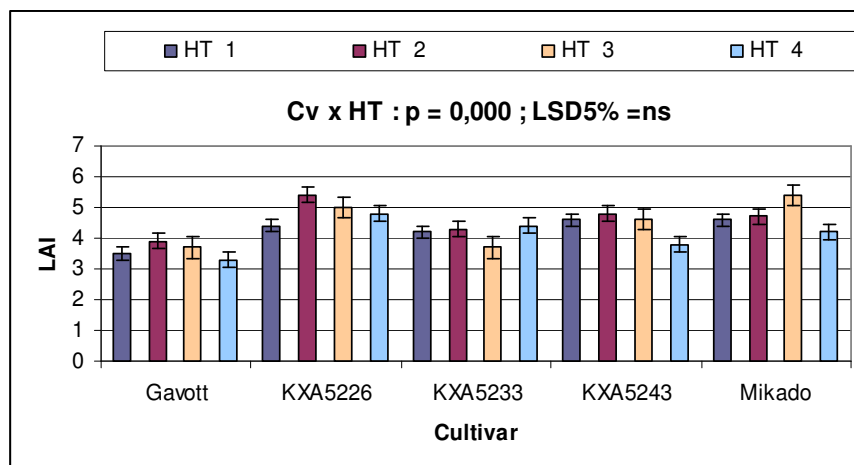


Fig. 4.3: Maize Leaf area index (LAI) according to cultivar and harvest time, Giessen 2005

The highest leaf area index (5,4) was observed with KXA5226 and Mikado at the second and third harvest respectively. Gavott showed the lowest leaf area index (3,3) at the fourth harvest time. There was no significant cultivar harvest interaction for LAI.

4.2.2 NIRS analysis results

Using the new cultivars the same NIRS was used to analyse for the same chemical components that were also analysed for the cultivars in 2004.

Maize crude protein (CP) contents

Table 4.12 below shows that with the exception of Gavott, delaying harvest significantly decrease the crude protein contents of the rest of the maize cultivars in accordance with Wiersma et al (1993). A significant ($p = 0,000$) interaction ($LSD = 0,7$) between cultivar and harvest time was observed.

Table 4.12: Maize crude protein content (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	9,8	8,1	7,6	8,0
KXA5226	10,2	8,4	7,5	6,4
KXA5233	9,5	8,0	8,0	6,3
KXA5243	10,9	8,5	8,1	6,7
Mikado	10,8	8,5	8,4	6,7
		CV	HT	CV*HT
p - value		0,020	0,000	0,000
LSD (5%)		0,4	0,3	0,7

While CP contents of KXA5226 and KXA5243 decreased continuously from first to fourth harvest, CP of KXA5233 and Mikado CP decreased to a plateau at the second and third harvest and further decreased to the fourth. On the other hand CP of Gavott decreased from first to third harvest and tended to increase at the fourth. The highest CP contents were found in KXA5243 (10,9%) at par with Mikado (10,8%) and KXA5226 (10,2%) when they were harvested at the first harvest time. The lowest CP contents were also produced at par by KXA5233 (6,3%), KXA5226 (6,4%), KXA5243 (6,7%) and Mikado (6,7%) when they were harvested at the fourth harvest time.

Maize crude fibre (CF) contents

According to table 4.13 below, delaying harvest decreased the CF contents of all the maize cultivars except in Mikado where CF contents plateau at the second and third harvest. In all cultivars however, the most significant decrease occurred during the transition from first harvest to the second harvest. A significant interaction between cultivar and harvest time was observed probably due to the plateauing of CF observed in Mikado at the second and third harvest.

Table 4.13: Maize crude fibre contents (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	29,3	24,6	22,7	19,7
KXA5226	28,2	24,6	22,7	20,5
KXA5233	28,2	22,9	21,4	20,7
KXA5243	30,2	26,7	25,8	22,4
Mikado	30,6	26,2	26,2	21,3
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		1,0	0,9	1,9

The highest CF contents were measured in Mikado (30,6%) at par with KXA5243 (30,2%) when both were harvested at the first harvest time. The lowest CF contents on the other hand were measured in Gavott (19,7%) at par with KXA5226 (20,5%) when they were harvested at the fourth harvest time.

Maize neutral detergent fibres (NDF)

From table 4.14 delaying harvest can be observed to have produced different patterns of variations in the NDF contents of the different maize cultivars. With the exception of KXA5226, NDF of the rest of the cultivars decreased for every delay in harvest but the only significant decrease was from first to the second harvest. A significant cultivar harvest time interaction was observed probably due to KXA5226 strongly increasing NDF at the second harvest while NDF of the rest of the cultivars were decreasing.

Table 4.14: Maize neutral detergent fibres content (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	67,0	51,1	50,1	49,5
KXA5226	35,7	57,9	53,4	49,4
KXA5233	64,7	55,0	52,3	51,9
KXA5243	68,7	61,9	58,4	52,5
Mikado	69,0	62,0	62,3	51,1
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		1,8	1,6	3,6

KXA5226 showed a very significant increase in NDF between the first (35,7 %) and second (57,9%) harvest. From this second harvest, NDF of KXA5226 decreased like the rest of the cultivars at the third harvest through to the fourth. Mikado (69,0 %) produced the highest NDF contents at par with KXA5243 (68,4 %) and Gavott (67,0 %) when they were harvested at the first harvest time. The lowest (35,7%) NDF contents were measured in KXA5226 at the first harvest.

Maize acid detergent fibre (ADF)

Table 4.15 below shows the impact of delaying harvest on the acid detergent fibres of five different maize cultivars. As can be observed from the table, delaying harvest affected the ADF contents of the different cultivars differently and a cultivar harvest time interactions (LSD = 2,7) was observed. This might have been due to the lack of change in the ADF contents of Gavott at the second harvest time.

Table 4.15: Maize enzyme soluble substances (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	35,5	35,5	23,9	20,9
KXA5226	35,7	28,7	26,5	22,3
KXA5233	34,0	26,4	24,5	22,3
KXA5243	37,6	31,6	30,2	25,9
Mikado	37,9	31,1	30,7	24,8
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		1,4	1,2	2,7

The highest NDF contents were measured in Mikado (37,9%) at par with KXA5243 (37,6 %) when they were harvested at the first harvest time and the lowest in Gavott when it was harvested at the fourth harvest time.

Maize enzyme soluble substances (ELOS)

From table 4.16 below, ELOS values can be observed to be far below the usual average (65%). Delaying harvest however had no significant effects on ELOS of the different maize cultivars. Besides being very low, ELOS variations therefore did not agree with observations of Darby and Lauer (2002) who established that ELOS should decrease by delaying maize harvest. However the ELOS of the individual cultivars did differ significantly ($p = 0,000$). An interaction (LSD = 0,7) between cultivar and harvest time was observed probably at the third harvest when the ELOS of KXA5233 did not change from the value observed at the second harvest.

Table 4.16: Maize enzyme soluble substances (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	9,8	10,2	9,5	10,9
KXA5226	10,8	8,1	8,4	8,0
KXA5233	8,5	8,5	7,6	7,5
KXA5243	8,0	8,1	8,4	8,0
Mikado	6,4	6,3	6,7	6,7
		CV	HT	CV*HT
p -value		0,000	0,080	0,000
LSD (5%)		0,4	ns	0,7

The highest ELOS was measured in Gavott (10,9 %) when it was harvested at the fourth harvest time at par with KXA5226 (10,8 %) when it was harvested at the first harvest time. Mikado (6,7 %) produced the lowest ELOS when it was harvested at the third harvest time.

Maize sugar content

From table 4.17 it can be observed that except for Mikado, delaying harvest decreased the sugar content of all the maize cultivars from first to third harvest when they all produce their specific lowest sugar contents. From the third harvest to the fourth the sugar contents of the individual cultivars again increased.

Table 4.17: Maize sugar contents (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	12,0	11,1	6,1	13,2
KXA5226	14,3	10,9	7,0	12,0
KXA5233	15,0	12,7	7,3	13,2
KXA5243	13,2	13,5	8,1	13,7
Mikado	13,2	17,7	11,8	15,6
		CV	HT	CV*HT
p -value		0,000	0,080	0,000
LSD (5%)		1,1	ns	2,2

Sugar contents of Mikado increased from first harvest (13,2 %) to the second harvest (17,7 %) and decreased (11,8 %) to its lowest level at the third harvest time. From the third harvest sugar content of Mikado again increased (15,6 %) at the fourth

harvest time. The highest sugar content (17,7 %) was produced at the second harvest by Mikado and the lowest (6,1 %) by Gavott at the third harvest. A significant cultivar harvest time interactions observed might have been due to the sharp increase in sugar content shown by Gavott in the transition period from first to second harvest.

Maize starch content

Table 4.18 shows delaying harvest to affect maize starch content in a pattern which is an exact mirror image of the sugar content pattern. Except for Mikado, delaying harvest increased the starch content of the rest of the cultivars to the highest level at the third harvest from where it dropped to the fourth. Increasing starch contents by delaying maize harvest have also been reported by Hunt et al. (1989) but the values of the sugar contents of all the cultivars in this experiment are far above those observed by Ballard et al. (2001) and Thomas et al. (2001).

Table 4.18: Maize starch content (%) according to cultivar and harvest time, Giessen 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	5,3	21,9	28,1	23,3
KXA5226	4,0	15,0	26,3	22,1
KXA5233	3,3	15,1	26,4	21,8
KXA5243	5,1	6,1	17,8	15,2
Mikado	4,7	1,4	11,8	15,2
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		2,5	2,2	5,0

In Mikado starch content decreased from first (4,7 %) to the second (1,4 %) harvest and increased continuously from second through the third to the fourth harvest time. A significant cultivar harvest time interaction (LSD = 5,0) was observed may be due to the sharp drop (1,4%) in sugar content shown by Mikado at the second harvest.

4.2.3 Anaerobic digestion results

The importance of maize inorganic matter and the organic matter contents in anaerobic digestion have been explained above. In the following results organic matter is also referred to as volatile solids and abbreviated VS. Inorganic matter (impurities and mineral salts) though not measured in the thesis is referred to generally as ash content.

Maize organic matter content

By comparing the dry matter yields and the volatile solids (VS) yields of all the maize cultivars presented in table 4.19, one realises that their differences are significantly small. The significance of whole plant silage maize rich in organic matter and the impacts of its lignification to digestibility been highlighted in the literature.

Table 4.19: Maize dry matter yield, dry matter content, volatile solids, biogas yield, methane yield and percentage methane concentrations according to Cultivar and harvest time, Giessen 2005

CV	HT	DMY dt /ha	VS dt/ha	DMC %	Gas nL /kg VS	CH ₄ nL /kg VS	CH ₄ %
Gavott	1	109,0	103,1	19,0	656	384	58,5
Gavott	3	152,8	145,5	33,4	701	392	55,9
Gavott	4	147,9	139,4	40,6	643	375	58,3
KXA5233	1	120,3	112,6	17,1	735	417	56,7
KXA5233	3	176,8	168,4	29,6	764	421	55,1
KXA5233	4	184,0	173,6	36,7	687	384	55,9

DMY-dry matter yield, DMC-dry matter content, VS-volatile solids, nL-norm litre, HT- harvest time, CV-cultivar

Each sample from each selected harvest time was digested over a retention time of twenty one days. The daily specific biogas and methane productivity within these twenty one days depended on the composition of the organic matter content of each sample. Hence the ratio of cell wall (NDF) contents to cell contents. The higher gas productivity observed during the first few days mainly came from the cell contents. As time went on more and more of the organic matter left constituted mainly the cell wall material. Due to the slow digestibility of the cell wall contents the gas curves slowly plateaued. as can be inferred in figures 4.4 to 4.9 below for Gavott and KXA5233. The values shown for each measurement day is a sum of the actual values measured for that day and the values of the preceding measurements. Hence the total biogas and methane productivity of each harvest time is the final value at the end of the curve.

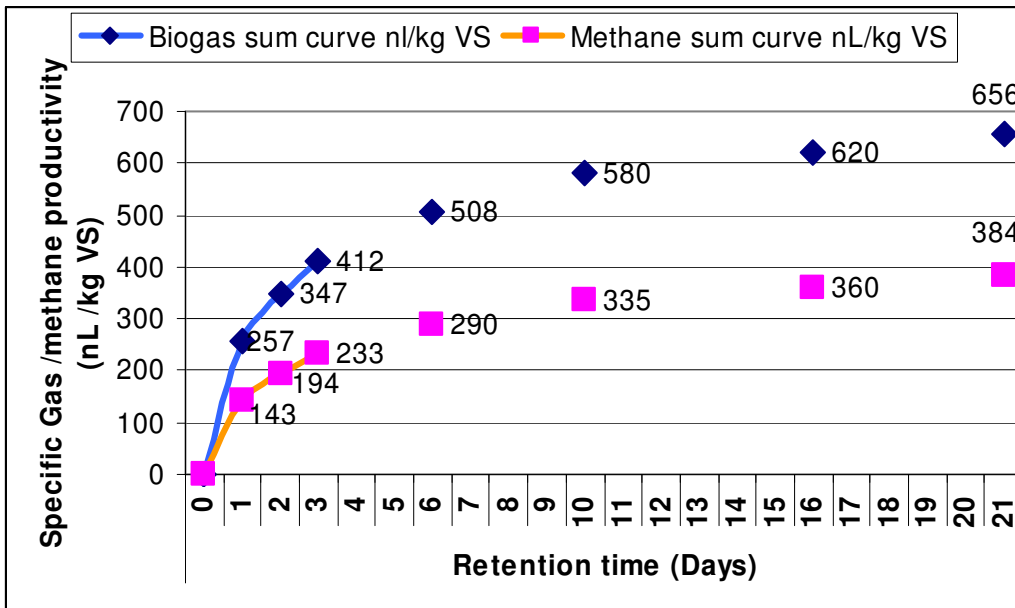


Fig. 4.4: Cumulative curves of biogas and methane yields of Gavott grown in Giessen and harvested at the and first harvest time in 2005

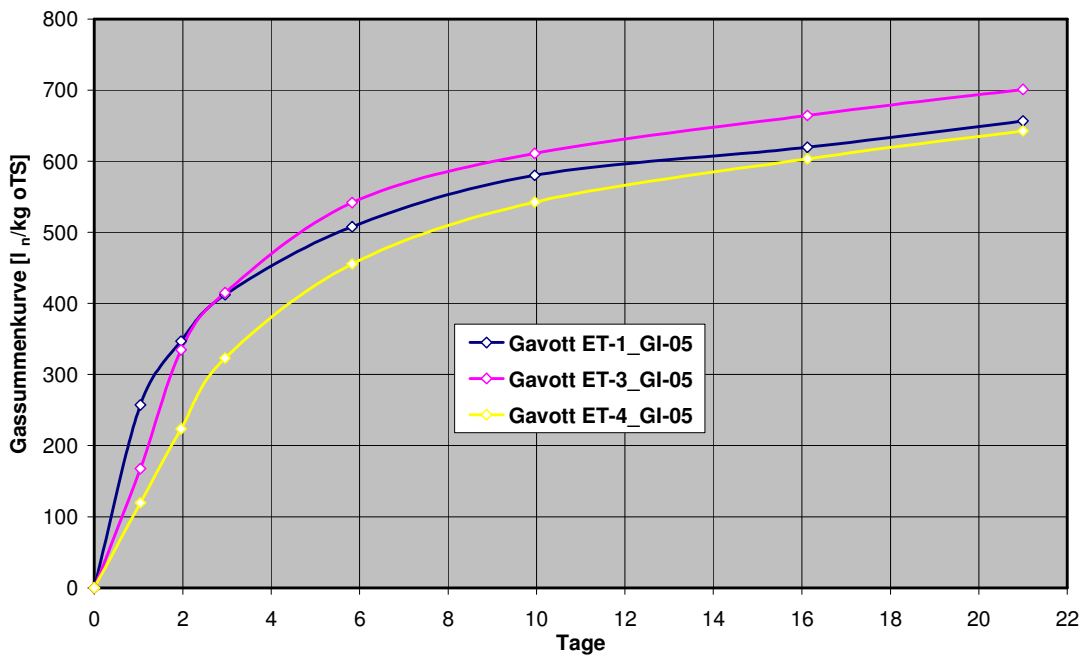


Fig. 4.5: Cumulative curves of biogas yields of Gavott (S 250) according to retention time and harvested at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ;oTS-Volatile solids; GI-Giessen 2005

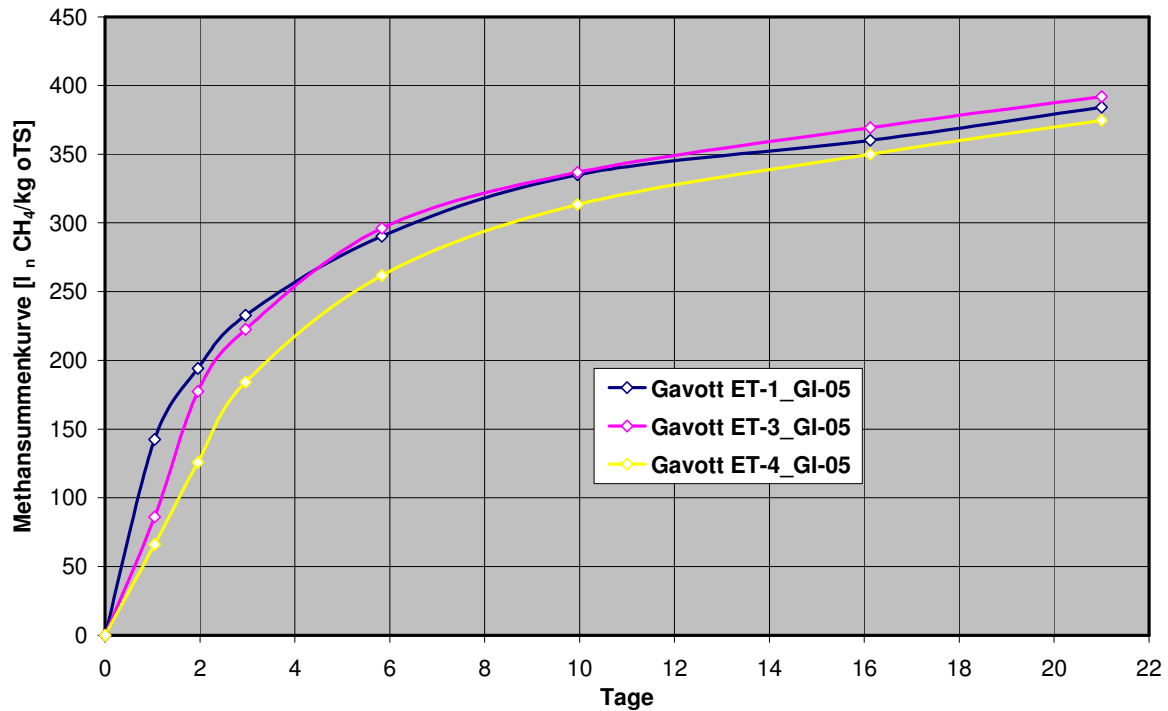


Fig. 4.6: Cumulative curves of methane yields of Gavott (S 250) according to retention time and harvested at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time; oTS-Volatile solids; GI-Giessen 2005

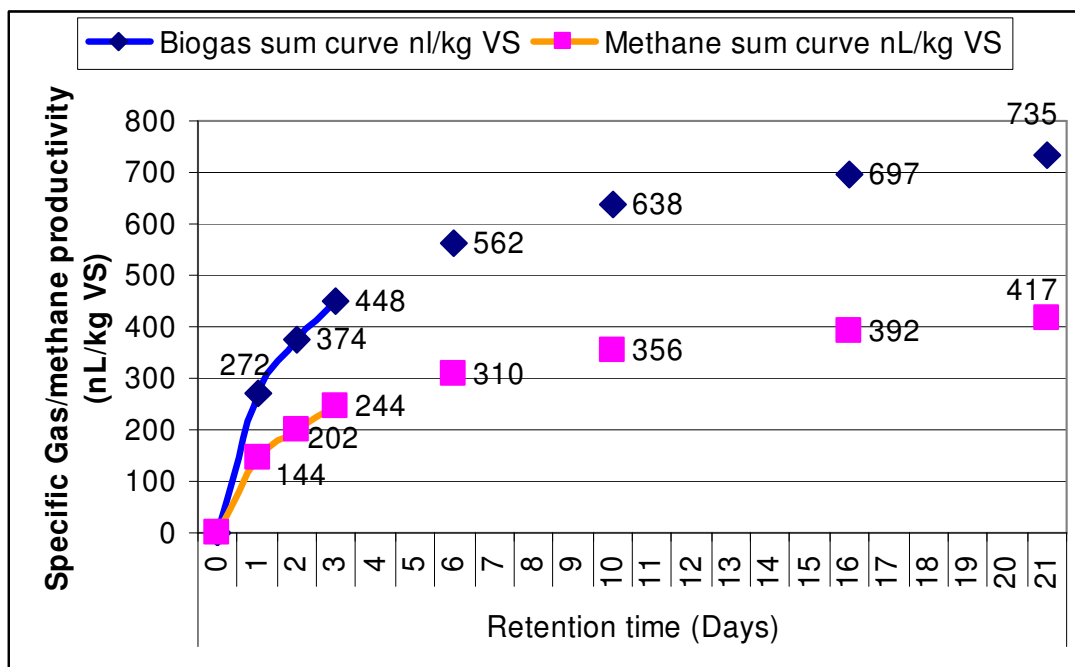


Fig. 4.7: Cumulative curves of biogas and methane yields of KXA5233 grown in Giessen and harvested at the and first harvest time in 2005

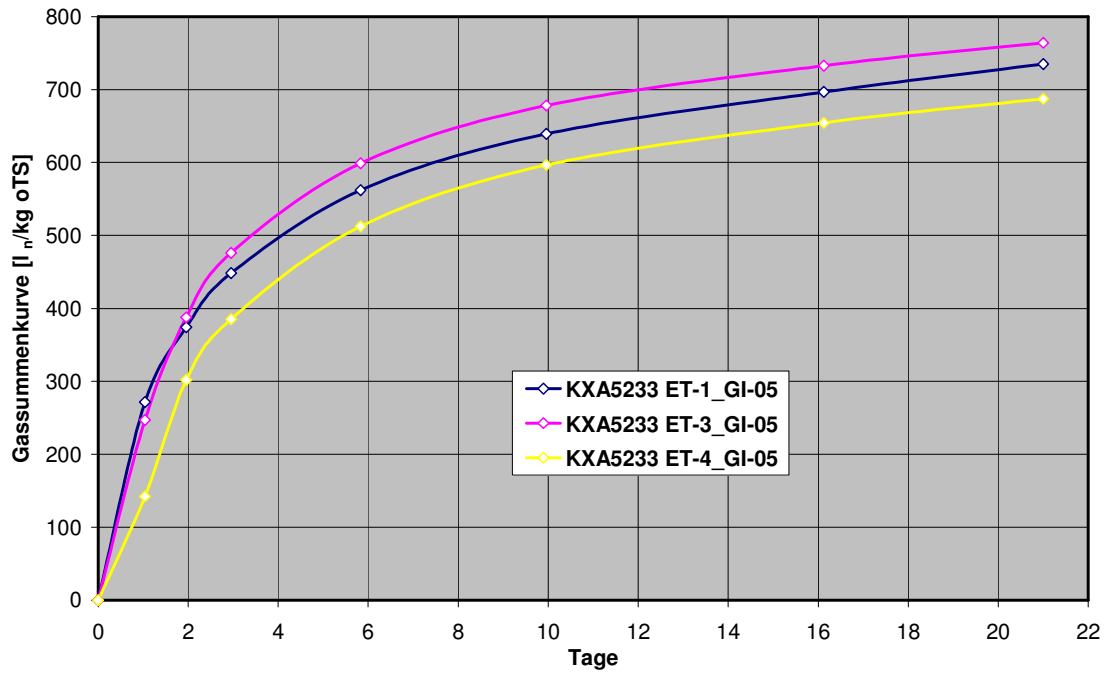


Fig. 4.8: Cumulative curves of biogas yields of KXA5233 (S 270) according to retention time and harvested at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ;oTS-Volatile solids; GI-Giessen2005

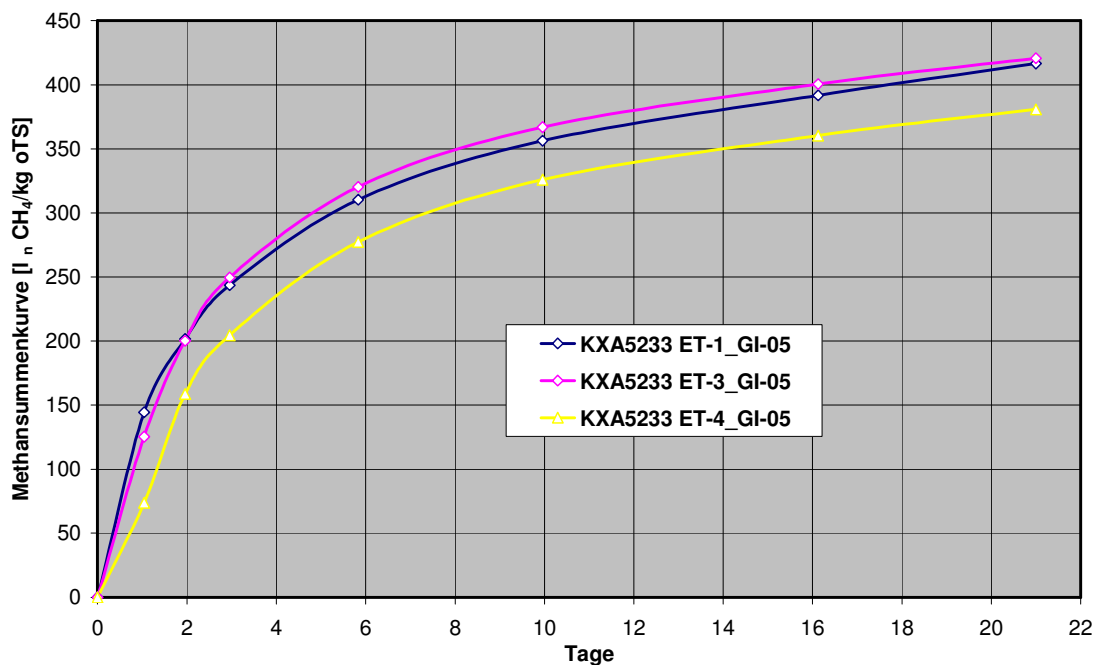


Fig 4.9: Cumulative Curves of methane yields of KXA5233 (S 270) according to retention time and harvested at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time;oTS-Volatile solids; GI-Giessen 2005

Maize dry matter content

The importance of optimum dry matter content in deciding optimum yield and yield quality for any products envisaged has also been mentioned in the preceding literature too. Table 4.19 shows DMC of Gavott and KXA5233 to have increased with delay in harvest and that both cultivars produced optimum DMCs only at the second harvest. How this affects biogas and methane productivity might become clear in the results below.

Maize biogas and methane productivity

Table 4.19 and fig 4.10 below shows maize biogas productivity of both Gavott and KXA5233 increasing from first harvest to the highest value at the third harvest from where a further delay in harvest to the fourth harvest decreased the biogases of both cultivars. The biogas values considered are those at the end of each cumulative curves for each cultivar and harvest time after a retention time of twenty one days.

KXA5233 (S 270) can be observed to have produced higher specific biogas volumes than Gavott (S 250) at each of the three harvest times. The rates of increase and decrease can be seen to be faster in Gavott than in KXA5233.

Methane productivity of both cultivars also increased from first harvest to the highest values at the third harvest from where it dropped with further delay to the fourth harvest.

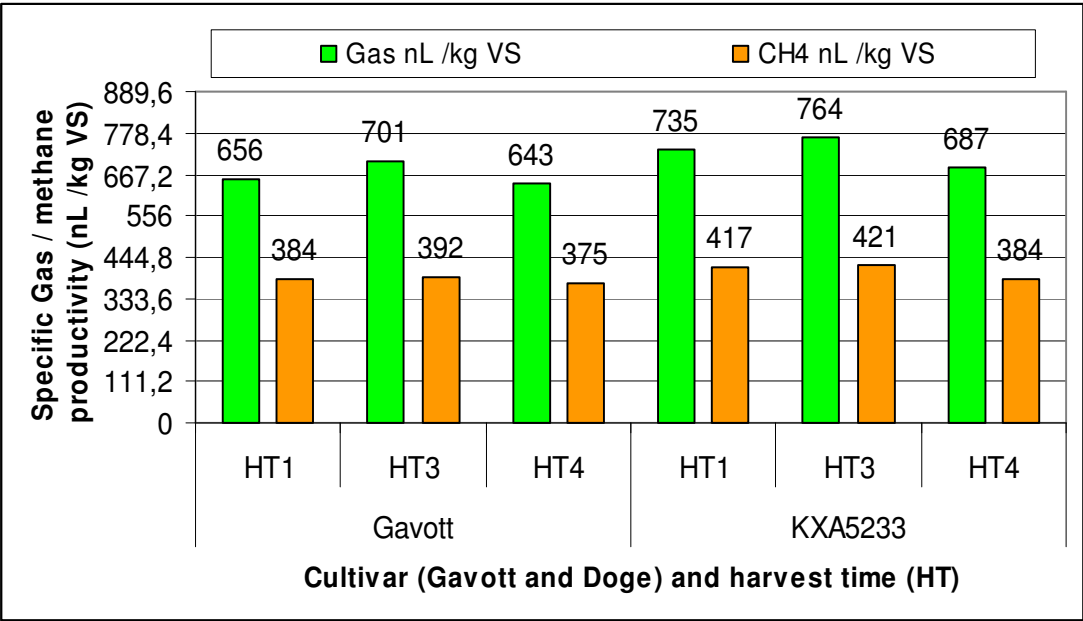


Fig. 4.10: Biogas and methane productivity of Gavott according to harvest time HT1 to HT4 = harvest time 1to harvest time 4, Giessen 2005

Similar to biogas productivity, KXA5233 (S 270) produced the highest specific methane volumes at all the three harvest times than Gavott (S 250) and the rates of increase and decrease are also faster in Gavott than in KXA5233.

4.3 Giessen 2006

In 2006 one field experiment and two laboratory analyses were carried as has been the case in 2004 and 2005. A germplasm of four maize cultivars (Gavott, Atletico, Magitop and Beatus) and two inbred lines (KXA5233 and KXA5243) which for convenience will all be referred to in this thesis as cultivars was used.

4.3.1 Field experiment results

During field experiment dry matter yield (DMY), dry matter content (DMC) heights and leaf area indexes were measured at every harvest time for all the six cultivars used. The cultivars were also exposed to the same growing conditions and also differed mainly in maturity classification as has been the case in 2004 and 2006. They included the middle early Magitop (S240) and Gavott (S 250) and the middle late KX5233 (S 270), KXA5243 (S 290), Atletico (S 280) and Beatus (S 260). Gavott's milk stage again determined the first harvest date for all the cultivars.

Maize dry matter yield (DMY)

Table 4.20 shows every delay in harvest to have steadily increase the dry matter yields of the maize cultivars with the exception of Magitop in which DMY decreased by delaying harvest from third to the fourth. All the variations in yield were significant but a cultivar harvest time interaction was observed. This might have been due to the very sharp increase in yield shown by KXA5243 at the fourth harvest relative to the others.

Table 4.20: Maize dry matter yield (dt / ha) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	109,5	152,4	173,5	199,5
Atletico	131,2	159,8	203,2	265,5
Magitop	134,1	180,0	213,6	213,5
KXA5233	136,0	156,5	193,1	248,6
KXA5243	119,7	151,5	187,5	283,4
Beatus	136,6	173,7	199,2	241,5
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	14,4	11,8	28,8

It can also be inferred that KXA5243 (283,4 dt/ha) produced the highest dry matter yield at par with Atletico(265,5 dt /ha) when both were harvested at the fourth harvest time. The lowest DMY was measured in Gavott when it was harvested at the first harvest time.

Maize dry matter content (DMC)

Table 4.21 presents the results of maize DMC. With the exception of Atletico, each delay in harvest increased the dry matter content of the rest of the cultivars significantly. The highest DMC (39,7%) was measured in Atletico when it was harvested at the fourth harvest and the lowest (18,7) in KXA5243 at par with KXA5233 (19,8%) and Beatus (20,5%) when they were harvested at the first harvest time.

Table 4.21: Maize dry matter content (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	21,2	25,2	31,6	35,9
Atletico	35,9	24,0	30,5	39,7
Magitop	21,7	27,6	32,8	36,7
KXA5233	19,8	22,0	29,5	35,9
KXA5243	18,7	20,4	25,5	35,9
Beatus	20,5	25,8	31,4	38,4
		CV	HT	CV*HT
		0,000	0,000	0,000
		LSD (5%)	1,2	3,0

Atletico showed an abnormal behaviour by producing a very high DMC (35,9 %) at the first harvest and then dropping to 24,0% at the second from where it increased through the third harvest to the fourth. The very high DMC of Atletico at the first harvest might be the cause of the Cultivar harvest time interaction (LSD = 3,0) observed. With the exception of KXA5243, all the other cultivars were at optimum DMC at the third harvest time.

Maize heights

Maize heights as presented in figure 4.7 shows maize cultivars differing in height among themselves ($p = 0,020$) as well as between the harvest times ($p = 0,000$). A significant ($p = 0,000$) cultivar harvest time was also observed. All the plants were above 200 cm but the tallest (325,5cm) plants were measured in KXA5243 at par with KXA5233 (317,3cm) and Atletico (316,0cm) at the fourth harvest time.

Maize height decreased from first to second harvest and increased from second steadily to the fourth for all cultivars.

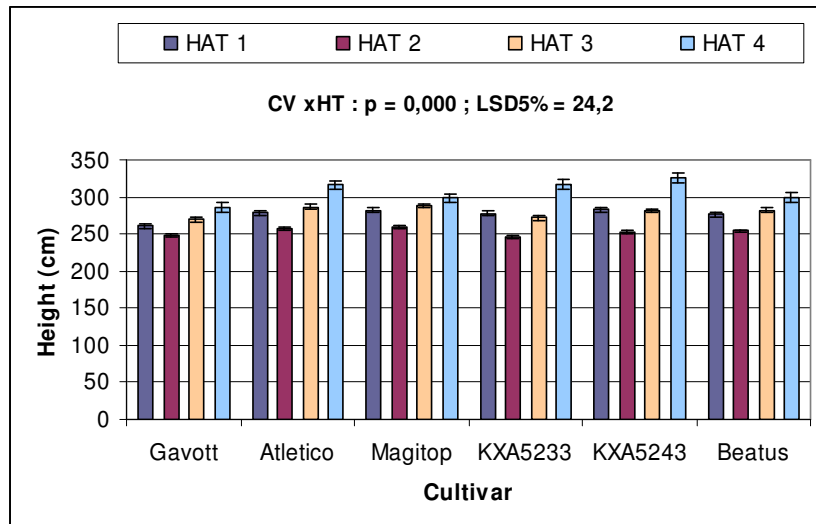


Fig. 4.11: Maize plant height (cm) according to cultivar and harvest time, Giessen 2006

Due to lack of significant differences between the shorter heights, it suffices to say that the shortest maize plants were recorded in all cultivars when they were harvested at the second harvest.

Maize leaf area index (LAI)

Figure 4.12 below shows maize leaf area indexes to have insignificantly varied among the cultivars ($P = 0,970$) as well as between the harvest times ($p = 0,320$). Again no interactions ($p = 0,970$) between cultivar and harvest time was observed.

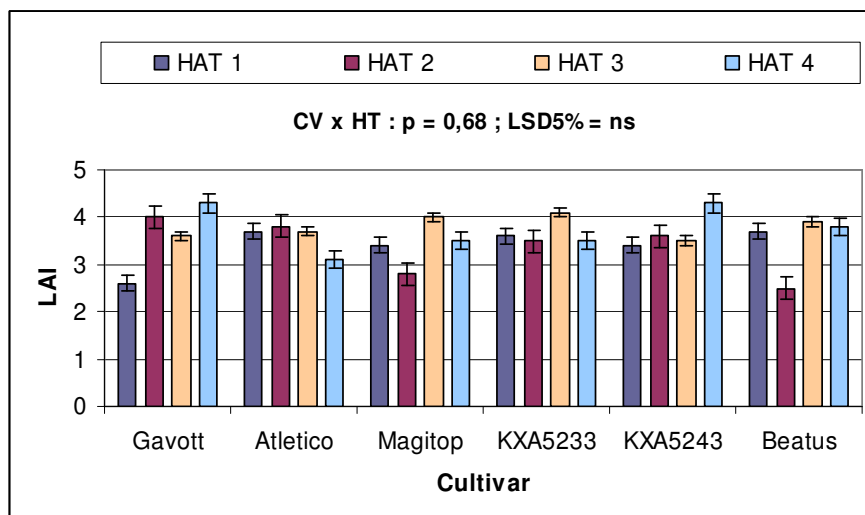


Fig. 4.12: Maize Leaf area index (LAI) according to cultivar and harvest time, Giessen 2006

In Gavott and KXA5243 LAI increased from first to second harvest, decreased at the third and again increased at the fourth. Magitop, KXA5233, and Beatus reacted to delaying harvest by decreasing LAI from the first to the second harvest, increasing to the third and again decreasing at the fourth.

4.3.2 NIRS analysis results

Maize samples were analysed for the same chemical components using the same method as has been used in the preceding experiments in 2004 and 2005 in Giessen as well as Gross-Gerau.

Maize crude protein (CP) content

The results presented in table 4.22 shows CP of the six different maize cultivars to have reacted differently to each delay in harvest. While no significant differences ($p = 0,060$) among the cultivars could be detected, statistical evaluation showed CP of the individual cultivars to vary significantly ($p = 0,000$) between the harvest times. A significant ($p = 0,000$) interaction ($LSD = 0,9$) between cultivar and harvest time was also observed. With the exception of Beatus CP of all the cultivars decreased from first to second harvest and increased at the third. From the third harvest to the fourth CP increased in Gavott and KXA5233 and decreased in Atletico, Magitop and KXA5243. Beatus was the only cultivar in which CP increased from first to second harvest, decreased at the third and slightly increased at the fourth.

Table 4.22: Maize crude protein content (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	8,6	7,8	8,2	8,5
Atletico	8,9	7,5	7,8	7,3
Magitop	8,3	7,4	7,7	6,8
KXA5233	8,5	6,9	7,5	7,7
KXA5243	8,9	7,4	7,8	7,0
Beatus	8,0	9,0	7,5	7,6
		CV	HT	CV*HT
p - value		0,060	0,000	0,000
LSD (5%)		ns	0,4	0,9

This unique behaviour of Beatus at the first harvest must have been the cause of the interactions observed between cultivar and harvest time. Crude proteins of all the cultivars were very similar (6,8 – 9%) across the harvest times. Crude proteins in this range have also been observed by Given et al (1995) and Offer et al (1996)

Maize crude fibre (CF) content

By referring to table 4.23, one recognises that delaying harvest significantly ($p = 0,000$) influenced maize CF among the cultivars as well as between the harvest times for each cultivar. A significant cultivar harvest time interaction ($LSD = 4,7$) was also observed. The crude fibres contents of all the cultivars were also very similar across the harvest times. All the cultivars produced their highest CF when they were

harvested at the first harvest time. With the exception of Magitop (S 240) CF contents of the rest of the cultivars were very similar at this first harvest.

Table 4.23: Maize crude fibre contents (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	31,8	21,5	20,7	15,4
Atletico	31,8	20,5	21,7	20,0
Magitop	29,3	19,0	19,9	20,7
KXA5233	32,6	23,0	23,2	18,0
KXA5243	32,6	25,1	25,5	25,1
Beatus	32,4	20,6	21,3	18,1
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	1,5	1,0	4,7

The lowest CF (15,4%) contents was measured in Gavott when it was harvested at the fourth harvest time. Delaying harvest did not affect CF of the cultivars in any common pattern.

Maize neutral detergent fibres (NDF) content

It can be inferred by comparing table 4.23 and 4.24 that delaying harvest affected maize NDF in the same pattern as it did for CF. The variations were significant among the cultivars ($p = 0,000$) as well as between the harvest times ($p = 0,000$) just as was observed with CF. Similarly a significant ($p = 0,000$) interaction (LSD = 3,9) also occurred between cultivar and harvest time. NDF of Gavott and KXA5243 decreased with each delay in harvest and NDF of the rest of the cultivars decreased from first to second harvest and increased from there on to the fourth harvest

Table 4.24: Maize neutral detergent fibres content (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	66,8	50,8	49,2	40,1
Atletico	68,1	48,7	50,4	47,8
Magitop	62,5	45,6	46,5	48,2
KXA5233	68,4	52,4	52,5	44,1
KXA5243	69,7	56,2	54,6	54,3
Beatus	66,6	48,6	49,1	44,3
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		2,0	1,6	3,9

The highest NDF were measured in all the cultivars except Magitop when they were harvested at the first harvest time. The lowest NDF was found in Gavott when it was harvested at the fourth harvest time. The neutral detergent fibres of all the cultivars were above in the range observed by Given et al (1995), Offer et al (1996) and Ballard et al (2001).

Maize acid detergent fibres (ADF) content

Table 4.25 also shows delaying harvest to influence maize ADF in the same pattern as CF, and NDF. Variations were also statistically shown to be significant among cultivars ($p = 0,000$) as well as between the harvest times ($p = 0,000$). Similar to observations made with CF and NDF, a significant ($p = 0,000$) interaction ($LSD = 3,2$) between cultivar and harvest time was also observed for ADF.

Table 4.25: Maize acid detergent fibres content (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	39,7	25,4	24,4	20,6
Atletico	39,9	24,8	25,7	23,8
Magitop	35,7	22,8	23,9	24,6
KXA5233	40,7	27,0	27,3	21,1
KXA5243	41,1	30,2	30,3	30,0
Beatus	38,9	26,4	25,8	21,7
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		1,6	1,3	3,2

The values for each cultivar were largely in the range also observed by Ballard et al (2001). The values among the cultivars were also very similar across the harvest times.

Maize cell wall digestibility (ELOS)

Results of maize ELOS as presented in table 4.26 shows delaying harvest to increase ELOS for all cultivars from first to second harvest from where a further delay decreased ELOS at the third harvest also for all Cultivars. Delaying harvest from third to fourth induced different patterns of variation on ELOS of the different cultivars.

Table 4.26: Maize enzyme soluble organic substances (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	46,4	66,7	64,1	79,5
Atletico	47,2	68,2	63,8	64,9
Magitop	52,1	70,8	67,1	64,7
KXA5233	46,4	66,1	62,2	68,1
KXA5243	45,9	61,8	59,4	57,7
Beatus	47,4	67,9	63,7	67,4
		CV	HT	CV*HT
P - Value		0,000	0,000	0,000
LSD (5%)		1,7	1,4	3,5

With the exception of Magitop and KXA5243, where ELOS further decreased from third to the fourth harvest, a further delay in harvest increased ELOS in the rest of the cultivars with Gavott showing the most significant increase. The ability of middle early cultivars to show high cell wall and organic matter digestibility higher than the late or middle late cultivars has been reported by Barrière et al. 2003 and Barrière et al.1992. All the variations were statistically significant ($p = 0,000$) among the six cultivars as well as between the harvest times for each cultivar. Also a significant ($p = 0,000$) interaction ($LSD = 3,5$) occurred between cultivar and harvest time.

Maize sugar content

From table 4.27, it can be observed that delaying harvest even though statistically produced significant (0,000) differences in the sugar contents of each maize cultivar, the patterns of changes were not common for all the cultivars except the observation that sugar content surged very highly in all the cultivars at the second harvest. From this very significantly high sugar contents at the second harvest, any further delay in harvest decreased sugar contents in all the cultivars with the exception of Magitop (S 240) where sugar content decreased at the third harvest and increased at the fourth.

Table 4.27: Maize sugar content (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	9,7	18,4	9,7	7,5
Atletico	10,2	16,9	9,3	9,0
Magitop	10,5	16,1	9,3	11,0
KXA5233	10,2	20,2	12,0	9,0
KXA5243	11,5	19,6	10,1	8,4
Beatus	9,3	16,6	8,3	7,0
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	1,1	0,9	2,1

A significant interaction (LSD = 2,1) occurred between cultivar and harvest time probably at the second harvest at which all cultivars showed extremely very high sugar contents.

Maize starch content

Result of maize starch contents are presented in table 4.33 and show each delay in harvest to increase the starch contents of Gavott, Atletico, and Beatus. Increasing sugar content by delaying harvest of whole plant silage maize has also been reported by many scientists like Darby and Lauer (2002), Wiersma et al. (1993), Ganoe and Roth (1992), Cammel et al. (2000) and Cox and Cherney (2001).

This expectedly normal behaviour of maize starch content with advancing maturity was not observed in Magitop, KXA5233 and KXA5243. In Magitop delaying harvest decreased starch content only from first to third harvest from where it decreased at the fourth. In KXA5233 and KXA5243 on the other hand delaying harvest decreased starch contents from first to second harvest from where further delays increased starch contents right through to the fourth harvest.

Table 4.28: Maize starch content (%) according to cultivar and harvest time, Giessen 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	5,1	8,0	23,5	36,5
Atletico	6,2	14,0	24,1	29,5
Magitop	8,0	19,0	27,6	24,3
KXA5233	4,8	3,9	16,8	30,9
KXA5243	5,9	1,3	16,1	19,6
Beatus	5,3	13,4	26,6	33,3
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		3,4	2,8	6,7

A cultivar harvest time interaction observed may have been due to the very low sugar contents measured in KXA5243 at the second harvest time.

4.3.3 Anaerobic digestion results

With the exception of KXA5243 (DMC = 25,5 %), all the maize cultivars attained optimum DMCs first at the third harvest time. For this reason maize samples from all the cultivars (including KXA5243) were selected from the third harvest for anaerobic digestion analysis. Using this third harvest the impacts of cultivar on methane and biogas productivity could be evaluated. By adding samples of Atletico and KXA5243 from the fourth harvest, the impacts of harvest time could also be evaluated.

Maize organic matter (volatile solids –VS) content

From table 4.29 very insignificant differences between dry matter yield and volatile solids yields can be observed. These observations points to whole maize silage rich in organic matter than inorganic (ash content) and has previously been explained.

The same as in 2004 and 2005, each sample from each selected harvest time was digested over a retention time of twenty one days. The specific biogas productivity within these twenty one days as usual depended on the organic matter content of each sample and decreased as time went on due to exhaustion of cell substances and overabundance of cell wall contents. Biogas and methane productivity dynamics within the twenty one days retention time has been illustrated below (figures 4.13, 4.14 and 4.15) for Magitop (S240), Gavott (S 250) and KXA5243 (S290).

Table 4.29: Maize dry matter yield, dry matter content, volatile solids, biogas yield, methane yield and percentage methane concentrations according to cultivar and harvest time, Giessen 2006

CV	HT	DMY dt /ha	VS dt/ha	DMC %	Gas nL /kg VS	CH ₄ nL /kg VS	CH ₄ %
Gavott	3	173,6	165,6	31,6	625	367	58,7
KXA5233	3	193,0	184,7	29,5	614	316	51,5
KXA5243	3	187,5	179,3	25,5	671	390	58,1
KXA5243	4	283,4	270,5	35,9	654	374	57,2
Atletico	3	203,2	194,4	30,5	678	380	56,1
Atletico	4	265,5	252,8	39,7	576	345	59,9
Beatus	3	199,2	190,6	31,4	646	372	57,6
Magitop	3	213,7	205,1	32,8	444	237	53,4

DMY-dry matter yield, DMC-dry matter content, VS-volatile solids, nL-norm litre, HT- harvest time, CV-cultivar.

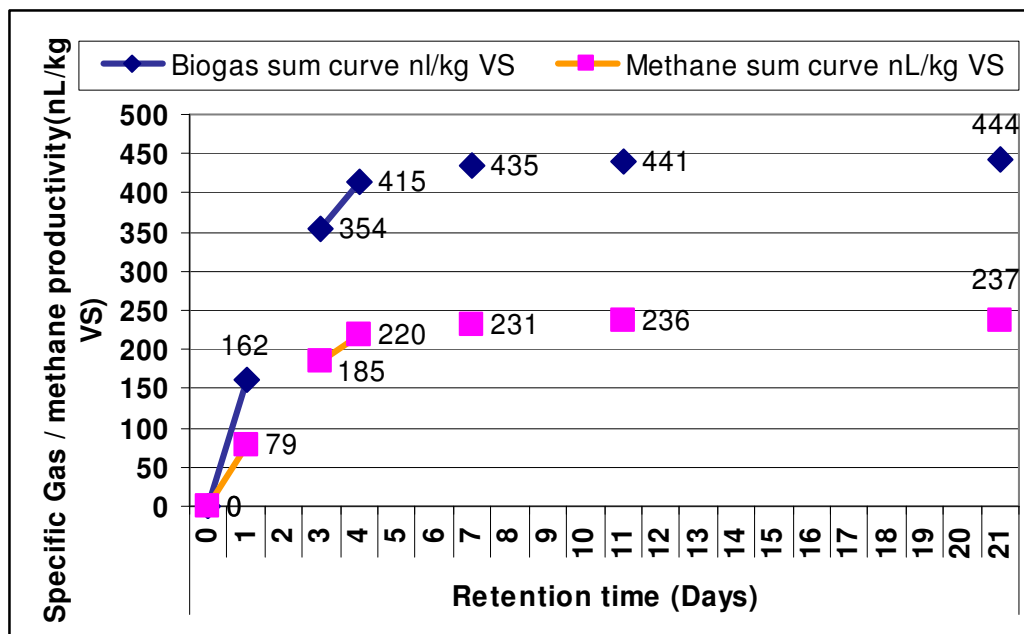


Fig. 4.13: Cumulative curves of biogas and methane yields of Magitop (S240) grown in Giessen and harvested at the third harvest time in 2006

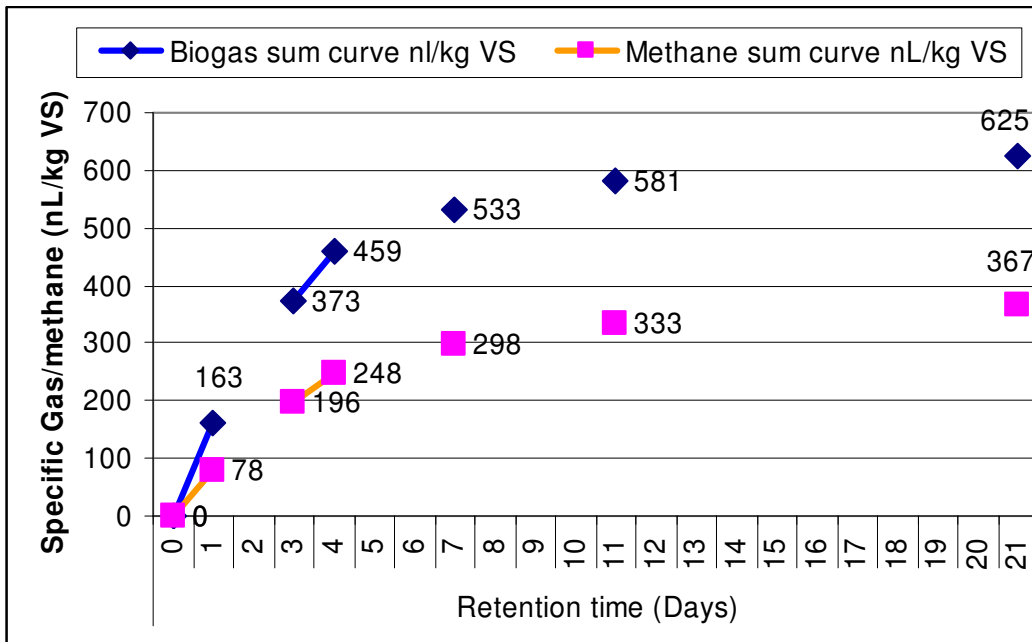


Fig. 4.14: Cumulative curves of biogas and methane yields of Gavott (S250) grown in Giessen and harvested at the and first harvest time in 2006

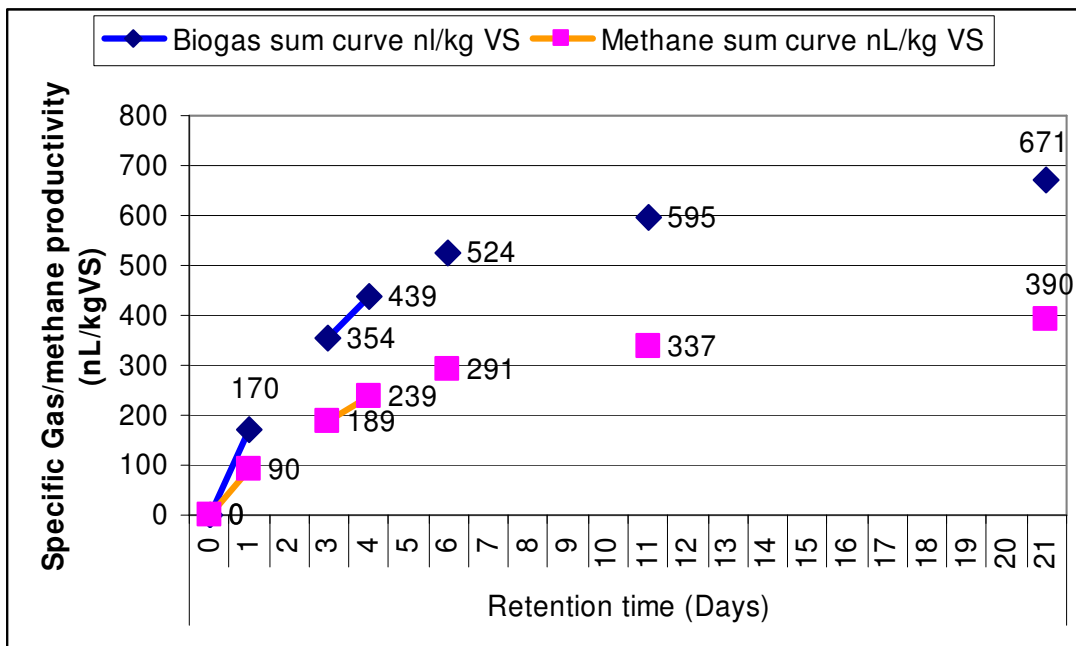


Fig 4.15: Cumulative curves of biogas and methane yields of KXA5243 (S 290) grown in Giessen and harvested at the and first harvest time in 2006

Maize dry matter content

The importance of optimum dry matter content in deciding optimum yield and yield quality has also been mentioned in the preceding literature too. Table 4.29 shows that with the exception of Atletico harvested at the fourth harvest time all the other

samples were within the conventional optimum. How this affects biogas and methane productivity might become clear in the results below.

Maize biogas and methane productivity

From table 4.29 maize biogas productivity from samples selected from the third harvest time can be compared. These comparisons shows Magitop (S 240) producing the least specific biogas volume (444 nL/kg VS). KXA5233 (S 270) produced 614 nL /kg VS and Gavott (S 250) produced 625nl/kg VS. Atletico (S 280) competed very strongly with KXA5243 (S 290) and Beatus (S 260) in producing the highest specific biogas among the cultivars. The biogas productivity seem to depend on maturity class. This is clear as the cultivars Gavott (S250), Beatus (S 260), KXA5233 (S270),Atletico (S 280) and KXA5243 (S 290) all belonging to the middle late maturity class had produced very similar volumes (614-678nl) of biogases compared with 444nl produced by the early cultivar Magitop.

KXA5233 (S 270) produced 614 nL /kg VS and Gavott (S 250) produced 625nl/kg VS. Atletico (S 280) competed very strongly with KXA5243 (S 290) and Beatus (S 260) in producing the highest specific biogas among the cultivars.

Specific methane volume productivity followed the same trend for each cultivar as did biogas (infer table 4.29 and figure 4.16). The volumetric methane concentrations of the cultivars are also shown to depend on maturity class in the same way as did biogas. Hence early maturing cultivars (Magitop S 240) were observed to produce lower specific methane volumes (237 nLCH₄/kg VS) compared with late maturing cultivars (KXA5243 S 290 producing 390 nLCH₄/kg VS)

The impact of harvest time on methane and biogas productivity of the different cultivars was best judged by comparing Atletico and KXA5243. Fig 4.16 below shows Biogas to decrease from third to fourth harvest in both KXA5243 and Atletico. The decrease is slower in KXA5243 than in Atletico. Methane productivity can also be observed to have also decreased with delay in harvest (from third to fourth) for KXA5243 as well as Atletico. The rate of decrease was also faster for Gavott than for KXA5243.

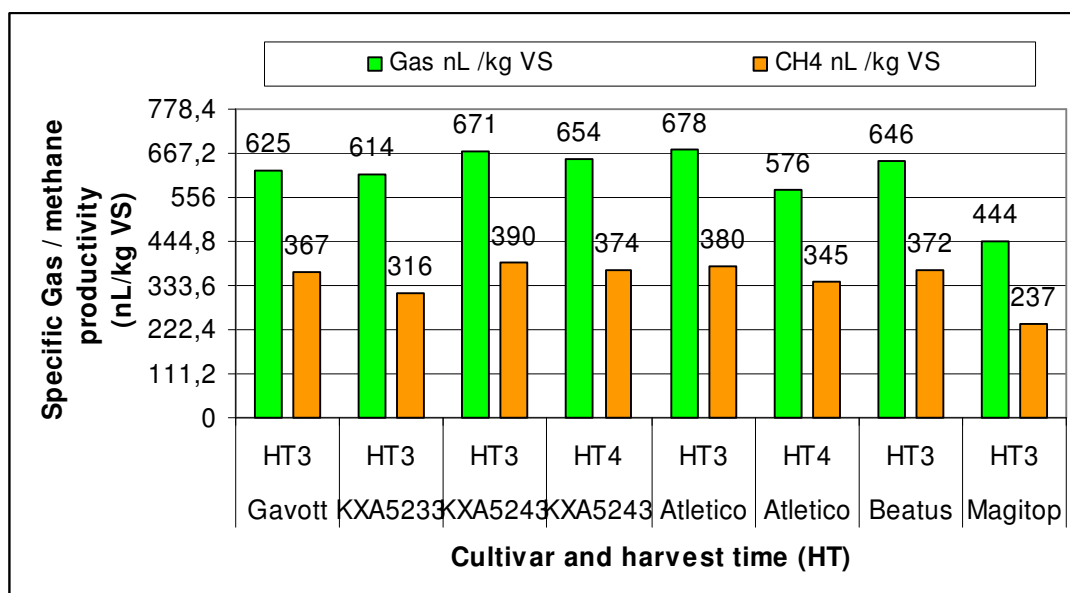


Fig. 4.16: Maize biogas and methane productivity according to cultivar and harvest time, Giessen 2006

4.4 Gross-Gerau 2004

In 2004 one field experiment was carried out using the same germplasm as those used in the 2004 experiments in Giessen. Members of the germplasm are also for convenience referred to here as cultivars. Samples from each cultivar were taken to Giessen for laboratory analysis.

4.4.1 Field experiment results

During field experiment in Gross-Gerau, dry matter yield (DMY), dry matter content (DMC) and heights were measured at every harvest time for all the four cultivars used. The cultivars were also exposed to the same conditions, but Gross-Gerau is different from Giessen both in climate and soil conditions.

Maize dry matter yield (DMY)

According to table 4.30 delaying harvest did not produce the same pattern of variation in DMY of the different cultivars as was the case in Giessen. Dry matter yields of all the cultivars increased with every delay in harvest from first to third harvest only. From the third harvest DMY decreased or increased to the fourth harvest. A significant ($p = 0,000$) interaction (LSD 0 10,6) between cultivar and harvest time was observed probably due to the sharp increase in yield produced by Doge at the fourth harvest time compared with the rest of the cultivars.

Table 4.30: Maize dry matter yield (dt / ha) according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	118,0	145,3	158,8	149,2
KX2352	125,1	163,1	170,3	175,7
Vitalina	125,9	164,5	172,2	172,0
Doge	112,7	148,9	171,9	182,9
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		5,3	5,3	10,6

The highest DMY (182,9 dt /ha) was measured in Doge when it was harvested at the fourth harvest time and the lowest DMY (112,7 dt /ha) was also measured in Doge during the first harvest time. Doge (FAO 700) is a very late cultivar compared with the rest and so inherently had the potentials to add biomass at late harvesting periods when the early and middle late cultivars are experiencing senescence.

Maize dry matter content

From table 4.31, the different maize cultivars can be seen to react to delay harvest by increasing dry matter content. The different cultivars produced optimum ($28\% \leq \text{DMC} \leq 35\%$) dry matter contents at different harvest times as a result of differences in their maturity classification. Gavott expectedly achieved a dry matter content of 28,3% at the second harvest earlier than the rest of the cultivars.

Optimum dry matter contents of the middle late Cultivars KX2352 (S 270) and Vitalina (S 280) were attained at the third harvest. Doge achieved optimum DMC of 30% at the fourth harvest .This was unlike in Giessen where Doge's DMC could not reach optimum at any of the four harvest times. Being a late maturing cultivar, Doge requires more temperature sum to complete its phenology. Gross-Gerau is warmer than Giessen and certainly allowed a quick accumulation of the necessary temperature sum than could be achieved in Giessen.

Table 4.31: Maize dry matter content according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	23,5	28,3	35,1	43,3
KX2352	21,7	26,6	33,7	43,4
Vitalina	20,9	26,6	32,0	41,0
Doge	17,7	19,9	23,1	30,0
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,6	0,6	1,2

The highest DMC was measured KX2352 (43,4 %) at par with Gavott (43,3 %) and Vitalina (41,0 %) when they were harvested at the fourth harvest time. Doge produced the lowest (17,7 %) when it was harvested at the first harvest time. An interaction (LSD 1,2) between cultivar and harvest time for DMC was observed.

Maize height (stem length-SL)

According to fig 4.17 delaying harvest did not produce any significant change in heights of maize cultivars. Significant (p = 0,000) height differences however existed among the cultivars.

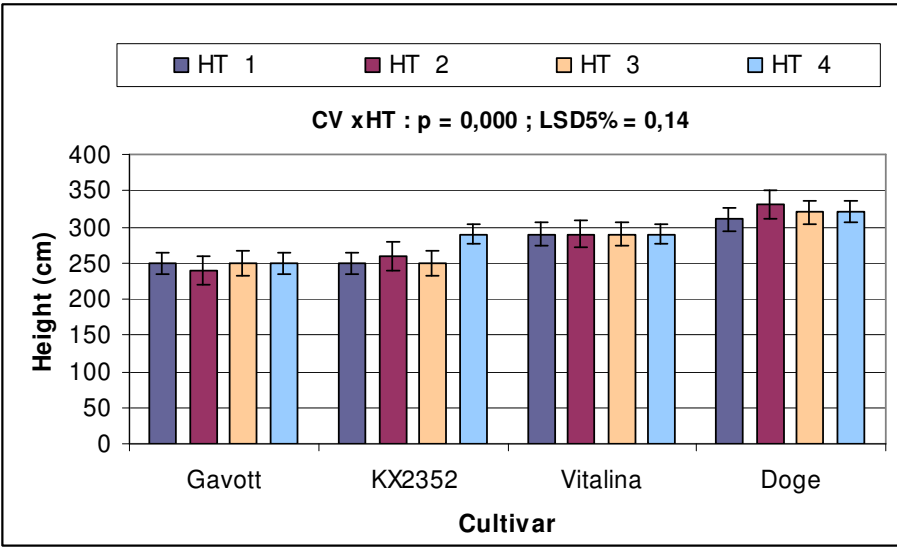


Fig. 4.17: Maize plant height according to cultivar and harvest time, Gross-Gerau 2004

Doge had the tallest (330 cm) plants when it was harvested at second harvest time and Gavott the shortest (240 cm) when it was also harvested at the same second harvest. A significant interaction between cultivar and harvest time was observed probably due to KX2352's rapid increase in height at the fourth harvest time.

4.4.2 NIRS analysis results

Samples of maize grown in Gross-Gerau were analysed for the same chemical components as those samples from Giessen. The results and suitable comments are presented in tables below in tables

Maize crude protein (CP) contents

From table 4.32 delaying harvest decreased the crude protein contents of all cultivars from first to third harvest. A significant interaction (LSD = 0,2) between cultivar and harvest time was observed. From the third harvest to the fourth CP plateau for Gavott, KX2352 and Vitalina but increased slightly for Doge.

Table 4.32: Maize crude protein content according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	6,7	6,2	5,7	5,7
KX2352	6,7	6,2	5,8	5,8
Vitalina	6,2	6,0	5,7	5,7
Doge	6,4	6,0	5,5	5,6
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,1	0,1	0,2

The highest CP (6,7 %) was observed in Gavott and KX2352 when both were harvested at the first harvest time. Doge produced the lowest (5,5 %) CP when it was harvested at the third harvest time. CP were below the averages observed by Darby and Lauer (2002).

Maize crude fibre content

Crude fibre contents of all cultivars decreased with every delay in harvest as shown in table 4.33 below. An interaction (LSD = 0,5) between cultivar and harvest time was also observed. The most significant decrease was between the first and the second harvest for each cultivar.

Table 4.33: Maize crude fibre contents according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	23,4	18,5	17,3	15,9
KX2352	24,5	18,9	17,3	15,3
Vitalina	26,2	19,7	17,6	15,9
Doge	27,3	20,5	18,9	17,0
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,3	0,3	0,5

The highest CF content (27,3 %) was found in Doge at par with Vitalina (26,2 %) when they were both harvested at the second harvest time. The lowest (15,3 %) was measured in KX2352 when it was harvested at the fourth harvest time.

Maize neutral detergent fibres (NDF)

As shown in table 4.34 below, delaying harvest decreased maize's NDF of all cultivars in the same pattern as it did to CF. Hence NDF of all the cultivars decreased with each delay in harvest. NDF values of the cultivars were very similar across harvest times and seemed to depend on maturity class. There was also a significant interaction (LSD = 0,3) between cultivar and harvest time.

Table 4.34: Maize neutral detergent fibres content according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	51,7	41,3	39,3	37,4
KX2352	54,3	41,8	39,5	36,7
Vitalina	56,1	42,5	39,9	37,7
Doge	57,8	44,8	41,9	39,3
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,4	0,4	0,3

The highest NDF content (57,8 %) were measured in Doge when it was harvested at the first harvest time and the lowest (36,7 %) was measured in KX2352 at the fourth harvest time.

Maize acid detergent fibres (ADF)

Table 4.35 shows ADF of all cultivars to also have decreased with every delay in harvest for all cultivars in the same pattern as did CF and NDF. A significant interaction (LSD = 0,7) between cultivar and harvest time was also observed. Doge produced the highest (33,0%) ADF at the first harvest time and the lowest ADF was measured in KX2352 (19,2 %) at the fourth harvest time.

Table 4.35: Maize acid detergent fibres content according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	27,8	22,4	20,8	19,9
KX2352	29,3	22,8	21,0	19,2
Vitalina	31,6	23,3	21,4	19,8
Doge	33,0	24,8	22,9	21,1
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,3	0,3	0,7

The lowest ADF was measured in KX2352 (19,2 %) at the fourth harvest time. Like NDF, ADF values of the cultivars were similar across harvest times and in the range observed by Thomas et al. (2001).

Maize in vitro digestibility (ELOS)

Maize ELOS increased with delay in harvest for all the cultivars as can be seen in table 4.36. A significant interaction between cultivar and harvest time was observed. The most significant increase for each cultivar was from the first harvest to the second. While KX2352 produced the highest (74,1 %) ELOS at the fourth harvest, Doge produced the lowest (58,8 %) when harvested at the first harvest time.

Table 4.36: Maize enzyme soluble organic substances according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	63,3	70,5	71,8	73,2
KX2352	62,7	70,2	71,7	74,1
Vitalina	60,5	69,8	71,3	73,3
Doge	58,8	68,1	69,8	71,9
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,4	0,4	0,7

While KX2352 produced the highest (74,1%) ELOS at the fourth harvest, Doge produced the lowest (58,8%) when harvested at the first harvest time. Increasing digestibility with advancing maize maturity has been reported by Bal et al. (1997) and attributed to increasing grain ratio in whole plant maize silage.

Maize sugar content

From table 4.37 every delay in harvest can be observed to decrease the sugar contents of maize cultivars. KXA2352 (16,9%) produced the highest sugar content at par with Vitalina (16,8 %) when both were harvested at the first harvest time.

Table 4.37: Maize sugar content according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	14,2	10,5	7,1	6,1
KX2352	16,9	10,7	7,3	5,9
Vitalina	16,8	11,0	7,6	5,9
Doge	16,1	11,9	8,8	6,5
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,2	0,2	0,3

The lowest sugar content (5,9 %) was produced also by KX2352 and Vitalina at par with Gavott when they were harvested at the fourth harvest time. A significant interaction (LSD = 0,3) between cultivar and harvest time occurred .

Maize starch contents

Table 4.38 shows maize starch contents increasing with every delay in harvest for each cultivar. Despite the observed different rates of increases among the cultivars, the most significant increase for each cultivar was from the first harvest to the second.

Table 4.38: Maize starch content according to cultivar and harvest time, Gross-Gerau 2004

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	14,1	29,9	37,7	41,9
KX2352	8,2	29,0	37,4	43,4
Vitalina	6,3	27,9	36,5	42,6
Doge	5,6	24,4	32,6	39,6
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,6	0,6	1,2

KX2352 produced the highest starch content (43,4 %) at par with Vitalina(42,6 %) when both were harvested at the fourth harvest time. The lowest starch content (5,6 %) was measured in Doge at par with Vitalina (6,3 %) when they were harvested at the first harvest time. A significant interaction (LSD = 1,2) between cultivar and harvest time was observed .

4.4.3 Anaerobic digestion results

Maize dry matter consists of inorganic matter and the organic matter. Because micro-organisms can only digest organic matter, it was necessary to determine their contents prior to digestion. Organic matter is referred to in this thesis as volatile solids and abbreviated VS

Table 4.39: Maize dry matter yield, dry matter content, volatile solids, biogas yield, methane yield and percentage methane concentrations according to cultivar and harvest time, Gross-Gerau 2004

CV	HT	DMY dt /ha	VS dt/ha	DMC %	Gas nL /kg VS	CH ₄ nL /kg VS	CH ₄ %
Gavott	1	118,0	112,5	23,5	712	402	56,5
Gavott	3	158,8	152,9	35,1	642	348	54,2
Gavott	4	149,1	143,9	43,3	588	308	52,4
Doge	1	112,7	105,7	17,7	678	395	58,3
Doge	3	171,9	164,0	23,1	651	371	57,0
Doge	4	182,9	174,3	30,0	622	335	53,9

DMY-dry matter yield, DMC-dry matter content, VS-volatile solids, nL-norm litre, HT- harvest time, CV-cultivar

Maize organic matter content

By comparing the dry matter yields and the volatile solids (VS) yields of all the maize cultivars presented in table 4.39, their differences can be observed to be significantly small. In terms of anaerobic digestion this suggests whole plant maize silages rich in organic matter. Digestibility which depends on this organic matter is influenced by the degree of lignification of this organic portion of the dry matter.

In the experiments and laboratory analysis reports of Giessen, biogas productivity dynamics within the twenty one days retention time has been shown to depend on the ratio of cell contents and cell wall contents. Examples of these dynamics have been illustrated (figures 4.18 to 4.23) below for Gavott (S 250), Atletico (S 280) and Fiacre (S 350).

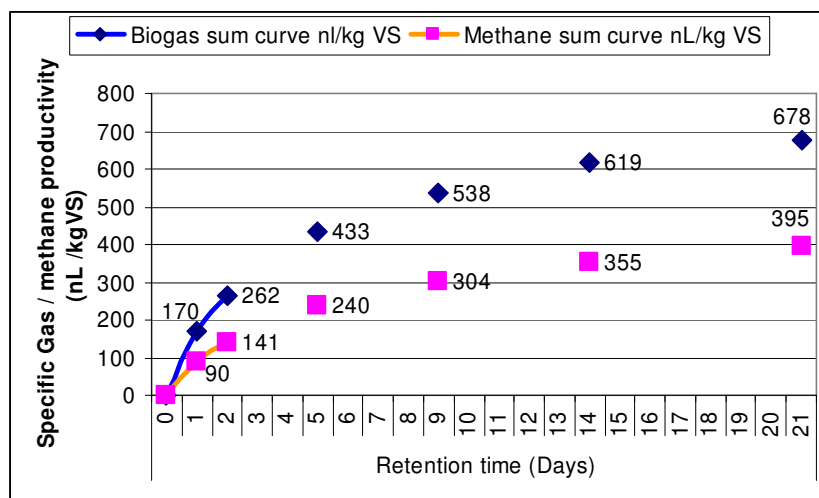


Fig. 4.18: Cumulative curves of biogas and methane yields of Doge (FAO 700) grown in Gross-Gerau and harvested at the and first harvest time in 2004

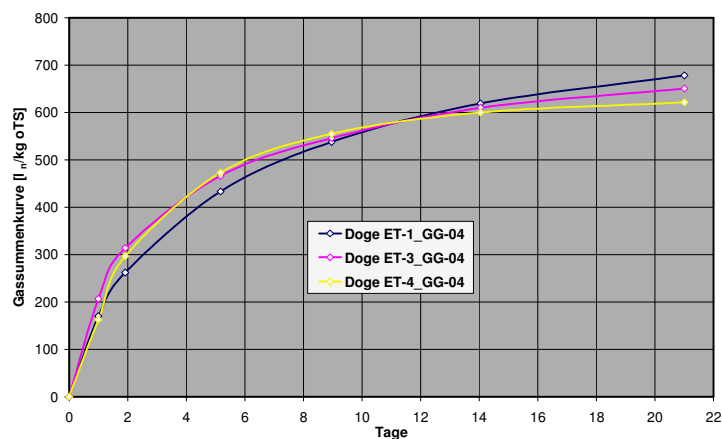


Fig. 4.19: Cumulative curves of biogas yields of Doge (FAO 700) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ; oTS-Volatile solids, GG-Gross-Gerau 2004

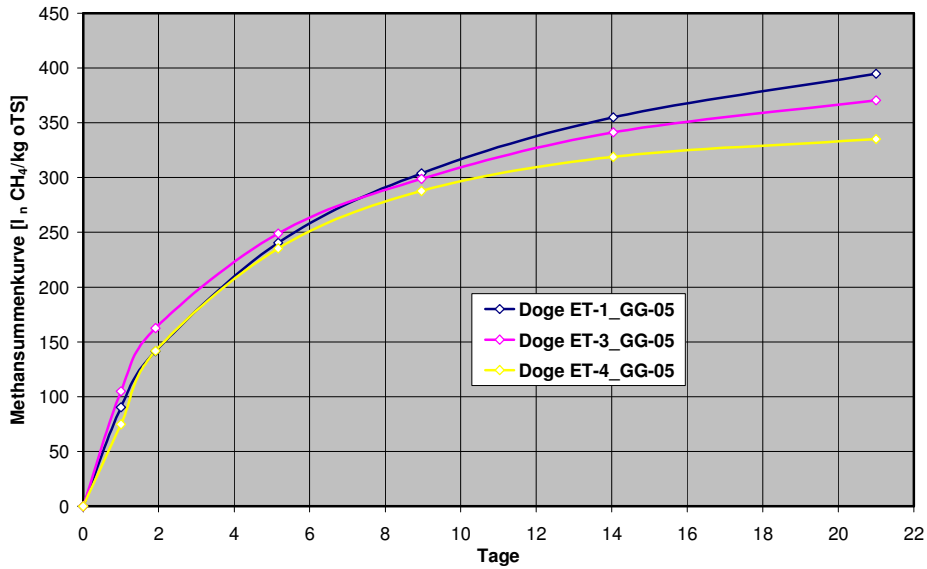


Fig. 4.20: Cumulative curves of methane yields of Doge(FAO 700) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ; oTS-Volatile solids, GG-Gross-Gerau 2004

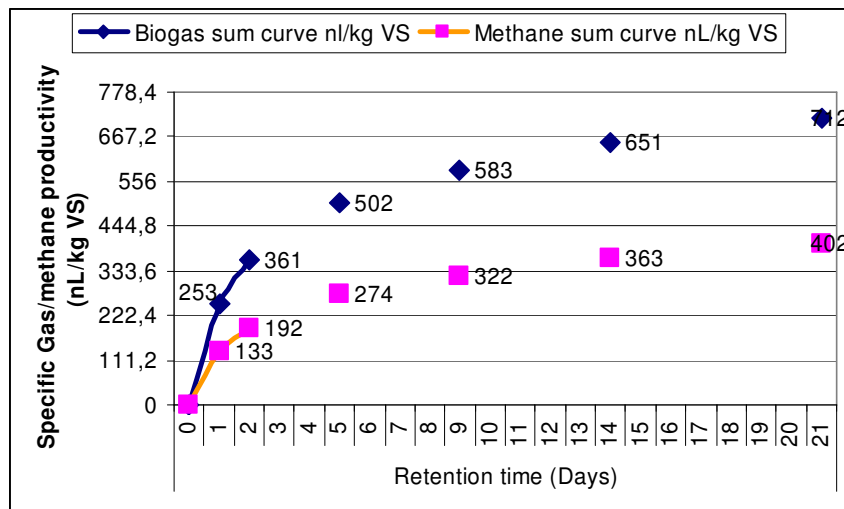


Fig 4.21: Cumulative curves of biogas and methane yields of Gavott (S 250) grown in Gross-Gerau and harvested at the and first harvest time in 2004

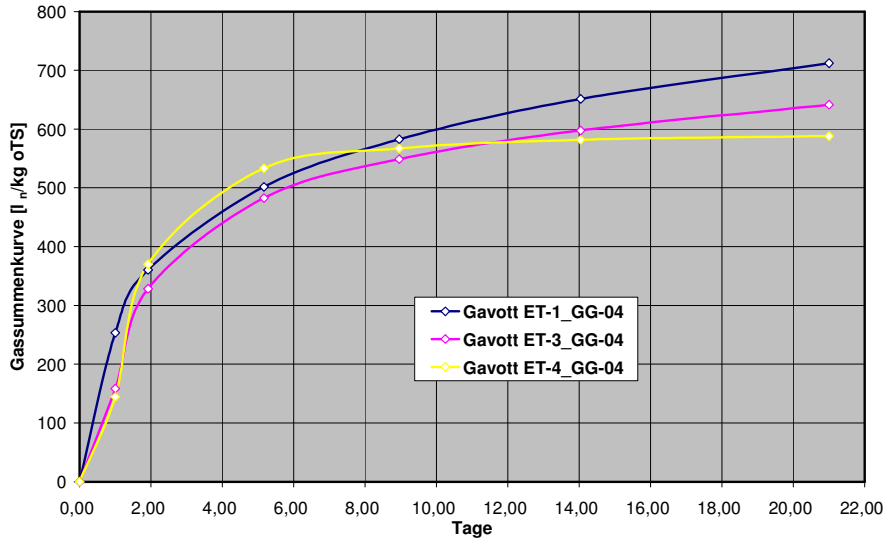


Fig. 4.22: Cumulative curves of biogas yields of Gavott (S 250) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ; oTS-Volatile solids, GG-Gross-Gerau 2004

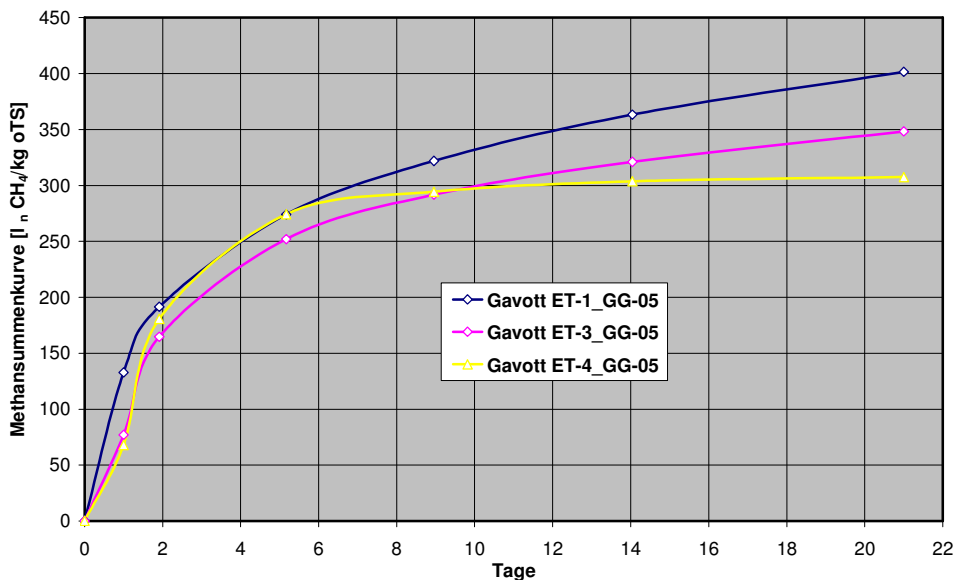


Fig 4.23: Cumulative curves of methane yields of Gavott (S 250) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ; oTS-Volatile solids, GG-Gross-Gerau 2004

Maize biogas and methane productivity

Table 4.39 and fig 4.24 below show delaying harvest to lead to decrease in biogas productivity of both Gavott and Doge. Gavott (S 250) produced higher specific biogas volumes at the first harvest compared to Doge (FAO 700). From third to fourth harvest however Doge produced higher specific biogas volumes than Gavott. This is

in agreement with Oechsner et al. (2003) who observed early cultivars to produce more biogas at the early harvest times than late cultivars but with the late cultivars outperforming the early ones at later harvest times. The rate of decrease in biogas productivity can therefore be seen (fig 4.244) to be faster in Gavott than in Doge.

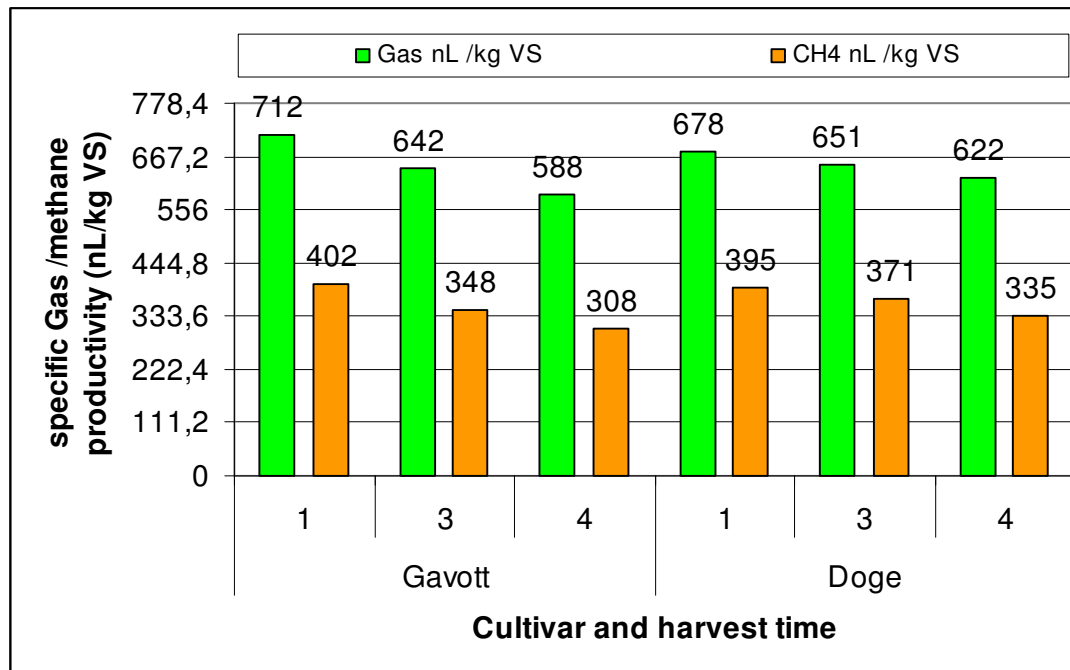


Fig. 4.24: Maize biogas and methane productivity according to cultivar and harvest time, Gross-Gerau 2004

Table 4.39 and fig 4.24 also show methane productivity of Gavott and Doge to decrease with each delay in harvest. The rates of decreases in both cultivars can be seen to follow the same pattern as did their biogases. Gavott (S 250) also produced higher specific methane volumes at the first harvest than Doge. From third to the fourth harvest. Doge can be observed to outperform Gavott in specific methane volume productivity in the same manner as was observed for biogas productivity.

4.5 Gross-Gerau 2005

In 2005 one field experiment was carried out using the same Germplasm as that also used for the field experiment of 2005 in Giessen. Members of the germplasm too are for convenience referred to also as cultivars. Samples of each cultivar were taken and analysed in Giessen for chemical composition, biogas productivity and methane concentrations.

4.5.1 Field experiment results

During field experiment, dry matter yield (DMY) and dry matter content (DMC) were measured at every harvest time for all the four cultivars used.

Maize dry matter yield (DMY)

Table 4.40 below shows delaying harvest to have increased the dry matter yields of all the maize cultivars steadily from first to the third harvest time. From the third harvest time DMY slightly decreased and increased respectively for Gavott and the rest of the cultivars.

Table 4.40: Maize dry matter yield (dt / ha) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	118,4	164,5	182,2	180,7
KXA5226	128,0	182,5	202,4	201,8
KXA5233	126,0	194,9	199,9	200,7
KXA5243	113,8	169,5	180,6	186,8
Mikado	109,0	165,3	196,1	202,2
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	8,9	7,9	17,7

The cultivar harvest time interaction (LSD = 17,7) observed may have been due to the sharp increase in the dry matter yield of KXA5233 at the second harvest relative to the rest of the cultivars. The highest dry matter yield (202,4 dt /ha) was measured in KXA5226 at par with Mikado(202,2 dt /ha) when they were harvested at the third and fourth harvest times respectively. Mikado also produced the lowest (109,0 dt /ha) dry matter yield when it was harvested at the first harvest time.

Maize dry matter content (DMC)

The results of maize DMC presented in table 4.41 below shows every delay in harvest to have also increased the dry matter content of each of the maize cultivars. Only Gavott (27,9 %) and KXA5233 (26,7%) achieved dry matter contents very close to optimum earlier at the second harvest. At the third harvest time Gavott, KXA5226 and KXA5233 had DMCs above optimum while the DMCs of KXA5243 and Mikado were exactly within the optimum range. By the fourth harvest all the cultivars showed DMCs above the optimum.

Table 4.41: Maize dry matter content (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	19,4	27,9	40,5	46,5
KXA5226	17,9	25,9	38,4	47,7
KXA5233	18,4	26,7	39,1	42,5
KXA5243	15,8	22,5	34,9	40,5
Mikado	14,6	20,2	30,6	36,2
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	1,5	1,4	3,1

An interaction (LSD = 3,1) between cultivar and harvest time was also observed. The highest DMC (47,7 %) of the experiment was measured in KXA5226 at par with Gavott (46,5%) when both were harvested at the fourth harvest time. Mikado produced the lowest DMC (14,6) at the first harvest time.

4.5.2 NIRS analysis results

Maize samples were analysed for the same chemical components that have so far been determined in all the previous experiments.

Maize crude protein (CP)

Referring to table 4.42, delaying harvest decreased the CP contents of Mikado, KXA5233 and KXA5226 but not Gavott and KXA5243. An interaction (LSD = 0,6) between cultivar and harvest time was observed. Crude protein of Gavott plateaued at the first and second harvest decreased at the third and increased at the fourth. In KXA5243, CP decreased from first to third and plateau between the third and the fourth harvest times.

Table 4.42: Maize crude protein content (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	6,5	6,5	6,0	6,1
KXA5226	5,9	5,6	5,5	4,9
KXA5233	6,0	5,7	5,4	4,9
KXA5243	6,2	5,3	5,2	5,2
Mikado	6,1	5,4	4,9	4,6
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		0,3	0,2	0,6

The highest CP (6,5%) was measured in Gavott at par with; KXA5233 (6,0 %); KXA5243 (6,2 %), and Mikado (6,1 %) when they were harvested at the first harvest time. Mikado produced the lowest CP (4,6 %) at par with KXA5226 (4,9 %) and KXA5233 (4,9 %) when they were harvested at the third harvest time.

Maize crude fibre (CF) content

With the exception of Mikado in which CF decreased to a plateau at the third and fourth harvest, delaying harvest of the other cultivars except Mikado and KXA5243, showed a steady increase in CF from first to the third harvest and an decrease from the third to the fourth harvest time. While CF of Mikado increased to the third harvest and decreased at the fourth, CF of KXA5243 decreased steadily for each delay in harvest. (Infer tab 4.43).

Table 4.43: Maize crude fibre contents (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	21,9	18,1	17,1	17,1
KXA5226	24,9	21,8	19,5	21,6
KXA5233	22,9	20,1	19,2	20,7
KXA5243	26,3	26,2	25,6	23,1
Mikado	25,3	26,4	26,8	25,6
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		0,8	0,8	1,7

The highest CF (26,8 %) was measured in Mikado at par with KXA5243 (26,3 %) when they were harvested at the third and first harvest times respectively. Gavott

produced the lowest CF (17,1 %) of the experiment when it was harvested at the third and fourth harvest time respectively. The observed cultivar harvest time interactions (LSD = 1,7) might have come from the increase observed in CF of Mikado at the third harvest when CF of the other cultivars were decreasing.

Maize neutral detergent fibre (NDF)

As can be inferred in table 4.44, every delay in harvest steadily decreased NDF of Gavott from first to the fourth harvest time. Delaying harvest for KXA5226 and KXA5233 decreased NDF from the first to the third harvest and increased it at the fourth. On the other hand KXA5243 showed a steady decrease in NDF for each delay in harvest and NDF of Mikado increased from first to the second harvest, and decreased steadily for every delay in harvest from the second to the fourth harvest.

Table 4.44: Maize neutral detergent fibres content (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	51,9	43,9	42,5	40,2
KXA5226	55,0	49,0	46,2	48,0
KXA5233	53,4	47,7	45,3	45,5
KXA5243	58,7	56,2	55,3	45,5
Mikado	57,3	57,8	56,8	53,5
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		1,2	1,1	2,5

The highest NDF (58,7 %) was measured in KXA5243 when it was harvested at the first harvest time at par with Mikado (57,8 %) when it was harvested at the second harvest time. Gavott produced the lowest (40,2 %) NDF when it was harvested at the fourth harvest time. A cultivar harvest time interaction (LSD = 2,5) was also observed. Gavott had the lowest average NDF of all certainly due to increased kernel maturity.

Maize acid detergent fibre (ADF)

From table 4.45 delaying harvest can be observed to have affected the ADF of Mikado in the same manner as it did to NDF. While ADF of Gavott, KXA5226 and KXA5243 decreased from first to the third harvest and increased from third to the fourth, every delay in harvest steadily decreased ADF of KXA5243 from first to the fourth harvest time. By delaying harvest of Mikado ADF decreased from first to second harvest, increased at the third and again decreased at the fourth harvest time.

Table 4.45: Maize acid detergent fibres content (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	26,5	21,5	20,3	20,4
KXA5226	30,9	25,9	23,5	25,6
KXA5233	27,6	23,3	23,8	24,6
KXA5243	31,4	31,2	30,2	27,5
Mikado	31,2	31,6	32,7	30,7
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		1,2	1,0	2,3

A cultivar harvest time interaction was also observed may be due to Mikado increasing ADF content at the second harvest as ADFs of the rest of the Cultivars were decreasing. The highest ADF (32,7 %) was measured in Mikado when it was harvested at the third harvest time at par with KXA5243 (31,4 %) when it was harvested at the first harvest time. The lowest ADF (20,3 %) was measured in Gavott when it was harvested at the third harvest time.

Maize enzyme soluble organic substances (ELOS)

Looking at ELOS of the different maize cultivars in table 4.46 one observes that delaying harvest affect the different cultivars differently and that a cultivar harvest time interaction (LSD = 2,7) occurred. Delaying harvest increased ELOS of Gavott (S 250), KXA5226 (S 260) and KXA5233 (S 270) from first to third harvest and decreased it from third to fourth harvest. A different pattern was shown by delaying harvest for KXA5243 (S 290) and Mikado. In both delaying harvest decreased ELOS from first to third harvest and increased it from third to fourth. All these patterns were in accordance with variations in ADF and NDF contents. Decreasing ADF is usually associated with increasing digestibility and vice versa. (Darby and Lauer 2002)

Table 4.46: Maize enzymes soluble organic substances (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	68,2	71,5	72,4	72,1
KXA5226	63,7	67,5	69,5	66,2
KXA5233	67,5	69,7	69,3	67,0
KXA5243	63,4	61,4	60,5	62,8
Mikado	63,5	61,1	58,0	59,8
		CV	HT	CV*HT
p -value		0,000	0,000	0,000
LSD (5%)		1,4	1,2	2,7

The highest ELOS (72,4 %) of the experiment was found in Gavott when it was harvested at the third harvest time. The lowest (58,0 %) was measured in Mikado when it was harvested also at the third harvest time.

Maize sugar content

Every delay in harvest as can be inferred in table 4.47 to have decreased the sugar content of each maize cultivar and a Cultivar harvest time interaction (LSD = 2,0) was observed.

Table 4.47: Maize sugar content (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	17,5	11,1	6,8	4,2
KXA5226	19,4	13,1	7,8	2,6
KXA5233	19,6	13,4	10,0	6,4
KXA5243	19,4	16,2	8,5	4,5
Mikado	20,7	17,9	12,7	4,5
		CV	HT	CV*HT
	p -value	0,000	0,000	0,000
	LSD (5%)	1,0	0,9	2,0

Mikado produced the highest sugar content (20,7 %) at par with KXA5233 (19,6 %), KXA5226 (19,4 %), and KXA5243 (19,4 %) when maize were harvested at the first harvest time. The lowest sugar content (2,6 %) was measured in KXA5226 when it were harvested at the fourth harvest time.

Maize starch content

Maize starch contents as presented in table 4.48 increased for every delay in harvest in all the cultivars. Mikado produced the highest starch content (40,4 %) when it was harvested at the fourth harvest time.

Table 4.48: Maize starch content (%) according to cultivar and harvest time, Gross-Gerau 2005

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	11,6	29,1	37,1	40,4
KXA5226	7,2	20,9	34,2	35,8
KXA5233	7,4	21,5	31,1	31,7
KXA5243	1,4	6,9	19,4	30,9
Mikado	2,7	3,6	12,9	25,4
		CV	HT	CV*HT
	p -value	0,000	0,000	0,000
	LSD (5%)	1,3	1,2	2,6

The lowest starch content (1,4 %) was measured in KXA5243 at par with Mikado (2,7 %) when both were harvested at the first harvest time.

4.5.3 Anaerobic digestion results

Maize samples Grown in Gross-Gerau were digested in Giessen and their biogases were analysed for methane contents using the same procedures that were used for those grown in Giessen .

Table 4.49: Maize dry matter yield, dry matter content, volatile solids, biogas yield, methane yield and percentage methane concentrations according to Cultivar and harvest time Gross-Gerau 2005

CV	HT	DMY dt/ha	VS dt/ha	DMC %	Gas nL /kg VS	CH ₄ nL /kg VS	CH ₄ %
Gavott	1	118,4	113,4	19,4	681	387	56,8
Gavott	3	182,2	174,6	40,5	685	377	55,0
Gavott	4	180,7	173,3	46,5	677	377	55,7
KXA5233	1	126,0	120,1	18,4	900	503	55,9
KXA5233	3	199,9	191,5	39,1	744	409	55,0
KXA5233	4	200,7	192,1	42,5	709	388	54,7

DMY-dry matter yield, DMC-dry matter content, VS-volatile solids, nL-norm litre, HT- harvest time, CV-cultivar.

Maize organic matter content

Table 4.49 shows the differences between dry matter yields (DMY) and volatile solids (VS) to be significantly small as was the case in Giessen. Hence whole plant maize silages rich in organic matter are also predicted here. The dynamics of biogas production within the twenty one days retention time are illustrated below for both Gavott and KXA5233.

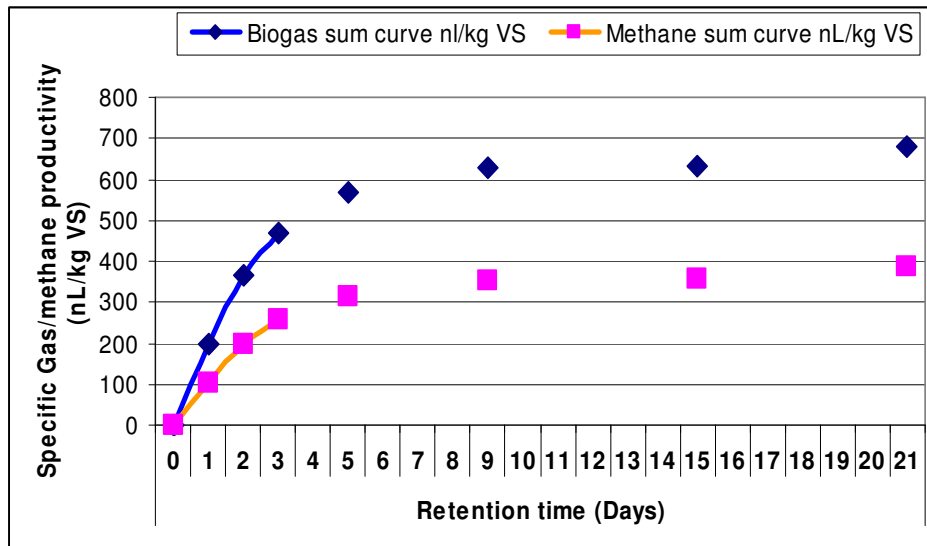


Fig. 4.25: Cumulative curves of biogas and methane yields of Gavott (S 250) grown in Gross-Gerau and harvested at the and first harvest time in 2005

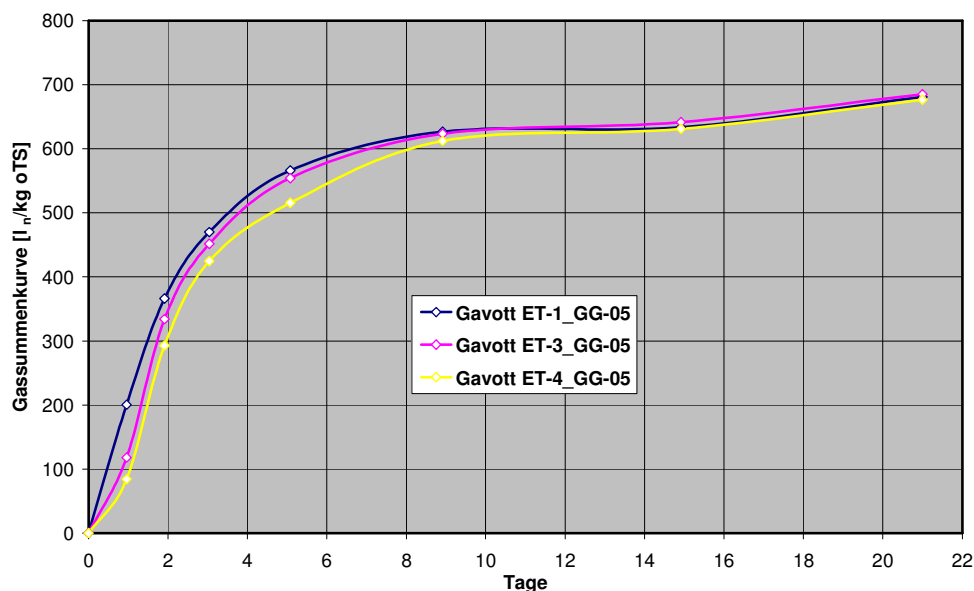


Fig. 4.26: Cumulative curves of biogas yields of Gavott (S 250) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ;oTS-Volatile solids; GG-Gross-Gerau.2005

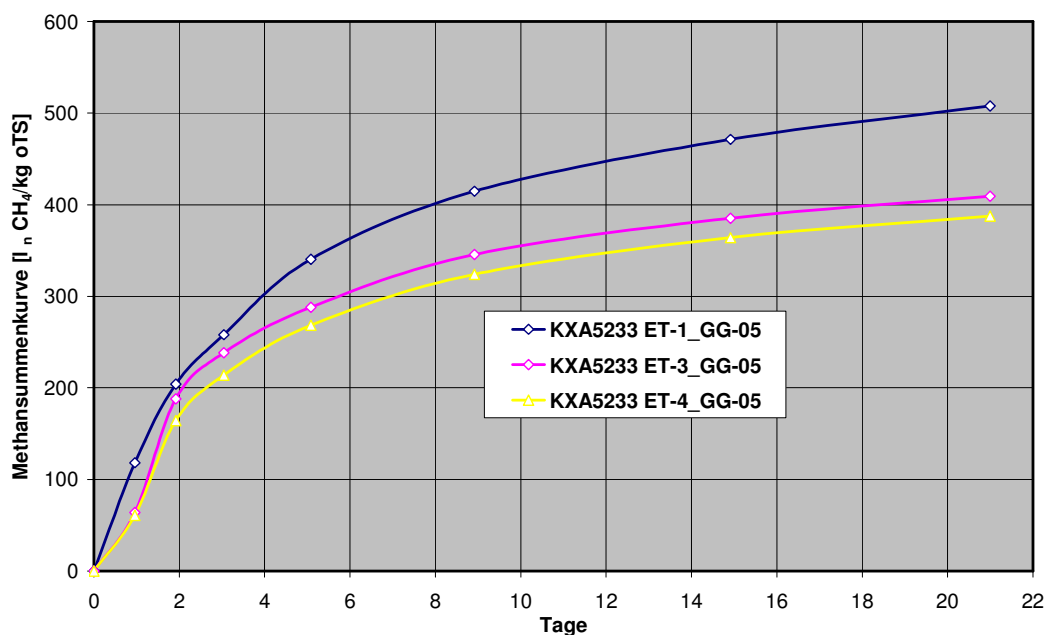


Fig. 4.27: Cumulative curves of methane yields of Gavott (S 250) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ;oTS-Volatile solids; GG-Gross-Gerau.2005

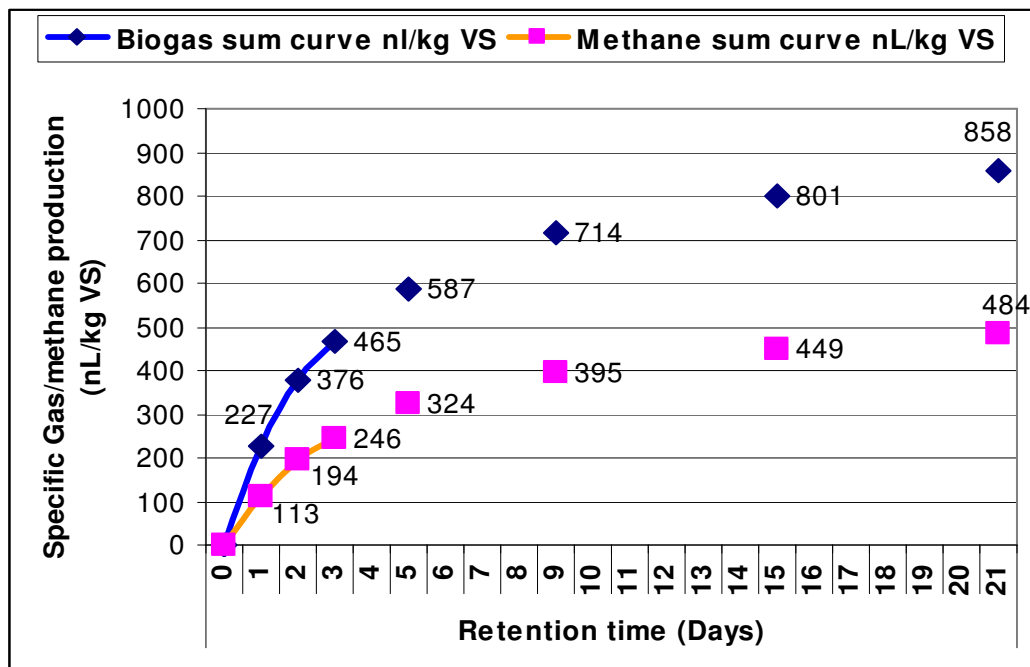


Fig. 4.28: Cumulative curves of biogas and methane yields of KXA5233 (S 270) grown in Gross-Gerau and harvested at the and first harvest time in 2005

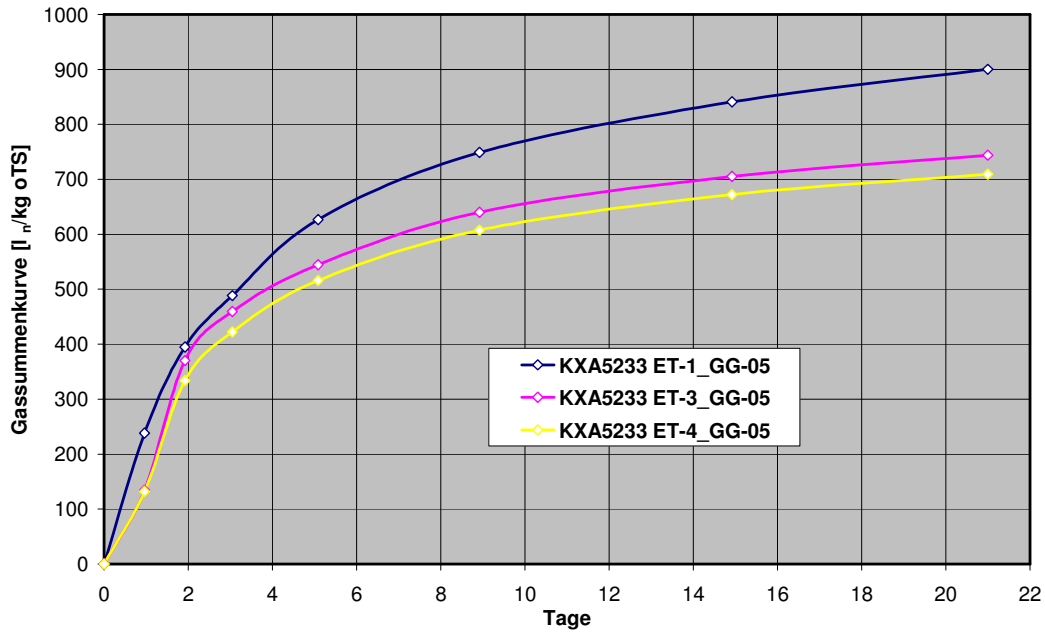


Fig. 4.29: Cumulative curves of biogas yields of KXA5233 (S 270) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ;oTS-Volatile solids; GG-Gross-Gerau. 2005

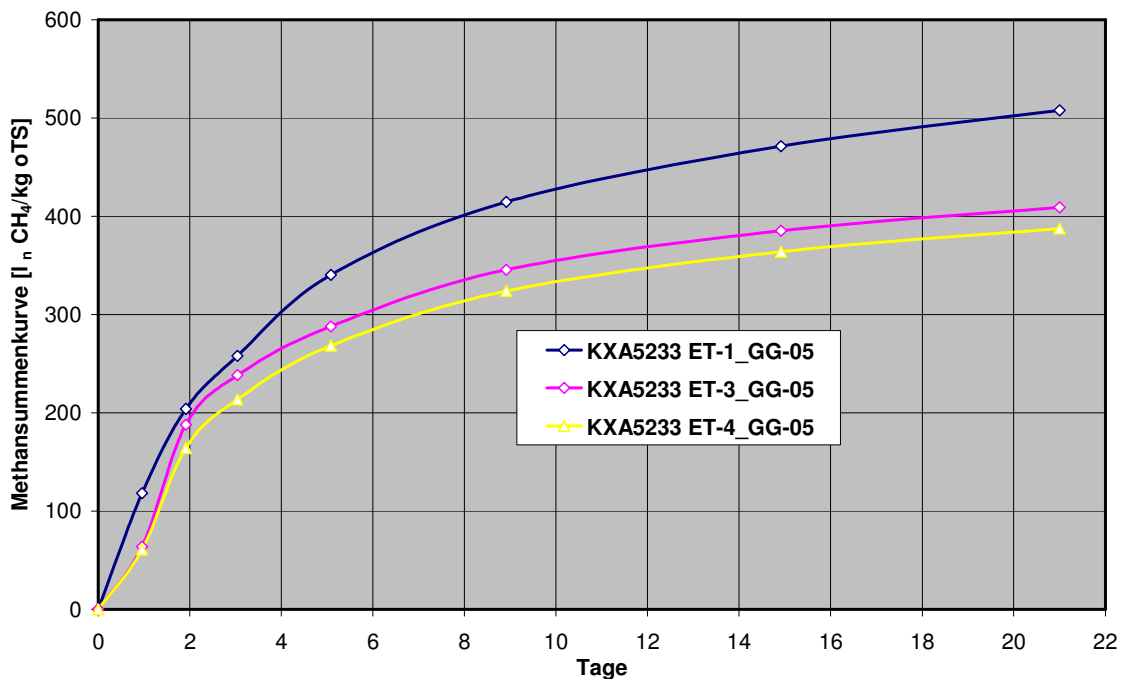


Fig. 4.30: Cumulative curves of methane yields of KXA5233 (S 270) according to retention time at the first, third and fourth harvest times. ET-1-First harvest, ET-3-third harvest time, ET-4-Fourth harvest time ;oTS-Volatile solids; GG-Gross-Gerau 2005

Maize dry matter content

From table 4.49, it can be observed that both Gavott and KXA5233 did not have optimum DMCs at any of the three harvest times considered. For anaerobic digestion both were too wet (DMC 19,4% and 18,4%) at the first harvest and too dry (DMC 39-42 %) at both the third and fourth harvest.

Maize biogas and methane productivity

From table 4.49 and fig 4.29 below biogas productivity of both Gavott and KXA5233 can be observed to decrease with each delay in harvest. The rate of decrease was slower in Gavott than in KXA5233.

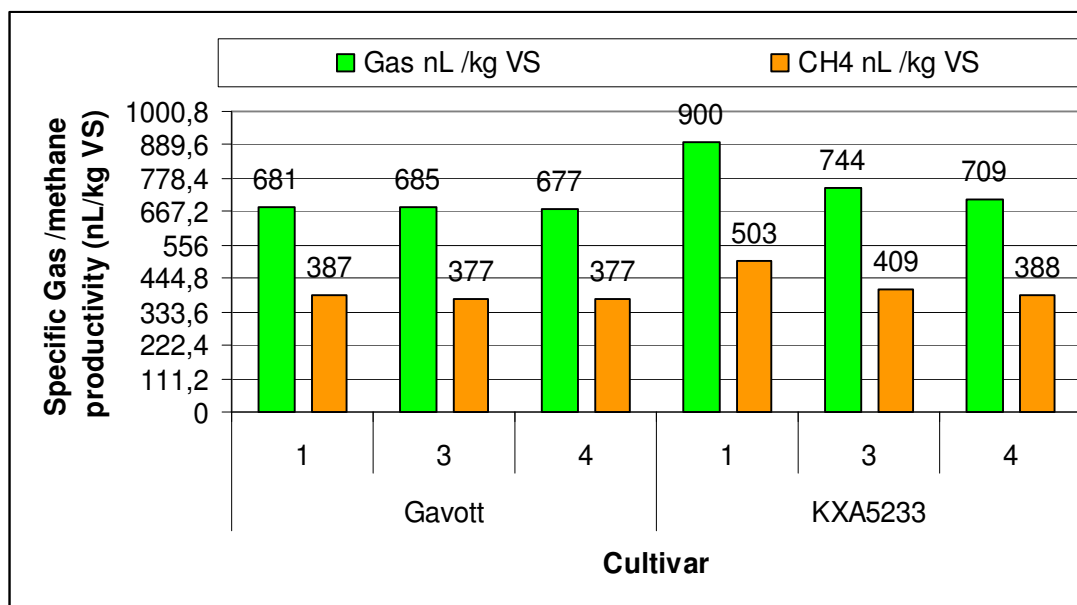


Fig. 4.31: Maize biogas and methane productivity according to cultivar and harvest time, Gross-Gerau 2005

KXA5233 (S 270) also produced more specific biogas volumes than Gavott (S 250) at all the three harvest times considered.

Methane productivity also decrease with delay in harvest for both Gavott and KXA5233 and the rate of decrease is also slower in Gavott than in KXA5233. KXA5233 (S 270) also produced higher specific methane volumes at each of the harvest times when compared with Gavott (S 250).

Biogas productivity would have been expected to increase with each delay in harvest as digestibility results suggested but this is not the case. The decreasing methane content with increasing DMC seems to agree with the belief that optimum DMC (28-35%) determines maize quality. The relationship of biogas and methane productivity with CP sugar and starch were neither clear nor could be related to the

theoretical gas equation which indicates proteins to produce more methane than carbohydrates.

4.6 Gross-Gerau 2006

In 2006 one field experiment was carried out using a germplasm of four maize cultivars (Gavott, Atletico, Fiacre and Baxter) and two inbred lines (KXA5233 and KXA5243). They are also for convenience referred to as cultivars.

4.6.1 Field experiment results

During field experiment in Giessen, dry matter yield (DMY), dry matter content (DMC) and heights were measured at every harvest time for all the six cultivars used. The cultivars even though exposed to the same growing conditions, differed mainly in maturity classifications. The complete members of the germplasm were: Gavott (S 250), KX5233 (S 270) and KXA5243 (S 290), and Atletico (S 280), Baxter (S 380) and Fiacre (S350). The date of first harvest for all the cultivars was again the milk stage of Gavott. Unlike 2004 and 2005, field experiments of 2006 were strongly influenced by late frost that came during the fourth leaf stage of maize. All the cultivars showed chlorotic leaves and which lasted at least two weeks. During anthesis and grain filling stages conditions were extremely hot and dry at the same time.

Maize dry matter yield (DMY)

With the exception of Gavott and KXA5233, table 4.50 shows each delay in harvest to have significantly added dry matter yields in the rest of the cultivars. In Gavott and KXA5233 this additional effect was only observed from first to the third harvest.

Table 4.50: Maize dry matter yield (dt / ha) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	127,1	150,0	166,6	157,1
KXA5233	143,8	159,2	173,9	171,8
KXA5243	129,8	160,5	171,2	189,0
Atletico	141,4	168,7	177,0	186,3
Baxter	118,8	148,2	156,9	172,2
Fiacre	128,4	163,3	186,0	204,3
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	11,6	9,4	23,1

A further delay in harvest from the third harvest to the fourth decreased the DMY of both Gavott and KXA5233. A cultivar harvest time interaction (LSD = 23,1) was

observed. The highest DMY (204,3 dt /ha) was measured in Fiacre at par with KXA5243(189,0 dt /ha) and Atletico (186,3 dt /ha) when they were harvested at the fourth harvest time. Baxter produced the lowest DMY (118,8 dt /ha) when it was harvested at the first harvest time.

Maize dry matter content (DMC)

Table 4.51 shows each delay in harvest to have increased the dry matter content (DMC) of all the maize cultivars steadily from first to the fourth harvest time. The variations were significant ($p = 0,000$) and a significant cultivar harvest time interaction ($LSD = 2,2$) was observed. The first optimum DMC (28,1%) was attained only by Gavott at the second harvest Time. By the third harvest time only Gavott (33,6%), Atletico (33,0%) and Fiacre (31,3%) achieved optimum DMC. KXA5233, KXA5243 and Baxter both had the same DMCs (27,8) which is very close to optimum. During the fourth harvest KXA5243 still had optimum DMC while the rest of the cultivars were already at DMCs above the optimum range.

Table 4.51: Maize dry matter content (%) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)				
	1	2	3	4	
Gavott	25,5	28,1	33,6	38,6	
KXA5233	23,0	24,8	27,8	35,1	
KXA5243	20,4	23,2	27,8	33,4	
Atletico	23,5	27,1	33,0	39,0	
Baxter	21,9	25,0	27,8	37,2	
Fiacre	23,2	27,0	31,3	40,5	
		CV	HT	CV*HT	
		0,000	0,000	0,000	
		LSD (5%)	1,1	0,9	2,2

The highest DMC (40,5 %) was measured in Fiacre at par with Atletico (39,0 %) and Gavott (38,6 %) when they were harvested at the fourth harvest time. The lowest (20,4 %) DMC was found in Baxter at par with KXA5243 (21,9%) when both were harvested at the first harvest time.

Maize plant height

Results of maize heights presented in figure 4.30 indicates no significant differences ($p = 0,640$) in heights between the harvest times but among the cultivars ($p = 0,000$). An interaction ($LSD = 19,2$) between cultivar and harvest time was also observed. The different cultivars reacted differently to each delay in harvest. The tallest plants (304,5 cm) were measured in KXA5243 when it was harvested at the first harvest

time at par with KXA5233 (294,5 cm) when it was harvested at the fourth harvest time and Fiacre (286,8 cm) when it was harvested at the third harvest time.

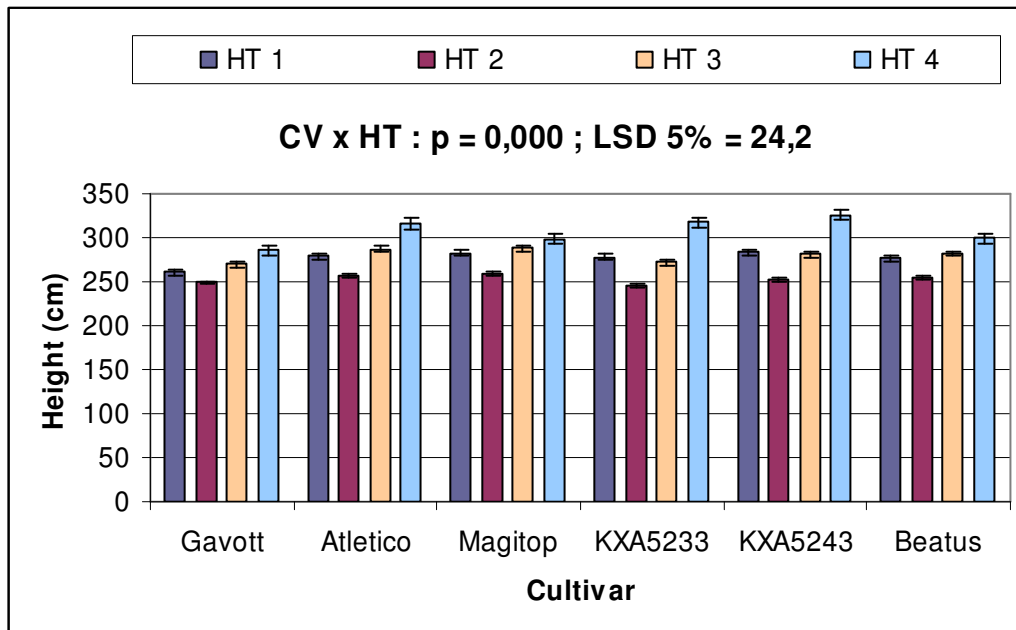


Figure 4.32: Maize plant height according to cultivar and harvest time, Gross-Gerau 2006

Gavott produced the shortest plants (238,5 cm) when it was harvested at the third harvest time.

4.6.2 NIRS analysis results

Maize samples from Gross-Gerau were analysed for chemical composition using the same NIRS methodology that has so far been described in this thesis.

Maize crude protein (CP) content

With the exception of KXA5233 and Atletico, table 4.52 shows maize CP of the rest of the cultivars to have decreased from first harvest to the second, increased at the third and again decreased at the fourth. In Atletico and KXA5233, CP increased from a plateau at the first and second harvest to the third and decreased from the third to the fourth. An interaction (LSD = 0,5) between cultivar and harvest time was observed. All the cultivars produced their lowest CP at the fourth harvest but the highest was not at the first harvest for all. KXA5243 and KXA5233 for instance produced their highest CP at the third harvest time. CP values for each cultivars were within the range held as normal for corn silage by Schroeder (2004) , Roth, and Heinrichs (2001).

Table 4.52: Maize crude protein content (%) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	7,4	7,3	7,4	6,4
KXA5233	6,5	6,5	6,8	5,9
KXA5243	6,7	6,2	6,9	5,7
Atletico	6,9	6,9	7,2	6,3
Baxter	7,1	6,9	7,0	6,4
Fiacre	6,6	6,4	6,5	6,1
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,2	0,2	0,5

The highest CP (7,4%) was measured in Gavott when it was harvested at the first and third harvest times at par with Baxter (7,1 %), Atletico (6,9 %) and KXA5243 (6,9 %) when they were harvested at the first and the third harvest times respectively. The lowest CP (5,7 %) was produced by KXA5243 at par with KXA5233 (5,9 %) and Fiacre (6,1 %) when they were harvested at the fourth harvest time.

Maize crude fibre (CF) content

According to table 4,53 every delay in harvest steadily increases CF of maize cultivars except in KXA5233 where this was disturbed by an increase at the third harvest time., According to statistics the observed variations in CF were significant among the cultivars ($p = 0,000$) as well as between the harvest times ($p = 0,000$) for each cultivar. An interaction ($LSD = 1,3$) between cultivar and harvest time was also observed.

Table 4.53: Maize crude fibre contents (%) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	19,1	15,6	15,2	14,8
KXA5233	22,7	19,6	20,0	16,7
KXA5243	24,3	23,1	21,2	19,7
Atletico	21,0	17,1	16,2	15,7
Baxter	22,2	19,4	19,0	16,8
Fiacre	21,8	18,2	16,8	15,3
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,6	0,5	1,3

KXA5243 produced the highest (24,3 %) CF when it was harvested at the first harvest time and the lowest CF (14,8 %) was measured in Gavott at par with KXA5233 (15,7 5) and Fiacre (15,3 %) when they were harvested at the fourth harvest time.

Maize neutral detergent fibres (NDF)

Table 4.54 shows a significant ($p = 0,000$) interaction ($LSD = 8,9$) between cultivar and harvest time . Each delay in harvest can be observed to steadily decrease NDF only in Baxter. In KXA5233 delaying harvest decreased NDF to a plateau at the second and third harvest and a further delay from third to fourth harvest again decreased NDF of KXA5233. In KXA5243 delaying harvest decreased NDF from first to the fourth harvest but with a plateau at the third and fourth harvest. Delaying harvest of Gavott and Fiacre on the other hand decreased NDF steadily from the first to the third harvest but a further delay from the third to the fourth instead increased NDF of both cultivars.

Table 4.54: Maize neutral detergent fibres content (%) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	46,9	40,4	39,5	40,0
KXA5233	54,0	47,9	47,9	44,9
KXA5243	57,4	54,0	48,9	48,9
Atletico	51,0	43,9	42,5	42,6
Baxter	54,8	46,6	44,7	42,1
Fiacre	52,5	43,1	40,6	67,4
		CV	HT	CV*HT
	p - value	0,000	0,000	0,000
	LSD (5%)	4,5	3,6	8,9

The relatively very high significant increase in NDF from the third to the fourth harvest observed in Fiacre might have been the cause of the cultivar harvest time interaction. NDF values of the rest of the cultivars were above the range (30 – 58%) observed as normal for corn by Schroeder (2004) and Roth and Heinrichs (2001).

Maize acid detergent fibres (ADF)

Table 4.55 shows each delay in harvest to steadily decrease ADF of maize cultivars except in Gavott where this decrease was interrupted by an increase at the third harvest time. ADF values were within the range also observed as normal for maize silage by Schroeder (2004) , Roth, and Heinrichs, (2001) and a significant ($p = 0,000$) interaction ($LSD = 1,5$) between cultivar and harvest time was also observed.

Table 4.55: Maize acid detergent fibres content (%) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	23,0	18,6	18,0	17,5
KXA5233	27,0	22,9	23,4	19,4
KXA5243	29,3	27,5	24,7	23,2
Atletico	25,4	20,7	19,3	18,8
Baxter	26,5	22,8	22,1	19,8
Fiacre	25,7	21,1	19,8	18,1
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,8	0,2	1,5

The highest ADF was measured in KXA5243 when it was harvested at the first harvest and the lowest (17,5 %) in Gavott at par with Fiacre (18,1 %) and Atletico (18,8 %) when they were harvested at the fourth harvest time.

Maize enzyme soluble organic substances (ELOS)

From table 4.56, each delay in harvest can be observed to have steadily increase ELOS of Fiacre and Baxter. Delaying harvest of Gavott and Atletico and KXA5243 increased ELOS from first to the third harvest time but a further delay from the third harvest decreased ELOS of each of the three cultivars. KXA5233 showed a unique reaction to delaying harvest by increasing ELOS from the first to the second harvest Decreasing at the third and again increasing at the fourth..

Table 4.56: Maize cell wall digestibility (%) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	68,6	72,1	73,1	72,6
KXA5233	64,4	68,4	67,6	70,2
KXA5243	61,2	63,2	66,4	66,3
Atletico	66,4	70,1	71,8	71,0
Baxter	64,0	68,7	69,1	71,1
Fiacre	65,3	70,6	72,5	72,9
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		0,9	0,7	1,7

A significant interactions (LSD = 1,7) was observed between cultivar and harvest time. The highest ELOS (73,1 %) was measured in Gavott at par with Fiacre (72,5 %) and Atletico (71,8 %) when they were harvested at the third harvest. KXA5243 produced the lowest (61,2 %) ELOS when it was harvested at the first harvest time.

Maize sugar content

The results of maize sugar contents presented in table 4.57 shows each delay in harvest to produce a decrease in the sugar contents of all the maize cultivars. An interaction (LSD = 2,1) between cultivar and harvest time was also observed. Delaying harvest decreased sugar contents to the lowest levels at the third harvest in all the cultivars. A further delay in harvest from the third to the fourth harvest time again increased the sugar contents in all the cultivars .

Table 4.57: Maize sugar content according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	15,3	11,7	8,6	11,3
KXA5233	20,5	17,8	13,5	16,3
KXA5243	21,5	19,6	13,8	15,4
Atletico	18,0	14,2	10,8	12,1
Baxter	20,7	15,4	10,5	11,7
Fiacre	19,1	12,5	9,0	10,7
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		1,0	0,9	2,1

The highest sugar content (21,5 %) was measured in KXA5243 at par with KXA5233 (20,5 %) and Baxter (19,1%) when they were harvested at the first harvest time. Gavott recorded the lowest (8,6 %)sugar content at par with Fiacre (9,0%) and Baxter (10,5 %) when they were harvested at the third harvest time.

Maize starch content

The results of maize starch contents are presented in table 4.58 and show each delay in harvest to steadily increase the starch contents of all the maize cultivars except in Gavott. In Gavott delaying harvest increased starch content only from the first to the fourth harvest and a further delay from the third to the fourth harvest time was observed to instead decreased starch content. A significant interaction (LSD = 5,0) between cultivar and harvest time was observed. The values of starch content were in the range observed by Schroeder (2004) with silage maize harvested between 1/3 ML and black layer.

Table 4.58: Maize starch content (%) according to cultivar and harvest time, Gross-Gerau 2006

Cultivar(CV)	Harvest time (HT)			
	1	2	3	4
Gavott	20,3	32,5	37,6	36,2
KXA5233	6,4	14,6	20,8	24,0
KXA5243	2,2	7,5	17,9	21,3
Atletico	13,6	27,3	33,1	34,5
Baxter	7,1	23,6	27,5	32,7
Fiacre	11,0	30,0	32,8	37,8
		CV	HT	CV*HT
p - value		0,000	0,000	0,000
LSD (5%)		2,5	2,0	5,0

The highest starch content (37,8 %) was found in Fiacre when it was harvested at the fourth harvest time at par with Gavott (37,6 %) and Atletico (34,5 %) when they were harvested at the third and fourth harvest times respectively. KXA5243 produced the lowest starch content (2,2 %) when it was harvested at the first harvest time.

4.6.3 Anaerobic digestion and biogas analysis result

All the maize cultivars attained optimum DMCs first at the third harvest time. For this reason maize samples from all the cultivars were selected from the third harvest for anaerobic digestion analysis. Using this third harvest the impacts of cultivar on methane and biogas productivity could be evaluated. By adding samples of Atletico and Fiacre from the fourth harvest, the impacts of harvest time could also be evaluated.

Table 4.59: Maize dry matter yield, dry matter content, volatile solids, biogas yield, methane yield and percentage methane concentrations according to cultivar and harvest time Gross-Gerau 2006

CV	HT	DMY dt /ha	VS dt/ha	DMC %	Gas nL/kgVS	CH ₄ nL/kgVS	CH ₄ %
Gavott	3	166,5	159,5	33,6	533	312	58,5
KXA5233	3	144,6	138,1	27,8	572	312	54,6
KXA5243	3	171,1	162,8	27,8	566	324	57,2
Atletico	3	177,0	169,4	33,0	554	304	54,9
Atletico	4	186,3	178,0	39,0	569	328	57,7
Baxter	3	156,9	150,0	27,8	592	342	57,8
Fiacre	3	186,0	177,7	31,3	602	349	58,0
Fiacre	4	202,3	193,9	40,5	662	366	55,3

DMY-dry matter yield, DMC-dry matter content, VS-volatile solids, nL-norm litre, HT- harvest time, CV-cultivar.

Maize organic matter content

Table 4.59 shows very little differences between dry matter yields (DMY) and volatile solids yields (VS). This again indicates whole plant silage maize rich in organic matter just like has been observed in Giessen 2006 as well as the experiments of 2004 and 2005. The speed of digestibility can be observed from the cumulative curves of biogas and methane gases produced by the samples of the different cultivars when they were digested over a retention time of twenty one days. Examples of biogas and methane productivity of the middle early (Gavott), Middle late (Atletico s-280) and the late (Fiacre –S 350) cultivars are illustrated below.

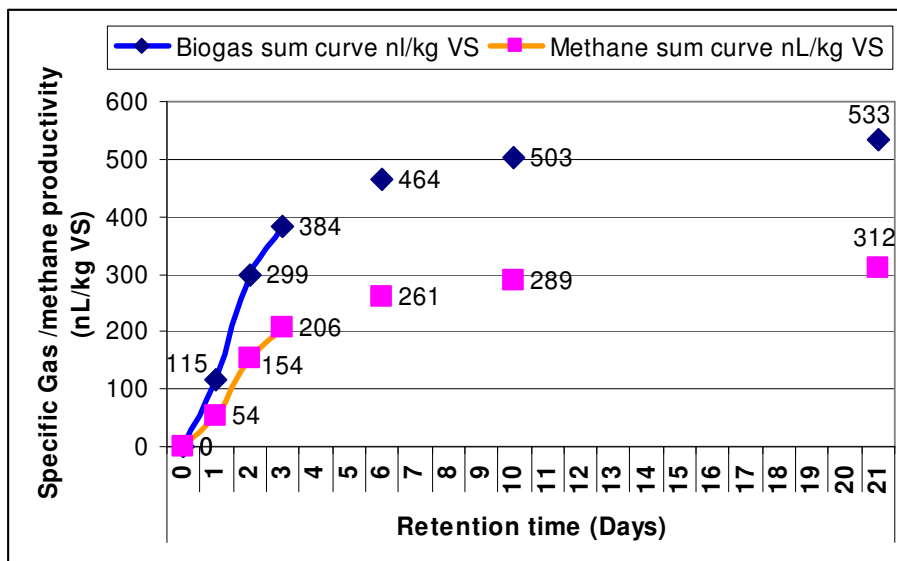


Fig. 4.33: Cumulative curves of biogas and Methane yields of Gavott (S 250) grown in Gross-Gerau and harvested at the third harvest time in 2006

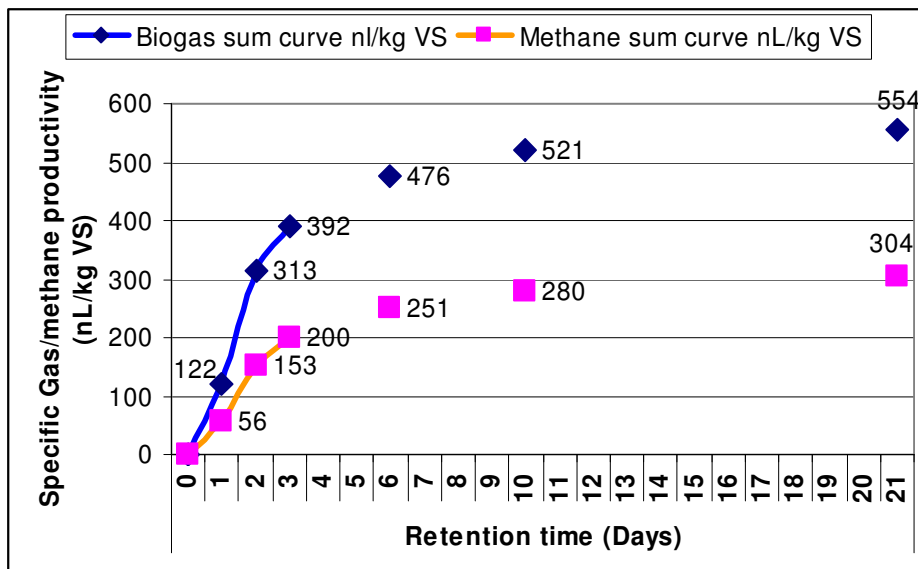


Fig. 4.34: Cumulative curves of biogas and Methane yields of Atletico (S 280) grown in Gross-Gerau and harvested at the third harvest time in 2006

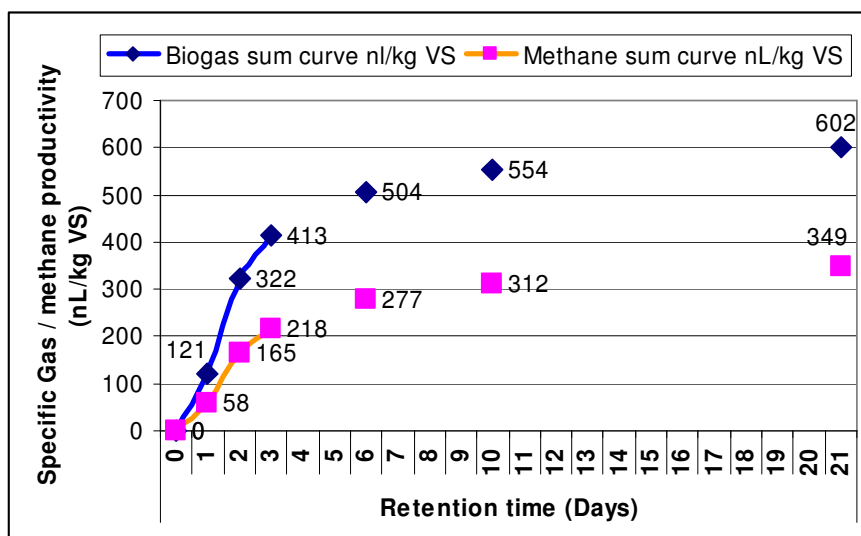


Fig. 4.35: Cumulative curves of biogas and Methane yields of Fiacre (S 350) grown in Gross-Gerau and harvested at the third harvest time in 2006

Maize dry matter content (DMC)

All the cultivars had dry matter contents within the optimum range when they were harvested at the third harvest time. DMC of Atletico and Fiacre were above the optimum range when they were harvested at the fourth harvest time.

Maize biogas and methane productivity

By comparing the biogas productivity of all the cultivars from the third harvest shown in table 4.59 and fig 4.34 below, it can be observed that the highest specific biogas volumes were produced by the late cultivars Baxter (S 300) and Fiacre (S 350).

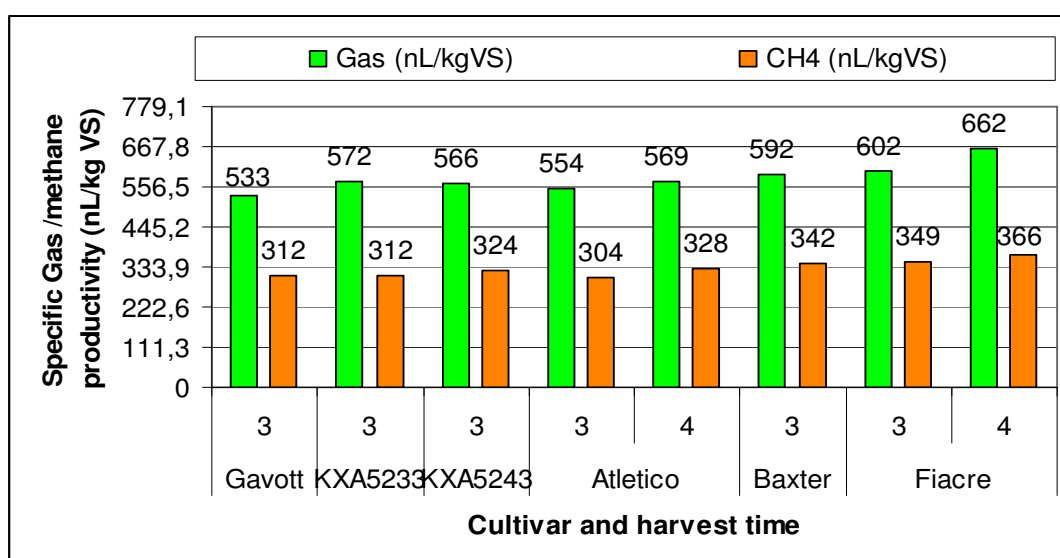


Fig. 4.36: Maize specific biogas and methane productivity according to cultivar and harvest time Gross-Gerau 2006

The early cultivar-Gavott (S 250) produced also the lowest specific biogas volumes. (533nL /kg VS). However KXA5243 (S 290) produced lower specific biogas volumes (566 nL/kg VS) than KXA5233 (572 nL/kg VS) and even much lower than Atletico (554 nL/kg VS).

From the same table and figure, it can be observed that despite the 39 nL difference in biogas productivity between Gavott and KXA5233 both had the same specific methane concentration (312nL/kg VS). The difference between methane productivity of KXA5233 and KXA5243 can also be observed to be much larger than between their biogases.

By comparing Atletico and Fiacre from table 4.59 and fig 4.34 above, biogas productivity can be observed to increase from third to fourth harvest for both cultivars. It can also be observed that at both harvest times, the specific biogas productivity of Fiacre (S 350) were higher than those of Atletico (S280). The same comparison of Atletico and Fiacre shows methane productivity to also increase from the third to the fourth harvest time. The specific methane concentration of their biogases can also be observed to be very similar between the harvest times than were the biogases.

5 Discussions

5.1 Field and laboratory analysis 2004

5.1.1 Impacts of cultivar and harvest time on dry matter yield 2004

The results of maize DMY and DMC respectively presented in tables 4.1 (Gi) / 4.30 (GG) and tables 4.2 / 4.31 show every delay in harvest to increase both the DMY and DMC of all the cultivars in Giessen as well as in Gross-Gerau in accordance with observations of Darby and Lauer (2002), Wiersma et al. (1993) and Farouzmand et al. (2005). No literature was found to explain the exceptional case shown by Gavott in Gross-Gerau whereby DMY decreased by delaying harvest from third to fourth harvest. However Wiersma et al. (1993) observed a plateauing rather than a decrease of maize DMY after the black layer. In this experiment Gavott should expectedly have been at the black layer stage of maturity given the facts that it was the earliest (S 250) among all the cultivars and that its milk stage was the orientation to begin harvest for all the cultivars.

Dry matter yields (DMC) of all cultivars were very significantly higher in Gross-Gerau than in Giessen. However, in the experiments of Gross-Gerau Doge produced both the lowest (112 dt/ha) and highest (182.9 dt/ha) DMY compared with Giessen where the lowest yields were from Gavott (62.9 dt /ha) and the highest from Doge with 144.4 dt/ha. These observations are contrary to expectations. According to Oechsner et al. (2003) cool environments like Giessen are expected to retard especially the juvenile stages of late maturing cultivars like Doge (FAO 700). Late cultivars are hence expected to outperform early cultivars instead at later maturity stages. Hence Doge should have expectedly produced lower yields in Giessen at the earlier harvest than Gavott. From the point of dry matter yield alone Gross-Gerau should have been the best production environment for all the Cultivars and Doge the best cultivar if it was harvested at the third harvest time.

According to observations of scientist like Darby and Lauer (2002) and Johnson et al. (2002), whole plant silage maize should best be harvested at dry matter contents (DMC) in the range 28-35% for both maximum optimum yield and yield quality. Applying this theory to the experiments of Giessen, Gavott, KX2352 and Vitalina should have been best harvested at the fourth harvest time as it was the time they all had highest yields and optimum DMCs. Doge could not attain optimum DMC at any of the four harvest times undertaken. Being a late (FAO 700) cultivar Doge could still have done better if the growing season in Giessen could be prolonged and a fifth harvest time was possible.

Applying the same theory to the experiment of Gross-Gerau, Gavott, KX2352 and Vitalina should have been harvested at the third harvest time but with a lot of yield sacrifices except for Gavott where further delay to the fourth harvest dropped yield. Doge attained both highest yield and optimum DMC (30%) at the fourth (last) harvest time and so should best have been harvested at this time.

Impacts of cultivar and harvest time on heights

Maize heights affects yield and yield quality by influencing stover content (leaf: stem). Being a plant with determinate growth a maize plant will attain maximum height after tasseling. The time taken to tassel depends on variety especially from the point of view of maturity classification as well as genotype environmental interactions. In these experiments (Giessen and Gross-Gerau), with the exception of Doge, the rest of the cultivars were in middle late classification range. Because the milk stage (post tasseling) of Gavott dictated the first harvest date for all the cultivars, one should expect only Doge to have the potentials to further increase in height by virtue of its late maturity classification. This was however not the case in both locations as can be inferred from figures 4.1 (Gi) and 4.17 (GG). Hence maize height did not directly affect DMY in these experiments.

However, Doge (FAO 700) expectedly produced the tallest (261,8 cm) plants at the fourth harvest time. Vitalina (S 290) competed with Doge in height but produced the tallest (208,0 cm) plants at the first harvest. Gavott (S 250) out performed KX2352 (S 270) in height and contradicted the theory that short season cultivars are shorter than long season cultivars. These observations suggest lack of uniformity in field conditions. Hence genotype x environmental effects.

5.1.2 Impacts of cultivar and harvest time on chemical composition

Impacts of cultivar and harvest time on crude proteins

From table 4.3 (Gi) and table 4.32 (GG), each delay in harvest was observed to decrease CP of all the cultivars in both Giessen and Gross-Gerau. This agrees with the observations of Roth et al. (1994), Xu et al. (1995), Hunt et al. (1993) and Harrison et al. (1996). However the reactions to delaying harvest shown in Gross Gerau whereby CP plateaued in Gavott, KX2352 and Vitalina and slightly increased in Doge when the harvest time was delayed from third to fourth could not be explained. It could also be observed by comparing the two tables that maize produced more CP in Giessen (range 12,6-7,6%) than in Gross-Gerau (range 6,7-5,8%). CP was observed to also decrease faster by delaying harvest in Giessen than in Gross Gerau.

Impacts of cultivar and harvest time on fibre content

Maize fibres were measured as crude fibres, neutral detergent fibres and acid detergent fibres. Every delay in harvest decreased the contents of all the fibre types with significant decreases occurring mainly between the first and the third harvest times. The decreasing effect of delaying harvest on maize CF, ADF and NDF have also been observed by Roth et al. (1994), Xu et al. (1995), Hunt et al. (1993) and Harrison et al. (1996). In Giessen however Doge and Vitalina did not exactly conform to these general observations. The decreases in the contents of the different fibres in Doge were not very significant between the harvest times. Hence Doges Fibres were within a narrow range at all the four harvest times executed. The plateauing of NDF

shown by Vitalina at the first and second harvest could not find any tangible explanation. The situation in Gross-Gerau was different. Here all the fibre types decreased in a uniform manner for each delay in harvest. Using NDF as the most effective measure of fibre according to Hofmann et al. 2003 and Van Soest & Robertson (1980), it can be observed that maize were more fibrous in Giessen (NDF range 69.8-37.7) than in gross-Gerau (NDF rang 57-37.4%). Again the fibre contents decreased faster with each delay in harvest in Giessen than in Gross-Gerau. All indicating that maize were much matured in Gross-Gerau at each harvest time than in Giessen.

Impacts of cultivar and harvest time on sugar and starch contents

The results of maize sugar and starch contents are respectively presented in tables 4.8 (Gi) / 4.37 (GG) and tables 4.9 (Gi) / 4.38 (GG). According to these results each delay in harvest decreased maize sugar contents and increased starch contents accordingly in Gross-Gerau but not in Giessen. Decreasing sugar contents and increasing starch contents with increasing maturity of whole plant silage maize have also been observed by Cammel et al. (2000), Johnson et al. (2002) and Bal et al. (1997). In Giessen delaying harvest affected the sugar contents in a pattern that is contrary to these observations. The observation whereby Doge's starch content increased to the second harvest and decreased from there with further delay in harvest are not explicable as no previous literature on this could be found.

5.1.3 Impacts of cultivar and harvest time on ELOS content 2004

The impact of harvest maturity on the digestibility of whole plant silages of the different maize cultivars were estimated from values of their cell wall digestibility measured as enzyme soluble organic substances (ELOS). Delaying harvest increased the digestibility of all the maize cultivars as can be inferred from increasing ELOS values in table 4.7 (Gi) and 4.36 (GG). This is contrary to Hofmann et al. 2003 according to whom delaying harvest should decrease NDF digestibility of maize. However scientists like Holland and Kezar (1999) have also observed the digestibility of whole silage maize to decrease with advancing maturity. According to Holland and Kezar breeders have been attempting in the last few years to breed silage maize varieties in which advancing maturity does not necessarily result in decreasing fibre digestibility. All the maize cultivars used in this experiment were certified or released between 2000 and 2006. Hence the tendency that they were developed in accordance with this concept is suggested by the results. Considering the fact that both ADF and NDF decreased with increasing maturity this results should also not be surprising. Lignin which is expected to decrease digestibility is part of ADF (Hofmann et al. 2003). Hence decreasing ADF should possibly mean decreasing lignification everything being equal. Following this argument and the observations made in Giessen and Gross-Gerau it is also not surprising that maize cultivars from Gross-Gerau were highly digestible than those from Giessen. Maize is known to be unique among grass forages in that its grain contents that increases with advancing maturity offsets the decline in fibre content and composition usually observed with other grass forages (Johnson et al. 1999). The higher digestibility observed with samples from

Giessen therefore suggest maize from Gross-Gerau to have contained more grains than those from Giessen.

5.1.4 Impacts of cultivar and harvest time on biogas and methane in 2004

From the four cultivars only doge and Gavott from Gross-Gerau were digested for biogas production. Out of the four harvest times only the first, third and the fourth were sampled for this digestion. The results of the biogases produced together with their methane contents are presented in table 4.39 and figure 4.24. Gavott was observed to produce the highest biogas and specific methane volumes at the first harvest time but by the third and fourth harvest times, Doge out performed Gavott in both biogas and methane productivity. This agrees with observations of Oechsner et al. 2003 and Amon et al. 2003. According to these two authors early maize cultivars always perform better than late cultivars at the earlier harvest times but late in the growing season late cultivars are expected to outperform early cultivars.

Both biogas and methane productivity of both cultivars decreased with advancing maturity. Many observations made on silage maize as feed are still being applied to make judgements on the quality of whole plant silage maize used as feedstock for anaerobic digestion. Phipps et al. (2000); Farouzmand et al. (2005) and Sutton et al. (2000) found the concentrations of milk protein per unit volumes of total milk produced to decrease with advancing maturity of maize hybrids used as feed for dairy cows. This supports the observations made with methane here in that it explains the ability of a maize maturity stage to affect maize harvest quality which further affects the amount of protein which is just a component of milk like methane is a component of biogas. Another possibility to approximately describe these observations would be to compare the chemical compositions of each cultivar at the corresponding harvest times by applying Boswell's theoretical equation. This theory might have applied considering that decreasing CP was also accompanied by decreasing biogas and methane. Boswells theory stipulates carbohydrates to produce more biogas and less methane than CP and Deggendorf (2006) observed a starch content of at least 20 % to be necessary for good biogas and methane productivity. Both of these observations could not be defended using the results of this experiments.

5.2 Field and laboratory analysis 2005

5.2.1 Impacts of cultivar and harvest time on dry matter yield 2005

Tables 4.10 (Gi) and 4.40 (GG) showed each delay in harvest to increase the dry matter yield and dry matter contents of all the maize cultivars in accordance with Darby and Lauer (2002), Wiersma et al. (1993) and Farouzmand et al. (2005). However DMY of Gavott and KXA5226 decreased by delaying harvest from the third to the fourth harvest time in Gross-Gerau while Gavott in Giessen also showed a decrease in DMY also by delaying harvest from the third to the fourth harvest time. Wiersma et al. (1993) observed a plateauing of DMY after the black layer but not a decrease. This unexplained observation therefore might require further

investigations. By comparing the two tables one can also realise that yields in Gross-Gerau were higher for each cultivar including the late Mikado than in Giessen. This was also the observation made with the cultivars used in 2004. The maize cultivars are suggested here to be well adapted to conditions in Gross-Gerau than Giessen. By comparing the behaviour of Mikado (FAO 500) in Giessen and Gross-Gerau, Mikado's yield can be observed from the two tables to have increased at a very slow rate in Giessen than in Gross-Gerau. By delaying harvest from third to fourth Mikado added only 0,1dt/ha in Giessen compared with 6.1dt/ha in Gross-Gerau. The same comparison can also be made with the rest of the cultivars. The suggestion is that the cool climate in Giessen retarded Mikado's growth and developments very strongly.

The relationship between maize height and leaf area index to yield were not very clear as the highest yields were neither from the tallest plants nor from those with the highest leaf area indexes. Both LAI and height were measured only in Giessen

From table 4.11 (Gi) and 4.41 (GG) the cultivars were observed to attain optimum dry matter contents earlier in Giessen than in Gross-Gerau. This however inexplicably contrasted the observations of 2004 whereby the cultivars attained optimum DMC in earlier in Gross-Gerau than in Giessen.

In Giessen Gavott and KXA5226 had optimum DMCs at the second and third harvest times and were already too dry for anaerobic ensiling at the fourth harvest. Hence these two cultivars could have been harvested at any time between the second and the fourth harvest times. However, in order to maximise yield Gavott was best harvested at the third harvest and KXA5226 any time between the third and the fourth. Even though KXA5233 was a little beyond the optimum at the fourth harvest it was still best harvested here for the sake of yield maximisation. At the fourth harvest KXA5243 and Mikado both had only 33.8% and 25.3% DMCs. From the observations that both had the tendency to increase yields they could even be harvested later than the fourth harvest time.

In Gross-Gerau, only KXA5243 and Mikado attained dry matter contents within the optimum range. All the other cultivars failed to produce DMCs within this range. The best harvest time for all the cultivars here was the third harvest time despite the observations that each cultivars DMC was a little above optimum DMC. However harvesting at this suggested harvest time would have been advantageous for Gavott and KXA5226 as both had their maximum yields here. Harvesting KXA5233 and KXA5243 at the third harvest time would have mean sacrificing yields (-1,2dt/ha for KXA5233 and -6,2dt/ha for KXA5243). Mikado could have been harvested at the fourth harvest time also to maximise yield.

5.2.2 Impacts of cultivar and harvest time on chemical composition 2005

Impacts of cultivar and harvest time on crude proteins

The results of maize crude proteins presented in tables 4.12 (Gi) and 4.42 (GG) revealed that with the exception of Gavott, each delay in harvest decreased maize

CP of the rest of the cultivars both in Giessen and Gross-Gerau. Decreasing CP with advancing maize maturity has also been reported by Hunt et al. (1993) and Harrison et al. (1996), Wiersma et al. (1993) and Darby and Lauer 2002 as has also been observed in 2004. CP of all the maize cultivars were higher in Giessen (range 10,9% - 6,3%) than in gross-Gerau (range 6.5% - 4.6%). Maize CP contents within these ranges has also been reported by Etle and Schwarz (2003). CP also decreased faster in each cultivar in Giessen than in Gross-Gerau just as has been observed in the 2004 experiments. CP of Gavott in both locations decreased only to the third harvest and tended to increase at the fourth. The plateauing of CP seen in Gavott at the first and second harvest could not be explained.

Impacts of cultivar and harvest time on fibre content 2005

The results of maize crude fibre (CF) {tables 4.13 (Gi) and 4.43 (GG)}, neutral detergent fibre contents (NDF) {tables 4.14 (Gi) and 4.44 (GG)} and acid detergent fibre contents (ADF) {tables 4.15 (Gi) and 4.45 (GG)}, showed delaying harvest to have consistently decreased CF, NDF and ADF of all the cultivars in Giessen in agreement with Roth et al. (1994), Xu et al. (1995), Hunt et al. (1993). CF, NDF and ADF of the cultivars in Gross-Gerau did not show any such uniform reaction pattern to delaying harvest. Each cultivar reacted uniquely in a way that could not be explained using any known literature. The differences in CF contents of the cultivars between Giessen (range 30,6 -19,7) and Gross-Gerau (range 26,8 -17,1) were not very significant. The NDF values between Giessen (range 69,0 - 49,4) and Gross-Gerau (range 58,7- 40,2) were more significantly different than the CF values. Hence maize cultivars in Gross-Gerau had less cell wall than those in Giessen. This suggest that the cultivars ears had more developed grains in gross-Gerau than in Giessen. According to Hofmann et al. (2003) and Coors et al. (1997) increasing grains usually dilute increasing NDF of corn silage as stover ages. ADF values between Giessen (37,9 - 20,9) and Gross-Gerau (32,7- 20,3) were like CF values also very similar.

Impacts of cultivar and harvest time on sugar and starch contents 2005

In Giessen (table 4.17), maize sugar contents of Gavott, KXA5226 and KXA5233 decreased from first to third harvest and increased at the fourth. Sugar contents increased from first harvest to second harvest, decreased at the third and increased at the fourth in KXA5243 and Mikado. Johnson and McClure (1968) reported increased soluble carbohydrates in stalk from tasseling to milk stage and a decline thereafter with advancing maize maturity. In Gross-Gerau (table 4.47), delaying harvest decreased sugar contents of all the maize cultivars consistently from first to fourth harvest contrasting the observations of Johnson and McClure (1968). Starch contents of all the cultivars increased in both Giessen (tab 4.18) and Gross-Gerau (tab 4.48) steadily from first to fourth harvest in a pattern that agrees with variations shown by sugar contents. Generally maize starch is produced at the expense of sugar and so starch content is expected to increase as sugar contents decreases (Johnson and McClure 1968, Shaver et al. 2003; Coors 1996).

5.2.3 Impacts of cultivar and harvest time on ELOS content 2005

Delaying harvest as was seen in table 4.16 (Gi), affected the enzymes soluble substances (ELOS) of maize cultivars in pattern that don't seem to have been reported so far. However there was a tendency to decrease ELOS in KXA5226 and KXA5233 in agreement with Hofmann et al. 2003. In Gross-Gerau (table 4.46) delaying harvest tended to increase ELOS in Gavott, KXA5226 and KXA5233. In Mikado and KXA5243, on the other hand, delaying harvest instead tended to decrease ELOS. The increases and decreases were only possible from first to third harvest. It can generally be said that ELOS variations for each delay in harvest were inconsistent as were ADF and NDF. Both ADF and NDF are potential determinants of ELOS.

5.2.4 Impacts of cultivar and harvest time on biogas and methane 2005

The results of specific biogas and methane productivity of Gavott and KXA5233 shown in tables 4.19 (Gi) and 4.49 (GG) showed delaying harvest to directly decrease biogas productivity in Gross-Gerau but not in Giessen. In Giessen both cultivars produced their highest specific biogases and methane volumes at the third harvest and in Gross-Gerau at the first harvest time. Optimum dry matter content seem to have played a role in determining both biogas and methane productivity in Giessen. In Giessen both Gavott and KXA5233 had optimum DMCs only at the third harvest. In Gross-Gerau none of the three harvest times showed optimum dry matter content (DMC). Specific biogases and methane volumes are also higher in Gross-Gerau than in Giessen for both cultivars. The fact that lower dry matter contents (19.4% and 18.3%) produced more biogas than 40.5% for example, contradicts the role of optimum DMC (28 - 35%) in determining yield quality (Bal et al. 1997) but not Boswells theory. This observation therefore suggest biogas and methane productivity to depend on a complex of factors than just DMC or chemical composition.

5.3 Field and laboratory analysis 2006

The growing season of 2006 was not the best for maize production Germany wide. Besides the late frost in the early juvenile stages that resulted in chlorotic plants, there were droughts and very high temperatures during anthesis and grain filling stages. In 2006, Giessen and Gross-Gerau each had two uncommon cultivars However all were grown under the same conditions, harvested and analysed same times and using the same techniques. Maize samples were analysed for the same chemical components as those of 2004 and 2005. The maturity ratings of the cultivars in Giessen ranged from middle early (S240) to middle late (S290) and in Gross-Gerau from middle early (S250) and Middle late (S270-290) to late (S300-S350).

5.3.1 Impacts of cultivar and harvest time on dry matter yield 2006

By comparing tables 4.20 (Gi) and 4.50 (GG), each delay in harvest was observed to lead to increases in the dry matter yields (DMY) of all the maize cultivars in Giessen

as well as Gross-Gerau. These observations have been made for both stations in 2004 as well as 2005. The yields of all the cultivars increased significantly between the harvest times in Giessen compared with Gross-Gerau. When the yields of Gavott, KXA5243 and KXA5233 between the two stations were compared, they were observed to be higher in Giessen than in Gross-Gerau. In 2005 these same cultivars gave higher yields in Gross-Gerau than in Giessen. The observed shift in performance from Gross-Gerau to Giessen in 2006 suggest the bad weather to have had a negative effect in Gross-Gerau and a positive effects in Giessen. The drop in yield of Gavott by delaying harvest from third to the fourth harvest time observed here has also been observed in 2004 and 2005. Although no literature was found documenting this, it remains a remarkable observation and need further explanation.

The results of maize dry matter contents presented in tables 4.21 (Gi) and 4.51 (GG) showed that with the exception of Atletico in Giessen, every delay in harvest also steadily increased the dry matter contents of all the other cultivars in Giessen as well as in Gross-Gerau. The sharp decrease in DMC of Atletico from first to second harvest doesn't seem to have been documented before. In both stations the majority of the cultivars attained optimum DMCs at the third harvest. However in order to maximise yield, all the cultivars in Giessen with the exception of Atletico, Beatus and Magitop were best harvested at the fourth harvest time. The best time to harvest Atletico, Beatus and Magitop should have been a little latter than the third but before the fourth harvest time. In Gross-Gerau the majority of the cultivars were best harvested at the third harvest time. However in order to maximise yield, all with the exception of Gavott should have best been harvested at a time later than the third but before the fourth harvest time. Like in 2004 and 2005 maize height and leaf area index (considered only in Giessen) did not have a direct influence on yield.

5.3.2 Impacts of cultivar and harvest time on chemical composition 2006

Impacts of cultivar and harvest time on crude proteins

Upon comparison of tables 4.22 (Gi) and 4.552 (GG), CP of all cultivars was observed to decreased from first harvest to the second in Giessen and from the third to the fourth in Gross-Gerau. In Giessen CP increased from the second harvest to the fourth in Gavott and KXA5233 but increased to the third and dropped at the fourth in Magitop, KXA5243 and Atletico. Beatus showed a different reaction to delay harvest. In Beatus CP increased significantly from first to the second harvest, decreased at the third and increased at the fourth. In Gross-Gerau CP also was observed to decrease from the first harvest time to the second in Gavott, KXA5243, Baxter and fiacre. From the second harvest CP increased to the third and decreased to the fourth in all these cultivars. KXA5233 and Atletico both showed plateauing of CP at the first and second harvest. From this plateau CP decreased to the fourth harvest. No literature could be found documenting these complex reactions of CP to harvest delay.

Impacts of cultivar and harvest time on fibre content

Tables 4.23 (Gi) and 4.53 (GG) showed the cultivars in Giessen (32 -19,0%) to contain more crude fibres (CF) than those in Gross-Gerau (25 -14,8%). In Gavott (in both Giessen and Gross-Gerau), KXA5243 Atletico and Baxter (in Gross-Gerau alone) every delay in harvest decreased CF steadily from first to fourth harvest time in accordance with, Xu et al. (1995) and Hunt et al. (1993). In the rest of the cultivars CF decreased from first harvest to the second, increased at the third and decreased at the fourth. These observations are to be seen as unique but no literature could be found to support them.

The results of NDF are to be found in tables 4.24 (Gi) and 4.54 (GG). From these tables NDF of maize cultivars in both Giessen and Gross-Gerau were found to inconsistently vary for each delay in harvest. In Giessen each delay in harvest steadily decreased the NDF of Gavott and KXA5233. In the rest of the cultivars NDF decreased from first harvest to the second harvest, increased from the second to the third and decreased from the third to the fourth harvest time. In Gross-Gerau only Baxter showed a continuous decrease in NDF with advancing maturity. In KXA5233 NDF decreased to a plateau at the second and third harvest, and further decreased at the fourth. In KXA5243 NDF decreased to a plateau at the third and fourth harvest while NDF of Gavott and Fiacre decreased from first to second, increased from second to the third and again decreased from the third to the fourth harvest. All the cultivars had more cell wall (NDF) in Giessen (69,7- 40,1%) than in Gross-Gerau (57,4 - 39,5%).

Tables 4.25 (Gi) and 4.55 (GG) presents the results of maize acid detergent fibres (ADF). The tables show the cultivars in Giessen (41,1-21,7%) to have more ADF than those in Gross-Gerau (30,0-17,5%). Delaying harvest induced a pattern of variations in NDF similar to those of CF in Giessen. In Gross-Gerau this was not the case. Here delaying harvest decreased ADF in KXA5233 from first to second harvest, increased it from the second to the third harvest and again decreased it from the third to fourth harvest. In the rest of the cultivars each delay in harvest steadily decreased ADF. Decreasing CF, ADF and NDF with advancing maize maturity has been reported by many scientists like Roth et al (1994), Xu et al. (1995), Hunt et al. (1993) and Harrison et al. (1996).

Impacts of cultivar and harvest time on sugar and starch contents

In tables 4.27 (Gi) and 4.57 (GG) maize cultivars in Gross-Gerau (21,5 - 9,0%) were shown to have more sugar than those in Giessen (20,2 - 7,0%). Delaying harvest steadily decreased sugar contents in all the cultivars in Gross-Gerau to the third harvest and increased it at the fourth. In Giessen on the other hand, Sugar contents of all cultivars increased to remarkable high values at the second harvest and decreased steadily from here to the fourth except in Magitop. In Magitop it decreased at the third harvest and increased at the fourth. Delaying harvest increased starch contents of all the cultivars in Giessen (tab 4.28) and Gross-Gerau (tab 4.58) as has been observed so far in the experiments and analysis of 2004 and 2005 in both

locations. The starch contents were comparatively higher in gross-Gerau than in Giessen.

5.3.3 Impacts of cultivar and harvest time on ELOS content 2006

By comparing tables 4.26 (Gi) and 4.56 (GG) delaying harvest was observed to have different effects on ELOS of the individual maize cultivars in Giessen and Gross-Gerau.

In Giessen ELOS were significantly different only between the first and the second harvest for all cultivars and between the third and the fourth for Gavott. Delaying harvest increased ELOS of all cultivars to the second and decreased at the third. A further delay from third to the fourth increased ELOS in all except in KXA5243 in which ELOS instead decreased. With the exception of the first and the second harvest times, ELOS did not vary significantly among the cultivars and between the rest of the harvest times. All the cultivars produced ELOS within the range 79,5-49,5% which is considered as normal for maize and have also been measured with brown midrib maize cultivars (Oba and Allen 1999a and 1999b)

In Gross-Gerau delaying harvest steadily increased ELOS in all the cultivars up to the third harvest. A further delay in harvest from the third to the fourth harvest however increased ELOS in Fiacre but decreased it in all the other cultivars. The variations in ELOS were neither significant among the cultivars nor between the harvest times. All the cultivars produced ELOS within the range 73,1- 61,2% which is also in accordance with Oba and Allen 1999a and 1999b. Increasing as well as decreasing digestibility of whole plant silage maize with advancing maturity has been reported by Hofmann et al. 2003 and Johnson et al. 1999 respectively.

5.3.4 Impacts of cultivar and harvest time on biogas and methane 2006

When the results of maize biogases between Giessen (4.29) and Gross-Gerau (Table 4.59) were compared, Magitop (S240) in Giessen was observed to produce not only the lowest specific biogas (444 nL/kg VS) and methane (237nL/kg) in 2006 but also of all the experimental years described in this thesis. In Gross-Gerau Gavott (S 250) produced the lowest specific biogas (533nL /kg VS) but the lowest specific methane was produced by Atletico (S 260). With the exception of Magitop in Giessen, Baxter(S 300) and Fiacre(S 350) in Gross-Gerau, all the other cultivars produced more biogas and methane in Giessen than in Gross-Gerau.

When the specific biogas and methane productivity of Fiacre(S 350) and Atletico (S 260) were compared at the third and the fourth harvest times, both biogas and methane were found to increase with increasing dry matter contents. By comparing Atletico (S 260) and KXA5243 (S290) in Giessen both biogas and methane productivity decreased with increasing dry matter contents. This observations reveals that the dry matter content within the range 28-35 % might be important for preservability but not necessarily for maximum biogas and methane productivity.

6 Conclusions

From the results and discussions of the above described experiments the following conclusions could be drawn:

The linear increase in dry matter yield (DMY) and dry matter contents (DMC) observed by delaying harvest for all the cultivars over the three years in Giessen as well as in Gross-Gerau showed delaying harvest to be a way to maximise yield as well as optimise DMC. However, the extent to which this can be done strongly depended on the cultivars chosen and their adaptability to the ecosystem in which they were grown. In the experiments of 2004 and 2005 Gross-Gerau was proven to be a much suitable environment for both middle early and late cultivars. The late maturing cultivars, Mikado (FAO 500) and Doge (FAO700) did not only attain higher yields in Gross-Gerau than in Giessen but also achieved optimum dry matter contents at the third and fourth harvest time which was also the time they both had maximum yields. Besides the impacts of location maize dry matter yield and dry matter contents were also found to depend on cultivars maturity class.

The reverse of high yields from Gross-Gerau to Giessen as a results of bad weather was proven in 2006 when the cultivars Gavott, KXA5233 and KXA5243 which yielded higher in Gross-Gerau in 2005 than in Giessen were observed to perform better in Giessen in 2006 compared with Gross-Gerau.

Unlike dry matter yield and dry matter contents, and with the exception of starch contents and the NIRS results of 2004, the impact of delaying harvest on the chemical composition were shown to be very unpredictable. However the cultivars did differ in their ability to accumulate the different chemical components. The impacts of location and cultivar on chemical composition were much clearer than the impact of harvest time. Giessen proved to favour crude protein, fibres and sugar formation than Gross-Gerau. However the cultivars showed higher starch contents in Gross-Gerau than in Giessen. The higher ELOS values shown by the cultivars when grown in Gross-Gerau as compared with Giessen further increased the validity of these observations in accordance with Hoffman et al 2003 and Johnson et al 1999.

Biogas and methane productivity were shown to depend on harvest time, cultivar as well as on the environments (location) in which the given cultivar was grown. The rates of increase or decrease in biogas and methane productivity were found to also depend on the maturity class of the cultivar in question.

In 2004 biogas and methane productivity which were produced only from samples grown in Gross-Gerau showed both biogas and methane productivity to decreased with advancing maize maturity. The decrease were also shown to be faster for the early cultivar (Gavott S 250) than for the late cultivar (Doge FAO 700). This lead to the late cultivars outperforming the early cultivars in accordance with Oechsner et al. 2003.

In 2005 biogas and methane increased from lower values at the first harvest to a maximum at the third from where it decreased at the fourth in Giessen. The same cultivars grown in Gross-Gerau showed instead decreasing biogas and methane with advancing maturity. KXA5233 (S 260) could be observed to outperformed Gavott (S 250) in both Giessen and Gross-Gerau.

In 2006 biogas and methane were observed to decrease with advancing maturity in Giessen but to increase in Gross Gerau. The late cultivars (Fiacre S 350 and Baxter S 300) again outperformed the earlier ones in Gross-Gerau. However by comparing the cultivars in Giessen to those in Gross-Gerau, both biogas and methane productivity were found to be higher in Giessen than in Gross-Gerau and the late cultivars in Gross-Gerau did not outperformed all the middle early cultivars in Giessen. While the impact of cultivar on maize chemical composition, biogas and methane productivity seemed to be clear, the impacts of harvest time all the three factors (chemical composition, biogas and methane) proved very obscured. In the same way the impact of maize chemical composition on biogas or methane productivity could not also be clearly defined.

The hypothesis at the beginning of the thesis that dry matter, biogas and methane yields are functions of genotype, maturity at harvest, and location can be said to have hold true according to the observations made with the experiments. However the hypothesis by which delaying harvest was expected to increase dry matter yield biogas and methane yields could not be established. That higher specific biogas volumes also should yield higher specific methane volumes was proven true in all the locations and experimental years.

Summary

Biogas is an alternative source of methane and can be used as a renewable substitute for natural petroleum gas. The major challenges faced by producers of biogas from energy crops like maize are the ability to choose appropriate genotypes and maturity stage to harvest for optimum dry matter, biogas and methane yields.

In 2004, 2005 and 2006, a germplasm consisting of four maize inbred lines and nine cultivars (hybrids) were selectively planted in combination with 4 harvest times at the research stations Giessen and Gross-Gerau. In the field experiments a randomised design in four blocks each with four replications was used. Each block with its four replications represented a harvest time. The cultivar Gavott (S 250) was used as a standard determining the first harvest time at the maturity stage milking ripeness. The second harvest time followed the first two weeks later, the third also followed the second two weeks later and the fourth followed the third also two weeks later. In all 6 experiments plant length, dry matter content and dry matter yield were measured. During maize growth leaf area index (LAI) only in Giessen 2005 and 2006 were determined. At each of the four harvest times samples were taken and NIRS analysis to determine crude protein (CP), crude fibre (CF), neutral detergent fibre (NDF), acid detergent fibre (ADF), sugar, starch and enzymes soluble substances (ELOS) were executed. Biogas and methane productivity (measured in batch digester) were determined only in first, third and fourth harvest time.

LAI showed significant cultivar harvest time interactions only in 2005. With the exception of Gavott the rest of the cultivars showed higher LAI in 2005 (LAI 4 – 5) compared to the drought affected experiments of 2006 (LAI 3 – 4). Late cultivars and inbred lines were clearly taller than the early ones in Giessen as well as in Gross-Gerau. The impact of location was such that both the early and late cultivars were taller in Gross-Gerau than in Giessen. In most cases there was no correlation between maize length and LAI.

Statistical evaluation of data from all the experimental years and locations showed significant cultivar and harvest time interactions in dry matter yield as well as in all chemical compounds (CP, CF, ADF, NDF, sugar, starch, ELOS) measured in both stations Giessen and Gross-Gerau. Delaying harvest proved a way to increase dry matter yield and dry matter concentration but not optimum biogas yield and methane content. Late cultivars and new inbred lines tended to produce more dry matter yield, biogas and methane than their early counterparts. Besides the impacts of cultivar and harvest time, dry matter yield, biogas and methane productivity also seemed to have been affected by location. Maize ELOS significantly increased with delaying harvest but there was no correlation between ELOS and biogas productivity. It can be concluded, that dry matter content, dry matter yield, biogas yield and methane yield of maize are functions of genotype, maturity at harvest and location.

Key words: Maize, biogas, methane, harvest time, cultivars

Zusammenfassung

Biogas ist eine alternative Methanquelle und kann als erneuerbare Ressource statt natürlichem Erdgas genutzt werden. Die größten Zweifel beziehen sich auf die Produktion von Biogas, die auf dem Anbau von Energiepflanzen wie zum Beispiel Mais beruht. Denn dafür werden die Energiepflanzen durch veränderte Genotypen und andere Reifestadien auf hohen Trockenmasseertrag, Biogasgewinn und Methangehalt optimiert.

In den Jahren 2004, 2005 und 2006 wurde ein Feldversuch mit Mais sowohl auf der Versuchsstation Gießen als auch in Groß-Gerau angelegt. Der Versuch bestand aus vier Inzuchtlinien und neun Hybridsorten. Jede Sorte wurde auf vier unterschiedliche Erntezeitpunkte getestet. Die Versuchsvarianten wurden randomisiert in vier Blöcken mit jeweils vier Wiederholungen angeordnet. Jeder Block hatte einen anderen Erntezeitpunkt. An der Sorte „Gavott“ (S 250) wurde der Erntezeitpunkt anhand der Entwicklungsphase Milchreife als Standard festgelegt. Die anderen Erntetermine folgten jeweils im Abstand von zwei Wochen. Es wurden Pflanzenlänge, Trockenmassegehalt, und Trockenmasseertrag gemessen. In Gießen wurde der Blattflächenindex (engl. leaf area index: LAI) während des Wachstums 2005 und 2006 gemessen. Von allen vier Erntetermin-Varianten wurden Proben genommen und mit Hilfe von NIRS analysiert um Rohprotein, Rohfaser, in neutralen Detergenzien unlösliche Faser (engl. neutral detergent fibre: NDF), in sauren Detergenzien unlösliche Fasern (engl. acid detergent fibre: ADF), Zucker, Stärke und enzymlösliche Substanzen (engl. enzymes soluble substances: ELOS) zu erfassen. Biogas und Methanproduktivität (gemessen in der Einzelproben-Biogasanlage) wurden für die Varianten des ersten, dritten und des vierten Erntetermins gemessen.

Der Blattflächenindex zeigt nur in 2005 signifikante Wechselwirkungen zwischen den Erntezeitpunkten. Mit Ausnahme der Sorte „Gavott“ zeigten alle Sorten einen höheren Blattflächenindex in 2005 (LAI 4–5) im Vergleich zu den Versuchen im verhältnismäßig trockenen Jahr 2006 (LAI 3-4). Späte Sorten und Inzuchtlinien wurden unabhängig vom Standort größer als frühe Sorten. Der Standortfaktor zeigte sich nur insofern, dass sowohl die frühen als auch die späten Sorten in Groß-Gerau eine höhere Pflanzenlänge als in Gießen erreicht haben. In den meisten Fällen bestand keine Korrelation zwischen Pflanzenlänge und LAI.

Die statistische Auswertung der Daten von allen Versuchsjahren und –Standorten ergab einen signifikanten Unterschied zwischen den Faktoren Sorte und Erntezeitpunkt sowohl in Bezug auf den Trockenmasseertrag als auch bezüglich der chemischen Komponenten (RP, RF, ADF, NDF, Zucker, Stärke, ELOS); in Gießen und ebenfalls in Groß-Gerau. Verzögerte Ernte erwies sich als eine Möglichkeit den Trockenmassegehalt und den Trockenmasseertrag zu steigern. Den optimalen Biogasertrag und Methangehalt erreicht man damit jedoch nicht. Späte Sorten und neue Inzuchtlinien tendieren zu einem erhöhten Trockenmasseertrag, Biogas- und Methangehalt im Vergleich zu ihren Vorgängern. Zusätzlich zum Einfluss der Sorte und des Erntezeitpunktes, des Trockenmasseertrages, der Biogas- und Methanproduktivität scheint es noch einen Effekt durch den Faktor Standort zu geben. Die enzymlösliche Substanz (ELOS) von Mais steigt signifikant mit einer verzögerten Ernte, aber es gibt keine Korrelation zwischen ELOS und der Biogasproduktivität.

Zusammenfassend kann man sagen, dass der Trockenmassegehalt, der Trockenmasseertrag, der Biogasertrag und Methanertrag von Mais vom Genotyp, Entwicklungsphase zur Ernte und dem Standort beeinflusst wird.

Schlüsselwörter: Mais, Biogas, Methan, Erntezeitpunkt, Sorten

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Appendices

1.GG 2004

CV	HT	DMY dt/ha	%DMC	SL(cm)
1	1	118,0	23,5	250,0
1	2	145,3	28,3	240,0
1	3	158,8	35,1	250,0
1	4	149,2	43,3	250,0
2	1	125,1	21,7	250,0
2	2	163,1	26,6	260,0
2	3	170,3	33,7	250,0
2	4	175,7	43,4	290,0
3	1	125,9	20,9	290,0
3	2	164,5	26,6	290,0
3	3	172,2	32,0	290,0
3	4	172,0	41,0	290,0
4	1	112,7	17,7	310,0
4	2	148,9	19,9	330,0
4	3	171,9	23,1	320,0
4	4	182,9	30,0	3,2
<hr/>				
1		142,81	32,53	247,00
2		158,55	31,36	255,00
3		158,64	30,11	291,00
4		154,10	22,68	320,00
<hr/>				
	1	120,45	20,95	275,00
	2	155,46	25,36	281,00
	3	168,29	30,94	270,00
	4	169,91	39,43	279,00
<hr/>				
CV p-value		0,00	0,00	0,00
HT		0,00	0,00	0,28
CV*HT		0,00	0,00	0,00
<hr/>				
CV LSD				
5%		5,29	0,58	0,07
HT		5,29	0,58	ns
CV*HT		10,6	1,16	0,14

1.GG 2004

CV	HT	CP%	CF(%)	NDF(%)	ADF(%)	S(%)	ST(%)	ELOS(%)
1	1	6,7	23,4	51,7	27,8	14,2	14,1	63,3
1	2	6,2	18,5	41,3	22,4	10,5	29,9	70,5
1	3	5,7	17,3	39,3	20,8	7,1	37,7	71,8
1	4	5,7	15,9	37,4	19,9	6,1	41,9	73,2
2	1	6,7	24,5	54,3	29,3	16,9	8,2	62,7
2	2	6,2	18,9	41,8	22,8	10,7	29,0	70,2

2	3	5,8	17,3	39,5	21,0	7,3	37,4	71,7
2	4	5,8	15,3	36,7	19,2	5,9	43,4	74,1
3	1	6,2	26,2	56,1	31,6	16,8	6,3	60,5
3	2	6,0	19,2	42,5	23,3	11,0	27,9	69,8
3	3	5,7	17,6	39,9	21,4	7,6	36,5	71,3
3	4	5,7	15,9	37,7	19,8	5,9	42,6	73,3
4	1	6,4	27,3	57,8	33,0	16,1	5,6	58,8
4	2	6,0	20,5	44,8	24,8	11,9	24,4	68,1
4	3	5,5	18,9	41,9	22,9	8,8	32,6	69,8
4	4	5,6	17,0	39,3	21,1	6,5	39,6	71,9
1		6,06	18,76	42,41	22,70	9,45	30,89	69,69
2		6,11	19,00	43,04	23,04	10,20	29,48	69,65
3		5,90	19,73	44,03	24,01	10,31	28,33	68,73
4		5,86	20,91	45,94	25,45	10,81	25,53	67,13
	1	6,50	25,37	54,94	30,38	15,99	8,54	61,31
	2	6,08	19,25	42,58	23,32	11,03	27,80	69,64
	3	5,67	17,76	40,13	21,53	7,68	36,03	71,14
	4	5,68	16,03	37,77	19,98	6,08	41,86	73,11
CV	p-value	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	HT	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	CV*HT	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CV	LSD 5%	0,1	0,26	0,36	0,33	0,16	0,6	0,36
	HT	0,1	0,26	0,36	0,33	0,16	0,6	0,36
	CV*HT	0,2	0,51	0,26	0,67	0,32	1,19	0,71

2.GG 2005

CV	HAT	DM(dt/ha)	DM%	RP%	RF%	NDF%	ADF%	ELOS	ST%	S%
1	1	118,4	19,4	6,5	21,9	51,9	26,5	68,2	11,7	17,5
1	2	164,5	27,9	6,5	18,1	43,9	21,5	71,5	29,1	11,1
1	3	182,2	40,5	6,0	17,1	42,5	20,3	72,4	37,7	6,8
1	4	180,7	46,5	6,1	17,1	40,2	20,4	72,1	40,4	4,2
2	1	128,0	17,9	5,9	24,9	55,0	30,9	63,7	7,2	19,4
2	2	182,5	25,9	5,6	21,8	49,0	25,9	67,5	20,9	13,1
2	3	202,4	38,4	5,5	19,5	46,2	23,5	69,3	34,2	7,8
2	4	201,8	47,7	4,9	21,6	48,0	25,6	66,2	35,8	2,6
3	1	126,0	18,4	6,0	22,9	53,4	27,6	67,5	7,4	19,6
3	2	194,9	26,7	5,7	20,1	47,7	23,3	69,7	21,5	13,4
3	3	199,9	39,1	5,4	19,2	45,3	23,8	69,3	31,1	10,0
3	4	200,7	42,5	4,9	20,7	45,5	24,6	67,0	31,7	6,4
4	1	113,8	15,8	6,2	26,3	58,7	31,4	63,4	1,4	19,4
4	2	169,5	22,5	5,3	26,2	56,2	31,2	61,4	6,9	16,2
4	3	180,6	34,9	5,2	25,6	55,3	30,2	60,5	19,4	8,5
4	4	186,8	40,5	5,2	23,1	45,5	27,5	62,8	30,9	4,5
5	1	109,0	14,6	6,1	25,3	57,3	31,2	63,5	2,7	20,7
5	2	165,3	20,2	5,4	26,4	57,8	31,6	61,1	3,6	17,9
5	3	196,1	30,6	4,9	26,8	56,8	32,7	58,0	12,9	12,7
5	4	202,2	36,2	4,6	25,6	53,5	30,2	59,8	25,4	4,5
1		161,43	33,58	6,25	18,52	44,63	22,17	71,06	29,73	9,89
2		178,66	32,46	5,48	21,95	49,54	26,44	66,64	24,50	10,69
3		180,37	31,66	5,49	20,72	47,98	24,84	68,38	22,91	12,35
4		162,67	28,41	5,48	25,29	53,89	30,08	62,01	14,65	12,13
5		168,13	25,39	5,26	26,01	56,33	31,40	60,59	11,16	13,91

	1	119,03	17,20	6,16	24,25	55,25	29,51	65,26	6,08	19,32
	2	175,32	24,64	5,69	22,50	50,92	26,71	66,24	16,40	14,33
	3	192,23	36,68	5,40	21,64	49,20	26,09	65,88	27,05	9,12
	4	194,43	42,69	5,13	21,61	46,54	25,65	65,58	32,84	4,42
CV	p-value	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
HT		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CV*HT		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CV	LSD									
5%		8,85	1,53	0,28	0,84	1,23	1,2	1,35	1,31	0,98
HT		7,91	1,37	0,25	0,75	1,10	1,0	1,21	1,18	0,87
CV*HT		17,7	3,07	0,57	1,67	2,45	2,3	2,7	2,63	1,95

3.GG 2006

CV	HT	DMdt/ha	DM %	SL(cm)
1	1	127,1	25,5	243,0
1	2	150,0	28,1	245,0
1	3	166,6	33,6	238,5
1	4	157,1	38,6	257,0
2	1	143,8	23,0	290,3
2	2	159,2	24,8	286,0
2	3	173,9	27,8	293,5
2	4	171,8	35,1	294,5
3	1	129,8	20,4	304,5
3	2	160,5	23,2	299,3
3	3	171,2	27,8	294,3
3	4	189,0	33,4	288,8
4	1	141,4	23,5	256,0
4	2	168,7	27,1	282,5
4	3	177,0	33,0	277,8
4	4	186,3	39,0	270,8
5	1	118,8	21,9	273,0
5	2	148,2	25,0	277,3
5	3	156,9	27,8	269,3
5	4	172,2	37,2	270,8
6	1	128,4	23,2	279,5
6	2	163,3	27,0	284,3
6	3	186,0	31,3	286,8
6	4	202,3	40,5	266,0
1		150,18	31,40	245,88
2		162,14	27,67	291,06
3		162,61	26,19	296,69
4		168,35	30,64	271,75
5		149,04	27,98	272,56
6		169,99	30,49	279,13
	1	131,55	22,91	274,38
	2	158,31	25,83	279,04
	3	171,92	30,20	276,67
	4	179,77	37,30	274,63
CV	P value	0,00	0,00	0,00
HT	Pvalue	0,00	0,00	0,64
CV*HT		0,00	0,00	0,00
CV	LSD5%	11,56	1,08	9,58
HT		9,44	0,88	ns

CV*HT **23,12 2,15 19,16**

3.GG 2006

CV	HT	RP(%)	RF(%)	NDF(%)	ADF(%)	ELOS	S(%)	ST(%)	SL(cm)
1	1	7,4	19,1	46,9	23,0	68,6	15,3	20,3	243,0
1	2	7,3	15,6	40,4	18,6	72,7	11,7	32,5	245,0
1	3	7,4	15,2	39,5	18,0	73,1	8,6	37,6	238,5
1	4	6,4	14,8	40,0	17,5	72,6	11,3	36,2	257,0
2	1	6,5	22,7	54,0	27,0	64,4	20,5	6,4	290,3
2	2	6,5	19,6	47,4	22,9	68,4	17,8	14,6	286,0
2	3	6,8	20,0	47,9	23,4	67,6	13,5	20,8	293,5
2	4	5,9	16,7	44,9	19,4	70,2	16,3	24,0	294,5
3	1	6,7	24,3	57,4	29,3	61,2	21,5	2,2	304,5
3	2	6,2	23,1	54,0	27,5	63,2	19,6	7,5	299,3
3	3	6,9	21,2	48,9	24,7	66,4	13,8	17,9	294,3
3	4	5,7	19,7	48,9	23,2	66,3	15,4	21,3	288,8
4	1	6,9	21,0	51,0	25,4	66,4	18,0	13,6	256,0
4	2	6,9	17,1	43,9	20,7	70,7	14,2	27,3	282,5
4	3	7,2	16,2	42,5	19,3	71,8	10,8	33,1	277,8
4	4	6,3	15,7	42,6	18,8	71,0	12,1	34,5	270,8
5	1	7,1	22,2	54,8	26,5	64,0	20,7	7,1	273,0
5	2	6,9	19,4	46,6	22,8	68,7	15,4	23,6	277,3
5	3	7,0	19,0	44,7	22,1	69,1	10,5	27,5	269,3
5	4	6,4	16,8	42,1	19,8	71,1	11,7	32,7	270,8
6	1	6,6	21,8	52,5	25,7	65,3	19,1	11,0	279,5
6	2	6,4	18,2	43,1	21,1	70,6	12,5	30,0	284,3
6	3	6,5	16,8	40,6	19,8	72,5	9,0	32,8	286,8
6	4	6,1	15,3	67,4	18,1	72,9	10,7	37,8	266,0
1		7,09	16,17	41,69	19,26	71,73	11,70	31,62	245,88
2		6,41	19,73	48,55	23,18	67,61	17,01	16,45	291,06
3		6,34	22,04	52,29	26,16	64,25	17,58	12,19	296,69
4		6,81	17,51	44,96	21,03	69,96	13,78	27,11	271,75
5		6,83	19,36	47,04	22,79	68,21	14,56	22,72	272,56
6		6,38	18,03	50,89	21,18	70,31	12,82	27,88	279,13
1		6,83	21,85	52,76	26,14	64,95	19,19	10,09	274,38
2		6,66	18,84	45,88	22,28	69,02	15,18	22,56	279,04
3		6,95	18,06	43,99	21,20	70,08	11,02	28,26	276,67
4		6,13	16,47	47,65	19,44	70,66	12,91	31,06	274,63
CV	P value	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
HT	Pvalue	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,64
CV*HT		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CV	LSD5%	0,23	0,63	4,45	0,76	0,87	1,04	2,48	9,58
HT		0,19	0,52	3,63	0,19	0,71	0,85	2,03	ns
CV*HT		0,47	1,3	8,9	1,51	1,73	2,08	4,97	19,16

Field experiment Giessen 2004

4.GI 2004

CV	HT	DMdt/ha	DM %	SL(cm)
1	1	62,86	18,20	195,00
1	2	69,10	24,70	172,00
1	3	90,68	26,73	177,75
1	4	122,33	30,98	191,00
2	1	75,37	17,03	195,25
2	2	88,57	22,95	166,50
2	3	108,68	25,80	176,50
2	4	137,54	29,88	184,00
3	1	69,73	16,50	208,00
3	2	79,99	22,38	190,00
3	3	106,44	25,05	194,00
3	4	139,70	29,68	207,00
4	1	66,79	14,03	202,75
4	2	88,04	17,13	218,00
4	3	114,60	18,10	242,75
4	4	144,40	18,95	261,75
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HT 1		68,69	25,15	183,94
2		81,42	23,91	180,56
3		105,10	23,40	199,75
4		135,99	17,05	231,31
<hr/>				
CV	1	86,24	16,44	200,25
	2	102,54	21,79	186,63
	3	98,96	23,92	197,75
	4	103,46	27,37	210,94
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CV		0,000	0,000	0,000
HT		0,000	0,000	0,020
CV*HT		0,000	0,000	0,000
<hr/>				
CV	LSD 5%	11,96	0,86	14,20
HT		11,96	0,86	ns
CV*HT		23,92	1,71	28,39

NIRS analysis Giessen 2004

4.GI 2004

CV	HT	CP(%)	CF(%)	NDF(%)	ADF(%)	S(%)	ST(%)	ELOS
1	1	11,28	30,18	67,98	36,63	10,15	5,45	48,58
1	2	9,78	22,55	51,88	26,48	8,70	22,45	63,28
1	3	8,38	17,15	41,53	20,55	8,70	32,90	71,85
1	4	7,48	15,53	37,73	18,40	9,73	36,50	73,48

2	1	11,38	30,15	68,40	36,68	11,48	4,20	48,73
2	2	10,00	25,63	57,70	30,08	9,73	13,93	58,33
2	3	8,28	19,23	44,50	22,98	11,60	25,23	69,78
2	4	7,33	16,20	38,93	19,20	10,58	34,53	73,35
3	1	11,08	30,93	69,23	37,68	11,13	4,10	48,05
3	2	10,13	26,08	58,60	37,68	9,23	13,83	57,95
3	3	8,30	19,35	45,18	23,35	11,68	25,08	69,58
3	4	7,28	17,45	41,25	20,83	11,20	30,73	71,33
4	1	12,58	31,05	69,80	39,38	14,15	6,48	46,23
4	2	11,68	29,33	65,53	36,70	11,60	9,15	50,83
4	3	8,85	27,63	58,95	33,38	14,35	5,18	57,23
4	4	7,60	24,03	52,63	29,00	20,18	3,23	64,20
1		9,23	21,35	49,78	25,51	9,32	24,33	64,29
2		9,24	22,80	52,38	27,23	10,84	19,47	62,54
3		9,19	23,45	53,56	29,88	10,81	18,43	61,73
4		10,18	28,01	61,73	34,61	15,07	6,01	54,62
	1	11,58	30,58	68,85	37,59	11,73	5,06	47,89
	2	10,39	25,89	58,43	32,73	9,81	14,84	57,59
	3	8,45	20,84	47,54	25,06	11,58	22,09	67,11
	4	7,42	18,30	42,63	21,86	12,92	26,24	70,59
CV		0,00	0,00	0,00	0,00	0,00	0,00	0,00
HT		0,00	0,00	0,00	0,00	0,00	0,00	0,00
CV*HT		0,00	0,00	0,00	0,00	0,00	0,00	0,00
CV		0,44	0,76	1,12	0,83	0,73	1,18	1,21
HT		0,44	0,76	1,12	0,83	0,73	1,18	1,21
CV*HT		0,89	1,53	2,24	1,66	1,46	2,37	2,43

5.GI2005

CV	HT	DMdt/ha	DM %	SL(cm)	LAI
1	1	108,95	18,98	218,38	3,50
1	2	143,65	28,00	220,63	3,85
1	3	152,75	33,38	216,75	3,73
1	4	147,90	40,55	222,38	3,33
2	1	114,43	16,85	245,13	4,40
2	2	147,73	23,00	247,75	5,38
2	3	173,20	29,60	250,63	5,00
2	4	183,38	38,13	249,13	4,80
3	1	120,28	17,05	258,00	4,18
3	2	163,20	24,25	247,75	4,25
3	3	176,78	29,60	242,63	3,70
3	4	183,10	36,70	249,13	4,40
4	1	108,00	16,00	255,13	4,63
4	2	149,28	20,95	264,38	4,75
4	3	173,20	24,45	267,38	4,55
4	4	181,78	31,80	264,25	3,78
5	1	97,50	16,00	271,00	4,58
5	2	144,28	19,35	267,25	4,70
5	3	169,80	21,80	271,50	5,40
5	4	169,90	25,33	272,88	4,18
1		138,31	30,23	219,53	3,60
2		154,68	26,89	248,16	4,89
3		160,84	26,90	249,38	4,13
4		153,06	23,30	262,78	4,43

5		145,37	20,62	270,66	4,71
	1	109,83	16,98	249,53	4,26
	2	149,63	23,11	249,55	4,59
	3	169,15	27,77	249,78	4,48
	4	173,21	34,50	251,55	4,10
CV	p-value	0,00	0,00	0,00	0,00
	HT	0,00	0,00	0,89	0,31
	CV*HT	0,00	0,00	0,00	0,08
CV	LSD 5%	6,9	0,78	6,80	0,65
	HT	6,17	0,7	6,08	0,58
	CV*HT	13,8	1,56	13,59	1,3

5.GI2005

CV	HT	RP(%)	RF(%)	NDF(%)	ADF(%)	S(%)	ST(%)	ELOS
1	1	9,75	29,33	67,00	35,45	11,95	5,25	9,75
1	2	8,10	24,58	51,13	35,45	11,08	21,85	10,18
1	3	7,63	22,70	50,13	23,93	6,08	28,05	9,50
1	4	7,98	19,70	49,53	20,88	13,18	23,30	10,85
2	1	10,18	28,23	35,65	35,65	14,25	3,98	10,78
2	2	8,43	24,58	57,85	28,65	10,90	14,95	8,10
2	3	7,48	22,70	53,40	26,45	7,03	26,25	8,43
2	4	6,43	20,48	49,40	22,25	11,98	22,08	8,03
3	1	9,50	28,23	64,70	34,00	15,00	3,33	8,50
3	2	8,03	22,93	54,98	26,43	12,70	15,05	8,50
3	3	7,95	21,35	52,25	24,50	7,28	26,40	7,63
3	4	6,33	20,73	51,90	22,25	13,18	21,83	7,48
4	1	10,85	30,20	68,70	37,55	13,20	5,08	7,95
4	2	8,50	26,68	61,88	31,55	13,53	6,05	8,08
4	3	8,08	25,75	58,40	30,20	8,08	17,75	8,38
4	4	6,65	22,35	52,48	25,88	13,68	15,20	7,98
5	1	10,78	30,55	68,98	37,90	13,18	4,73	6,43
5	2	8,50	26,20	61,95	31,05	17,70	1,43	6,33
5	3	8,38	26,20	62,25	30,73	11,83	11,80	6,65
5	4	6,68	21,30	51,10	24,78	15,40	15,20	6,68
1		8,36	24,08	54,44	28,93	10,57	19,61	10,07
2		8,13	23,99	49,08	28,25	11,04	16,81	8,83
3		7,95	23,31	55,96	26,79	12,04	16,65	8,03
4		8,52	26,24	60,36	31,29	12,12	11,02	8,09
5		8,58	26,06	61,07	31,11	14,53	8,29	6,52
	1	10,21	29,31	61,01	36,11	13,52	4,47	8,68
	2	8,31	24,99	57,56	30,63	13,18	11,87	8,24
	3	7,90	23,74	55,29	27,16	8,06	22,05	8,12
	4	6,81	20,91	50,88	23,21	13,48	19,52	8,20
CV	p-value	0,02	0,00	0,00	0,00	0,00	0,00	0,00
	HT	0,00	0,00	0,00	0,00	0,00	0,00	0,08
	CV*HT	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CV	LSD 5%	0,35	0,96	1,79	1,36	1,09	2,50	0,35
	HT	0,32	0,86	1,60	1,21	0,98	2,23	0,32
	CV*HT	0,71	1,91	3,57	2,71	2,19	5	0,71

6.GI 2006

CV	HT	DMdt/ha	DM %	SL(cm)	LAI
1	1	109,50	21,20	260,50	2,63
1	2	152,40	25,23	249,00	4,00
1	3	173,45	31,63	269,75	3,58
1	4	199,48	35,90	285,75	4,28
2	1	131,15	35,90	279,00	3,65
2	2	159,75	23,95	256,50	3,80
2	3	203,20	30,45	286,75	3,65
2	4	265,48	39,65	316,00	3,13
3	1	134,08	21,70	282,00	3,43
3	2	180,00	27,60	258,50	2,83
3	3	213,63	32,83	288,00	3,98
3	4	213,53	36,68	298,25	3,48
4	1	130,98	19,83	278,00	3,63
4	2	156,45	22,03	245,00	3,53
4	3	193,05	29,50	272,00	4,13
4	4	248,58	35,90	317,25	3,45
5	1	119,73	18,65	283,00	3,35
5	2	151,45	20,35	252,50	3,55
5	3	187,50	25,53	281,25	3,50
5	4	283,43	35,93	325,50	4,33
6	1	136,60	20,50	276,25	3,68
6	2	173,73	25,83	253,75	2,48
6	3	199,15	31,43	282,00	3,90
6	4	241,45	38,38	299,50	3,83
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1		158,71	28,49	266,25	3,62
2		189,89	32,49	284,56	3,56
3		185,31	29,70	281,69	3,43
4		182,26	26,81	278,06	3,68
5		185,53	25,11	285,56	3,68
6		187,73	29,03	277,88	3,47
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	1	127,00	22,96	276,46	3,39
	2	162,30	24,16	252,54	3,36
	3	195,00	30,23	279,96	3,79
	4	241,99	37,07	307,04	3,75
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		0,00	0,00	0,02	0,97
HT		0,00	0,00	0,00	0,32
CV*HT		0,00	0,00	0,00	0,68
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CV	LSD 5%	14,39	1,49	12,09	0,71
HT		11,75	1,21	9,87	0,58
CV*HT		28,79	2,97	24,18	1,42

6.GI 2006

CV	HT	RP(%)	RF(%)	NDF(%)	ADF(%)	S(%)	ST(%)	ELOS
1	1	8,58	31,80	66,78	39,68	9,68	5,08	46,43
1	2	7,75	21,48	50,83	25,40	18,43	7,98	66,65
1	3	8,20	20,73	49,18	24,40	9,65	23,48	64,08
1	4	8,48	15,38	40,08	20,60	7,50	36,53	71,48
2	1	8,93	31,80	68,05	39,90	10,20	6,20	47,23

2	2	7,50	20,53	48,65	24,78	16,85	14,00	68,20
2	3	7,80	21,70	50,38	25,73	9,25	24,13	63,78
2	4	7,30	19,95	47,78	23,75	8,95	29,48	64,93
3	1	8,33	29,28	62,45	35,73	10,50	8,03	52,13
3	2	7,40	19,00	45,58	22,78	16,13	19,03	70,83
3	3	7,73	19,85	46,48	23,88	9,33	27,55	67,10
3	4	6,78	20,70	48,15	24,63	10,98	24,33	64,65
4	1	8,45	32,63	68,40	40,73	10,18	4,75	46,40
4	2	6,93	22,98	52,43	27,03	20,15	3,90	66,08
4	3	7,45	23,15	52,50	27,28	11,95	16,75	62,20
4	4	7,73	17,95	44,13	21,08	8,98	30,85	68,05
5	1	8,88	32,43	69,68	41,05	11,45	5,88	45,88
5	2	7,43	25,13	56,20	30,15	19,60	1,30	61,80
5	3	7,78	25,50	54,60	30,28	10,10	16,08	59,35
5	4	7,43	25,05	54,25	29,95	8,40	19,58	57,68
6	1	8,00	31,55	66,55	38,93	9,25	5,30	47,38
6	2	8,95	20,60	48,63	26,35	16,58	13,43	67,88
6	3	7,53	21,28	49,10	25,80	8,25	26,63	63,73
6	4	7,63	18,13	44,28	21,70	7,03	33,30	67,40
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1		8,25	22,34	51,71	27,52	11,31	18,26	62,16
2		7,88	23,49	53,71	28,54	11,31	18,45	61,03
3		7,56	22,21	50,66	26,75	11,73	19,73	63,68
4		7,64	24,18	54,36	29,03	12,81	14,06	60,68
5		7,88	27,03	58,68	32,86	12,39	10,71	56,18
6		8,03	22,89	52,14	28,19	10,28	19,66	61,59
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	1	8,53	31,58	66,98	39,33	10,21	5,87	47,57
	2	7,66	21,62	50,38	26,08	17,95	9,94	66,90
	3	7,75	22,03	50,37	26,23	9,75	22,43	63,37
	4	7,55	19,53	46,44	23,62	8,64	29,01	65,70
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		0,06	0,00	0,00	0,00	0,00	0,00	0,00
	HT	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	CV*HT	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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CV	LSD 5%	0,43	1,53	1,95	1,60	1,05	3,37	1,74
	HT	0,35	0,96	1,6	1,30	0,86	2,75	1,42
	CV*HT	0,86	4,69	3,91	3,19	2,10	6,74	3,47
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Anaerobe Behandlung der Maissorte DOGE GROSS-GERAU 2004

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Doge ET-1_GG-04
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	3,33
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,895
Substratzugabe, einmalig	g	105
oTS zugeführt	g oTS	19,63
TR zugeführt	g TR	20,93
Gasproduktion	Norm Liter	13,32
Gasausbeute	m _n ³ / kg oTS _{zu}	0,678
Gasausbeute	m _n ³ / kg TR _{zu}	0,636
Gasausbeute	m _n ³ / kg Substrat	0,127
Methankonzentration	Vol.-%	58,96
Methanproduktion	Norm Liter	7,75
Methanausbeute	m _n ³ CH ₄ / kg oTS _{zu}	0,395
Methanausbeute	m _n ³ CH ₄ / kg TR _{zu}	0,370
Methanausbeute	m _n ³ CH ₄ / kg Substrat	0,074

	Einheit	Doge ET-3_GG-04
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	4,37
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,896
Substratzugabe, einmalig	g	105
oTS zugeführt	g oTS	25,76
TR zugeführt	g TR	27,00
Gasproduktion	Norm Liter	16,76
Gasausbeute	m _n ³ / kg oTS _{zu}	0,651
Gasausbeute	m _n ³ / kg TR _{zu}	0,621
Gasausbeute	m _n ³ / kg Substrat	0,160
Methankonzentration	Vol.-%	58,26
Methanproduktion	Norm Liter	9,54
Methanausbeute	m _n ³ CH ₄ / kg oTS _{zu}	0,371
Methanausbeute	m _n ³ CH ₄ / kg TR _{zu}	0,354
Methanausbeute	m _n ³ CH ₄ / kg Substrat	0,091

	Einheit	Doge ET-4_GG-04
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	4,95
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,895
Substratzugabe, einmalig	g	105
oTS zugeführt	g oTS	29,17
TR zugeführt	g TR	30,60
Gasproduktion	Norm Liter	18,13
Gasausbeute	m _n ³ / kg oTS _{zu}	0,622
Gasausbeute	m _n ³ / kg TR _{zu}	0,592
Gasausbeute	m _n ³ / kg Substrat	0,173
Methankonzentration	Vol.-%	55,88
Methanproduktion	Norm Liter	9,77
Methanausbeute	m _n ³ CH ₄ / kg oTS _{zu}	0,335
Methanausbeute	m _n ³ CH ₄ / kg TR _{zu}	0,319
Methanausbeute	m _n ³ CH ₄ / kg Substrat	0,093

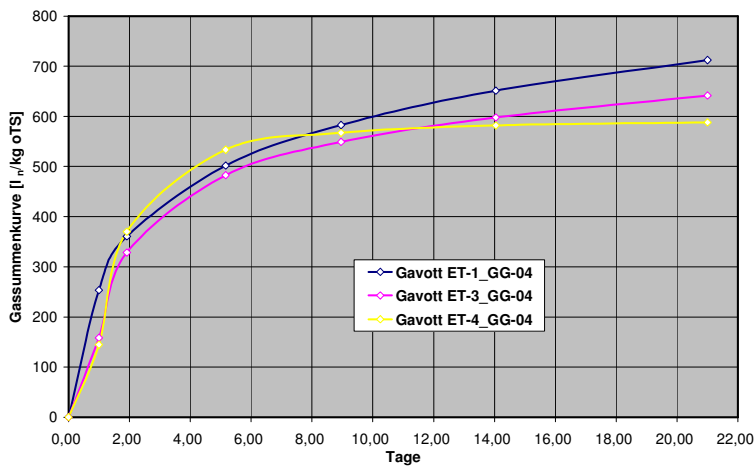
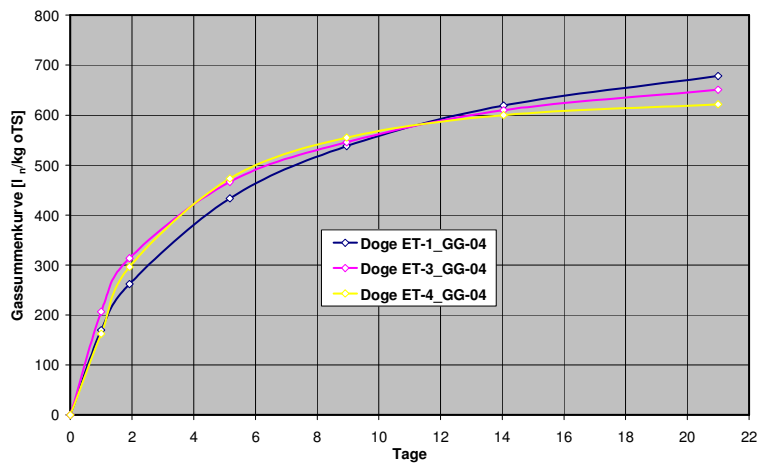
Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Gavott ET-1_GG-04
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	4,40
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,893
Substratzugabe, einmalig	g	107
oTS zugeführt	g oTS	25,92
TR zugeführt	g TR	27,18
Gasproduktion	Norm Liter	18,46
Gasausbeute	m _n ³ /kg oTS _{zu}	0,712
Gasausbeute	m _n ³ /kg TR _{zu}	0,679
Gasausbeute	m _n ³ /kg Substrat	0,173
Methankonzentration	Vol.-%	56,98
Methanproduktion	Norm Liter	10,41
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,402
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,383
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,097

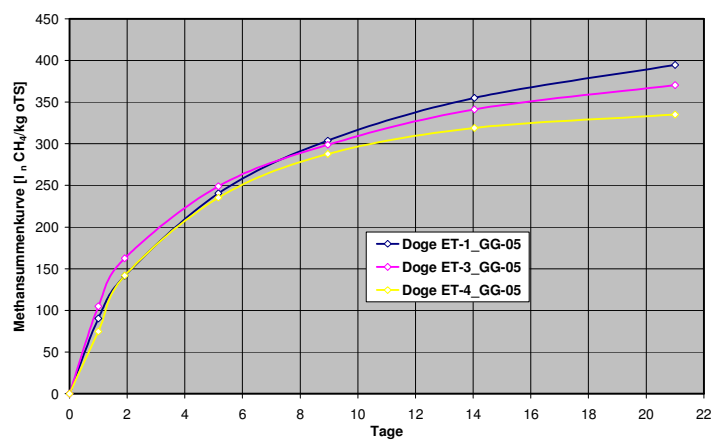
	Einheit	Gavott ET-3_GG-04
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	7,26
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,892
Substratzugabe, einmalig	g	108
oTS zugeführt	g oTS	42,76
TR zugeführt	g TR	44,41
Gasproduktion	Norm Liter	27,44
Gasausbeute	m _n ³ /kg oTS _{zu}	0,642
Gasausbeute	m _n ³ /kg TR _{zu}	0,618
Gasausbeute	m _n ³ /kg Substrat	0,254
Methankonzentration	Vol.-%	54,90
Methanproduktion	Norm Liter	14,89
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,348
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,335
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,138

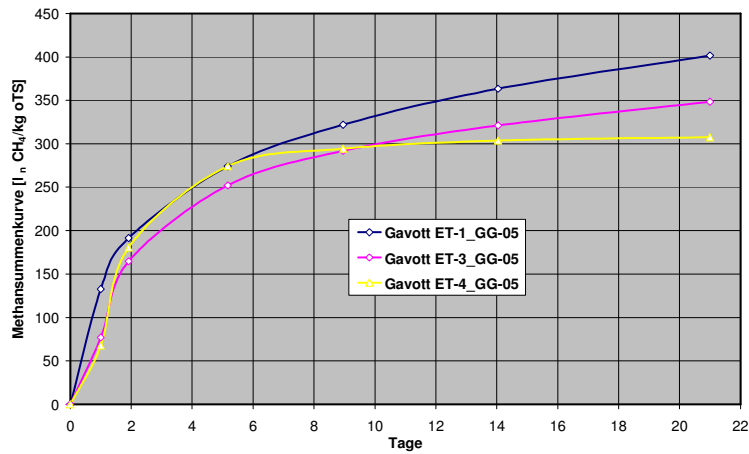
	Einheit	Gavott ET-4_GG-04
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	8,24
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,893
Substratzugabe, einmalig	g	107
oTS zugeführt	g oTS	48,56
TR zugeführt	g TR	50,31
Gasproduktion	Norm Liter	28,55
Gasausbeute	m _n ³ /kg oTS _{zu}	0,588
Gasausbeute	m _n ³ /kg TR _{zu}	0,567
Gasausbeute	m _n ³ /kg Substrat	0,266
Methankonzentration	Vol.-%	53,38
Methanproduktion	Norm Liter	14,94
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,308
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,297
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,139

Vergleich der oTS-Gassummenkurven



Vergleich der oTS-Methansummenkurven





Anaerobe Behandlung der Maissorte GAVOTT GIESSEN 2005

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Gavott ET-1_GI-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	3,33
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	19,64
TR zugeführt	g TR	20,76
Gasproduktion	Norm Liter	12,89
Gasausbeute	m _n ³ /kg oTS _{zu}	0,656
Gasausbeute	m _n ³ /kg TR _{zu}	0,621
Gasausbeute	m _n ³ /kg Substrat	0,129
Methankonzentration	Vol.-%	59,34
Methanproduktion	Norm Liter	7,54
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,384
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,363
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,075

**Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit**

	Einheit	Gavott ET-3_GI-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	5,75
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTSzugeführt	g oTS	33,95
TR zugeführt	g TR	35,63
Gasproduktion	Norm Liter	23,80
Gasausbeute	m _n ³ /kg oTS _{zu}	0,701
Gasausbeute	m _n ³ /kg TR _{zu}	0,668
Gasausbeute	m _n ³ /kg Substrat	0,238
Methankonzentration	Vol.-%	56,35
Methanproduktion	Norm Liter	13,31
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,392
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,373
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,133

**Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit**

	Einheit	Gavott ET-4_GI-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	6,80
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTSzugeführt	g oTS	40,10
TR zugeführt	g TR	42,54
Gasproduktion	Norm Liter	25,78
Gasausbeute	m _n ³ /kg oTS _{zu}	0,643
Gasausbeute	m _n ³ /kg TR _{zu}	0,606
Gasausbeute	m _n ³ /kg Substrat	0,258
Methankonzentration	Vol.-%	58,47
Methanproduktion	Norm Liter	15,03
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,375
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,353
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,150

Anaerobe Behandlung der Maissorte KXA5233 GIESSEN 2005

**Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit**

	Einheit	KXA5233 ET-1_GI-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	2,91
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTSzugeführt	g oTS	17,20
TR zugeführt	g TR	18,38
Gasproduktion	Norm Liter	12,64
Gasausbeute	m _n ³ /kg oTS _{zu}	0,735
Gasausbeute	m _n ³ /kg TR _{zu}	0,688
Gasausbeute	m _n ³ /kg Substrat	0,126
Methankonzentration	Vol.-%	57,56
Methanproduktion	Norm Liter	7,16
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,417
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,390
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,072

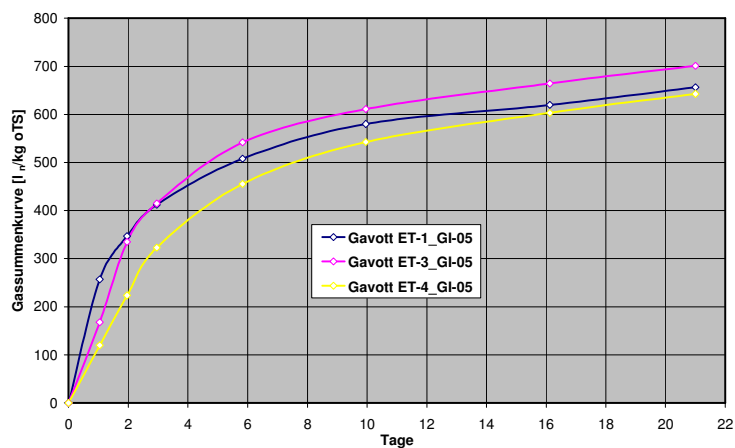
Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

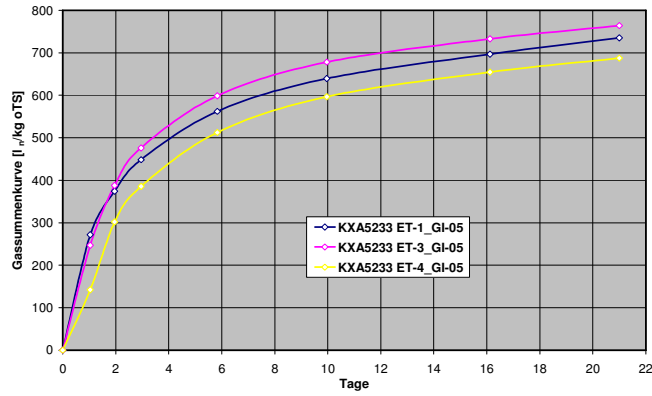
	Einheit	KXA5233 ET-3_GI-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	4,49
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	26,49
TR zugeführt	g TR	27,81
Gasproduktion	Norm Liter	20,24
Gasausbeute	m _n ³ /kg oTS _{zu}	0,764
Gasausbeute	m _n ³ /kg TR _{zu}	0,728
Gasausbeute	m _n ³ /kg Substrat	0,202
Methankonzentration	Vol.-%	55,81
Methanproduktion	Norm Liter	11,14
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,421
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,401
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,111

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

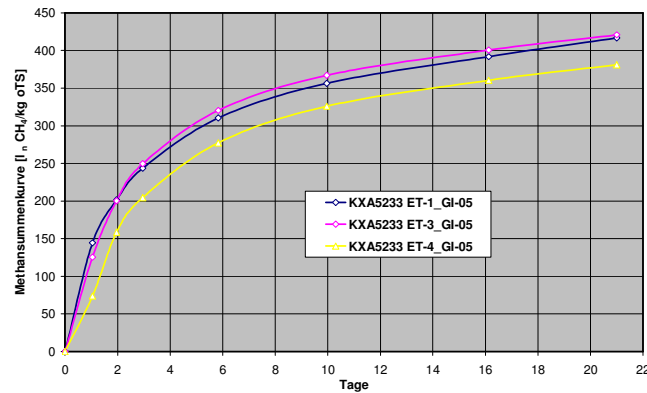
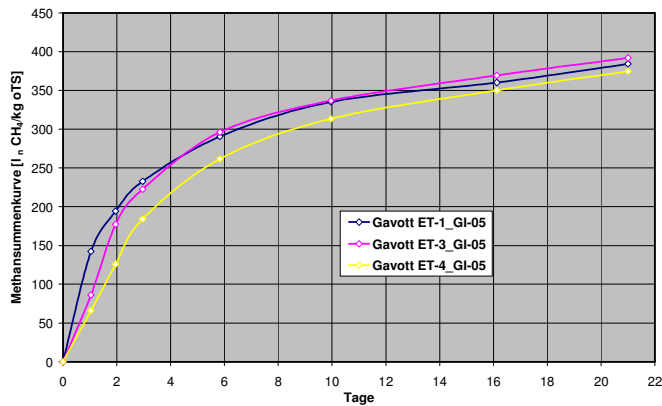
	Einheit	KXA5233 ET-4_GI-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	6,08
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	35,87
TR zugeführt	g TR	38,02
Gasproduktion	Norm Liter	24,66
Gasausbeute	m _n ³ /kg oTS _{zu}	0,687
Gasausbeute	m _n ³ /kg TR _{zu}	0,649
Gasausbeute	m _n ³ /kg Substrat	0,247
Methankonzentration	Vol.-%	55,79
Methanproduktion	Norm Liter	13,66
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,381
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,359
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,137

Vergleich der oTS-Gassummenkurven





Vergleich der oTS-Methansummenkurven



Anaerobe Behandlung der Maissorte GAVOTT GROSS-GERAU 2005

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Gavott ET-1_GG-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	4,09
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	24,13
TR zugeführt	g TR	25,20
Gasproduktion	Norm Liter	16,43
Gasausbeute	m _n ³ /kg oTS _{zu}	0,681
Gasausbeute	m _n ³ /kg TR _{zu}	0,652
Gasausbeute	m _n ³ /kg Substrat	0,164
Methankonzentration	Vol.-%	57,91
Methanproduktion	Norm Liter	9,33
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,387
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,370
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,093

**Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit**

	Einheit	Gavott ET-3_GG-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	6,71
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	39,57
TR zugeführt	g TR	41,30
Gasproduktion	Norm Liter	27,12
Gasausbeute	m _n ³ /kg oTS _{zu}	0,685
Gasausbeute	m _n ³ /kg TR _{zu}	0,657
Gasausbeute	m _n ³ /kg Substrat	0,271
Methankonzentration	Vol.-%	55,85
Methanproduktion	Norm Liter	14,92
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,377
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,361
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,149

**Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit**

	Einheit	Gavott ET-4_GG-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	7,88
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	46,52
TR zugeführt	g TR	48,51
Gasproduktion	Norm Liter	31,48
Gasausbeute	m _n ³ /kg oTS _{zu}	0,677
Gasausbeute	m _n ³ /kg TR _{zu}	0,649
Gasausbeute	m _n ³ /kg Substrat	0,315
Methankonzentration	Vol.-%	56,32
Methanproduktion	Norm Liter	17,52
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,377
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,361
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,175

Anaerobe Behandlung der Maissorte KXA5233 GROSS-GERAU2005

**Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit**

	Einheit	KXA ET-1_GG-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	3,72
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	21,92
TR zugeführt	g TR	23,00
Gasproduktion	Norm Liter	19,73
Gasausbeute	m _n ³ /kg oTS _{zu}	0,900
Gasausbeute	m _n ³ /kg TR _{zu}	0,858
Gasausbeute	m _n ³ /kg Substrat	0,197
Methankonzentration	Vol.-%	57,04
Methanproduktion	Norm Liter	11,13
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,508
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,484
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,111

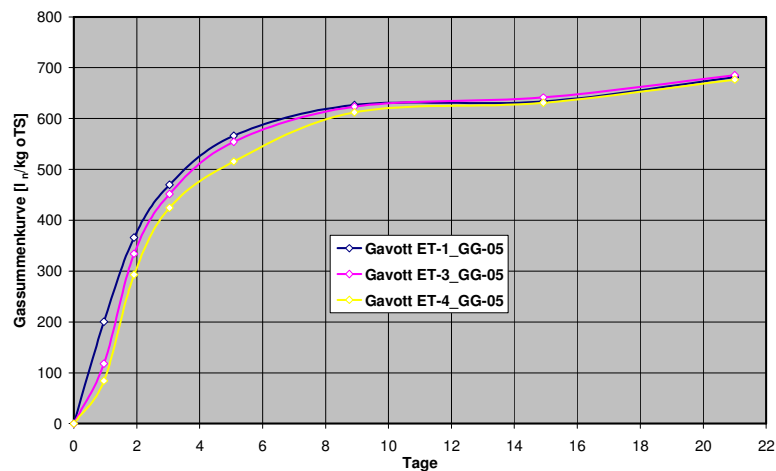
Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

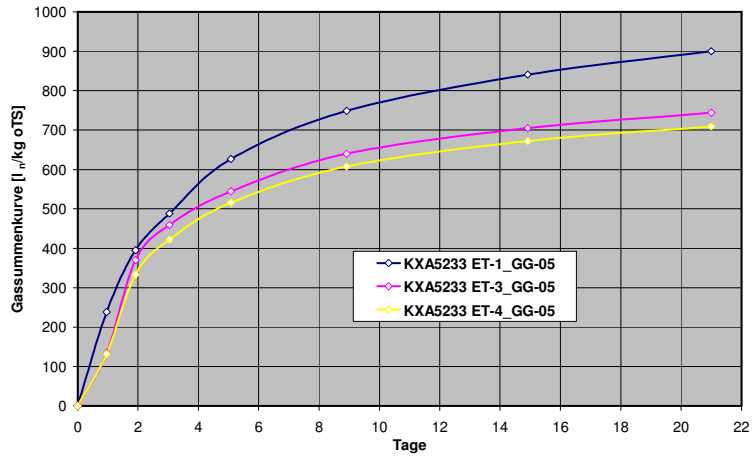
	Einheit	KXA ET-3_GG-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	6,47
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	38,16
TR zugeführt	g TR	39,85
Gasproduktion	Norm Liter	28,40
Gasausbeute	m _n ³ /kg oTS _{zu}	0,744
Gasausbeute	m _n ³ /kg TR _{zu}	0,713
Gasausbeute	m _n ³ /kg Substrat	0,284
Methankonzentration	Vol.-%	55,54
Methanproduktion	Norm Liter	15,61
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,409
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,392
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,156

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

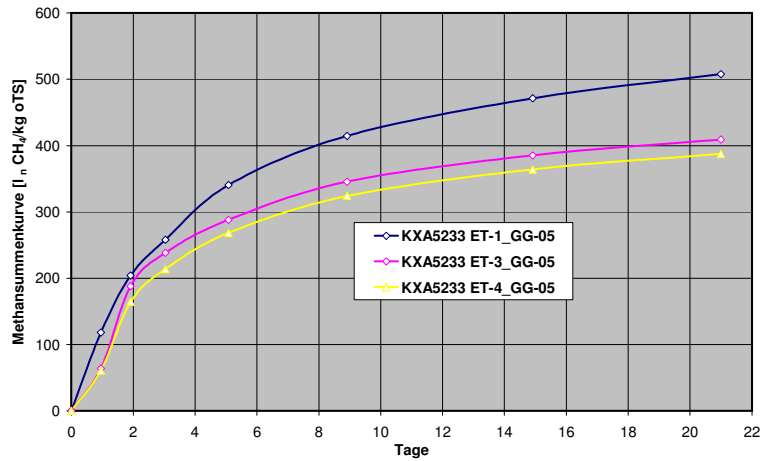
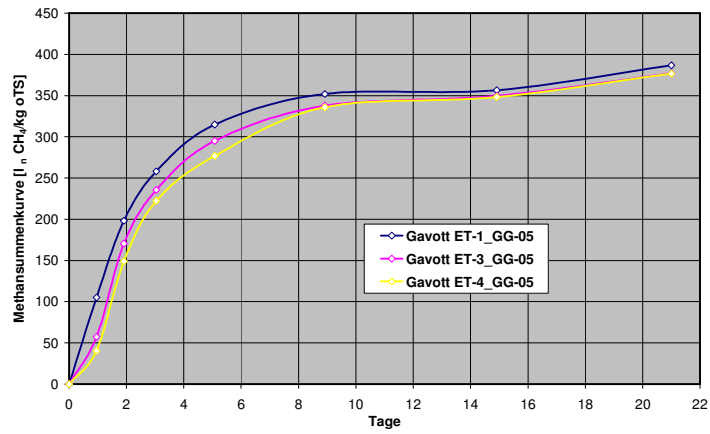
	Einheit	KXA ET-4_GG-05
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/ (m ³ ,d)	6,93
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	5,900
Substratzugabe, einmalig	g	100
oTS zugeführt	g oTS	40,86
TR zugeführt	g TR	42,68
Gasproduktion	Norm Liter	28,98
Gasausbeute	m _n ³ /kg oTS _{zu}	0,709
Gasausbeute	m _n ³ /kg TR _{zu}	0,679
Gasausbeute	m _n ³ /kg Substrat	0,290
Methankonzentration	Vol.-%	55,29
Methanproduktion	Norm Liter	15,83
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,388
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,371
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,158

Vergleich der oTS-Gassummenkurven





Vergleich der oTS-Methansummenkurven



Anaerobe Behandlung der Maissorte GAVOTT GIESSEN 2006
Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit

	Einheit	Gavott ET-3 GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,64
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	121
oTS zugeführt	g oTS	39,42
TR zugeführt	g TR	41,33
Gasproduktion	Norm Liter	24,63
Gasausbeute	m _n ³ /kg oTS _{zu}	0,625
Gasausbeute	m _n ³ /kg TR _{zu}	0,596
Gasausbeute	m _n ³ /kg Substrat	0,204
Methankonzentration	Vol.-%	60,04
Methanproduktion	Norm Liter	14,46
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,367
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,350
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,119

Anaerobe Behandlung der Maissorte MAGITOP GIESSEN 2006
Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit

	Einheit	Magitop ET-3 GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,73
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	122
oTS zugeführt	g oTS	39,99
TR zugeführt	g TR	41,67
Gasproduktion	Norm Liter	17,77
Gasausbeute	m _n ³ /kg oTS _{zu}	0,444
Gasausbeute	m _n ³ /kg TR _{zu}	0,426
Gasausbeute	m _n ³ /kg Substrat	0,146
Methankonzentration	Vol.-%	54,60
Methanproduktion	Norm Liter	9,49
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,237
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,228
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,078

Anaerobe Behandlung der Maissorte BEATUS GIESSEN 2006
Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit

	Einheit	Beatus ET-3 GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	6,01
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	126
oTS zugeführt	g oTS	41,95
TR zugeführt	g TR	43,85
Gasproduktion	Norm Liter	27,09
Gasausbeute	m _n ³ /kg oTS _{zu}	0,646
Gasausbeute	m _n ³ /kg TR _{zu}	0,618
Gasausbeute	m _n ³ /kg Substrat	0,216
Methankonzentration	Vol.-%	58,60
Methanproduktion	Norm Liter	15,61
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,372
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,356
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,124

Anaerobe Behandlung der Maissorte ATLETICO GIESSEN 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Atletico ET-3 GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,76
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	126
oTS zugeführt	g oTS	40,26
TR zugeführt	g TR	42,07
Gasproduktion	Norm Liter	27,30
Gasausbeute	m _n ³ /kg oTS _{zu}	0,678
Gasausbeute	m _n ³ /kg TR _{zu}	0,649
Gasausbeute	m _n ³ /kg Substrat	0,217
Methankonzentration	Vol.-%	56,61
Methanproduktion	Norm Liter	15,31
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,380
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,364
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,122

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Atletico ET-4 GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	6,95
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	127
oTS zugeführt	g oTS	48,53
TR zugeführt	g TR	50,96
Gasproduktion	Norm Liter	27,97
Gasausbeute	m _n ³ /kg oTS _{zu}	0,576
Gasausbeute	m _n ³ /kg TR _{zu}	0,549
Gasausbeute	m _n ³ /kg Substrat	0,221
Methankonzentration	Vol.-%	61,01
Methanproduktion	Norm Liter	16,75
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,345
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,329
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,132

Anaerobe Behandlung der Maissorte KXA5233 GIESSEN 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	KXA 5233 ET-3 GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,47
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	121
oTS zugeführt	g oTS	38,23
TR zugeführt	g TR	39,94
Gasproduktion	Norm Liter	23,48
Gasausbeute	m _n ³ /kg oTS _{zu}	0,614
Gasausbeute	m _n ³ /kg TR _{zu}	0,588
Gasausbeute	m _n ³ /kg Substrat	0,193
Methankonzentration	Vol.-%	52,86
Methanproduktion	Norm Liter	12,10
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,316
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,303
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,100

Anaerobe Behandlung der Maissorte KXA5243 GIESSEN 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	KXA 5243 ET-3_GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,06
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	127
oTS zugeführt	g oTS	35,36
TR zugeführt	g TR	36,99
Gasproduktion	Norm Liter	23,74
Gasausbeute	m _n ³ /kg oTS _{zu}	0,671
Gasausbeute	m _n ³ /kg TR _{zu}	0,642
Gasausbeute	m _n ³ /kg Substrat	0,186
Methankonzentration	Vol.-%	58,77
Methanproduktion	Norm Liter	13,79
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,390
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,373
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,108

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	XKA 5243 ET-4_GI-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	6,23
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	125
oTS zugeführt	g oTS	43,48
TR zugeführt	g TR	45,55
Gasproduktion	Norm Liter	28,44
Gasausbeute	m _n ³ /kg oTS _{zu}	0,654
Gasausbeute	m _n ³ /kg TR _{zu}	0,624
Gasausbeute	m _n ³ /kg Substrat	0,227
Methankonzentration	Vol.-%	57,71
Methanproduktion	Norm Liter	16,25
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,374
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,357
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,130

Anaerobe Behandlung der Maissorte GAVOTT GROSS-GERAU 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Gavott ET-3_GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	6,86
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	128
oTS zugeführt	g oTS	47,90
TR zugeführt	g TR	50,00
Gasproduktion	Norm Liter	25,54
Gasausbeute	m _n ³ /kg oTS _{zu}	0,533
Gasausbeute	m _n ³ /kg TR _{zu}	0,511
Gasausbeute	m _n ³ /kg Substrat	0,199
Methankonzentration	Vol.-%	59,91
Methanproduktion	Norm Liter	14,96
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,312
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,299
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,117

Anaerobe Behandlung der Maissorte ATLETICO GROSS-GERAU 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Atletico ET-3_GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	6,66
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	125
oTS zugeführt	g oTS	46,48
TR zugeführt	g TR	48,56
Gasproduktion	Norm Liter	25,76
Gasausbeute	m _n ³ /kg oTS _{zu}	0,554
Gasausbeute	m _n ³ /kg TR _{zu}	0,531
Gasausbeute	m _n ³ /kg Substrat	0,206
Methankonzentration	Vol.-%	55,87
Methanproduktion	Norm Liter	14,13
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,304
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,291
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,113

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Atletico ET-4_GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	7,29
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	125
oTS zugeführt	g oTS	50,91
TR zugeführt	g TR	53,29
Gasproduktion	Norm Liter	28,95
Gasausbeute	m _n ³ /kg oTS _{zu}	0,569
Gasausbeute	m _n ³ /kg TR _{zu}	0,543
Gasausbeute	m _n ³ /kg Substrat	0,232
Methankonzentration	Vol.-%	58,55
Methanproduktion	Norm Liter	16,67
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,328
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,313
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,133

Anaerobe Behandlung der Maissorte KXA5233 GROSS-GERAU 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	KXA5233 ET-3_GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,79
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	124
oTS zugeführt	g oTS	40,41
TR zugeführt	g TR	42,31
Gasproduktion	Norm Liter	23,12
Gasausbeute	m _n ³ /kg oTS _{zu}	0,572
Gasausbeute	m _n ³ /kg TR _{zu}	0,547
Gasausbeute	m _n ³ /kg Substrat	0,186
Methankonzentration	Vol.-%	55,26
Methanproduktion	Norm Liter	12,59
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,312
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,298
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,102

Anaerobe Behandlung der Maissorte KXA5243 GROSS-GERAU 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	KXA5243 ET-3_GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,56
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	125
oTS zugeführt	g oTS	38,80
TR zugeführt	g TR	40,78
Gasproduktion	Norm Liter	21,98
Gasausbeute	m _n ³ /kg oTS _{zu}	0,566
Gasausbeute	m _n ³ /kg TR _{zu}	0,539
Gasausbeute	m _n ³ /kg Substrat	0,176
Methankonzentration	Vol.-%	57,91
Methanproduktion	Norm Liter	12,59
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,324
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,309
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,101

Anaerobe Behandlung der Maissorte BAXTER GROSS-GERAU 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Baxter ET-3_GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,68
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	125
oTS zugeführt	g oTS	39,67
TR zugeführt	g TR	41,49
Gasproduktion	Norm Liter	23,47
Gasausbeute	m _n ³ /kg oTS _{zu}	0,592
Gasausbeute	m _n ³ /kg TR _{zu}	0,566
Gasausbeute	m _n ³ /kg Substrat	0,188
Methankonzentration	Vol.-%	59,14
Methanproduktion	Norm Liter	13,56
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,342
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,327
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,108

Anaerobe Behandlung der Maissorte FIACRE GROSS-GERAU 2006

Gasproduktionen und –ausbeuten sowie Belastungswerte nach 21 Tagen Laufzeit

	Einheit	Fiacre ET-3_GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ ,d)	5,87
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	125
oTS zugeführt	g oTS	41,03
TR zugeführt	g TR	42,94
Gasproduktion	Norm Liter	24,70
Gasausbeute	m _n ³ /kg oTS _{zu}	0,602
Gasausbeute	m _n ³ /kg TR _{zu}	0,575
Gasausbeute	m _n ³ /kg Substrat	0,198
Methankonzentration	Vol.-%	59,22
Methanproduktion	Norm Liter	14,34
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,349
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,334
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,115

**Gasproduktionen und –ausbeuten sowie Belastungswerte
nach 21 Tagen Laufzeit**

	Einheit	Fiacre ET-4 GG-06
Temperatur	°C	38
Raumbelastung, einmalig	kg oTS/(m ³ .d)	7,62
Reaktorvolumen, gesamt	Liter	6,00
Impfslammvolumen	Liter	6,984
Substratzugabe, einmalig	g	125
oTS zugeführt	g oTS	53,24
TR zugeführt	g TR	55,55
Gasproduktion	Norm Liter	35,23
Gasausbeute	m _n ³ /kg oTS _{zu}	0,662
Gasausbeute	m _n ³ /kg TR _{zu}	0,634
Gasausbeute	m _n ³ /kg Substrat	0,282
Methankonzentration	Vol.-%	55,82
Methanproduktion	Norm Liter	19,49
Methanausbeute	m _n ³ CH ₄ /kg oTS _{zu}	0,366
Methanausbeute	m _n ³ CH ₄ /kg TR _{zu}	0,351
Methanausbeute	m _n ³ CH ₄ /kg Substrat	0,156

Attestation

I Tatah Eugene Lenzemo born on September the 10th 1971 in Nkar-Jakiri (Cameroon), hereby testify that this thesis was personally written by me and only with the help of the literary works presented in the literature review.

Written by : Tatah Eugene Lenzemo

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