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Report 544

Effect of cutting management and nitrogen supply on yield and quality of Napier grass (Pennisetum purpureum)

Nitrogen supplied by fertilizer, cattle manure or Desmodium intortum

December 2011

LIVESTOCK RESEARCH
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Publisher
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Editing
Communication Services

Abstract
In a series of cutting experiments, average apparent nitrogen recovery of applied fertilizer N by Napier grass was approximately 50%. Incorporation of cattle manure improved nitrogen utilization. Mixtures with Desmodium intortum substantially improved yield and protein content. There was a fair to good relation between morphology and crude protein content and in vitro organic matter digestibility of Napier grass.

Keywords
Pennisetum purpureum, harvest age, fertiliser, cattle manure, Desmodium intortum, nitrogen utilization, yield, morphology, quality

Reference
ISSN 1570 - 8616

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Effect of cutting management and nitrogen supply on yield and quality of Napier grass (Pennisetum purpureum)

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December 2011

Preface

To improve the knowledge on Napier grass management and utilization a series of cutting experiments were conducted in Naivasha, Kakamega and Kisii in Kenya between 1983 and 1991. Napier grass is an important cultivated grass on smallholder dairy farms in Kenya. In these experiments cutting management and nitrogen supply from fertilizer, cattle manure or the forage legume Desmodium intortum were investigated, either alone or in combination. Sometimes Napier variety was also included. Duration of experiments varied. Two experiments, one with application of cattle manure and one on the management of Napier/Desmodium mixtures continued for 5 years. An important objective of these experiments was to support the efforts of the National Dairy Development Project (NDDP) in improving smallholder dairy farming in Kenya. The results of these experiments have so far not been reported in peer-reviewed scientific publications. This report reviews results and in addition provides the outcome of a meta-analysis of some characteristics, in particular also the relation between Napier morphology (contents of green and dead leaf and grass height), and other quality characteristics of Napier grass.
A 3 year during on farm experiment on Napier management and some other results of development work together with farmers are not reported, but are shortly discussed.

Research was performed under the umbrella of NDDP until 1990, and was since part of the Kenya Agricultural Research Institute (KARI). For details of most experiments reference is made to reports finalized at an earlier stage, but the accessibility of these reports is limited.

The authors are indebted to all who contributed to the execution of the original experiments and to this resulting overall report. We thank especially the Kenya Agricultural Research Institute (KARI), the National Dairy Development Project (NDDP), the director of the National Animal Husbandry Research Centre (KARI-NAHRC) in Naivasha, staff of the zero-grazing unit and laboratory of KARI-NAHRC, directors and staff of the KARI regional research centers in Kakamega and Kisii. We thank especially the late Mr Francis Wekesa and Mr William Ayako (both formerly KARI-NAHRC), because they contributed throughout the period that experiments were conducted.
For their suggestions to improve experiments and for their comments to improve the initial manuscript we thank especially Mr. S. Schukking, Mr. V. Hindle, Mr. Gert Jan Holshof and Mr. Anne Steg (present or former collaborators of Wageningen UR Livestock Research) and Mr Hugo van der Meer (Wageningen UR, Plant Research international). For support during statistical analysis of data we thank especially Mr Johan van Riel and Ronald Zom (all Wageningen UR Livestock Research). But the authors remain responsible for the content of the manuscript.

Summary

To improve the knowledge on elephant or Napier grass (Pennisetum purpureum, further referred to as Napier) management and utilization, a series of 15 cutting experiments (Exp 1-15) were conducted in Naivasha, Kakamega and Kisii in Kenya between 1983 and 1991. An important objective was also to support the efforts of the National Dairy Development Project in improving smallholder dairy farming in Kenya. The results of these experiments have so far not been reported in peer-reviewed scientific publications. This report reviews results. It also provides the outcome of a meta-analysis of the relationship between in particular Napier morphology (contents of green=L and dead=D leaf and grass height=H) and Napier quality, with emphasis on in vitro organic matter digestibility (=dOM). Also the relationship between yield of dry matter (DMY), leaf (LY) and nitrogen (NY) and cutting age and nitrogen (=N) supply was explored. A scenario approach explores the effects of variation in Napier management on potential milk production per kg applied N and per ha.

The most important variables investigated in the experiments were variation in cutting age (or cutting interval=CI) and rate and/or source of N on yields. Nitrogen was derived from various sources: fertilizer and/or cattle manure and/or green leaf Desmodium in a mixture with Napier (D. intortum, further referred to as Desmodium). Also season, Napier variety and location varied between experiments, but only variety was directly compared in 2 experiments. The most important measurements/analysis done were contents of green leaf, stem, dead leaf and grass height, contents of dry matter (=DM), CP and ash, in Exp 1-11 also dOM, and in a number of experiments also cell wall characteristics. To improve judgment of Napier quality for situations without laboratory facilities, predictive models were developed for the relationship between contents of dOM (and CP and ash), and, in particular contents of green and/or dead leaf and/or grass H, also in combination with or without cutting age and N rate, depending on the model. Results are compared with models based on chemical characteristics (Chapter 3.3).

Chapter 2 discusses the methodology of Exp 1-9 where fertilizer N only is applied (Table 1). The methodology of experiments involving the use of Napier/Desmodium (Exp 11 and 12) and cattle manure (Exp 13-15) is separately discussed in respectively Chapters 4 and 5 if deviating from Exp 1-9. Most experiments were designed as a randomized block, including a control without N and with 3 or 4 replicates. In Exp 1-4 and Exp 6-7 both cutting age and rate of fertilizer N varied. In Exp 6 and 7 nitrogen was divided over cuts, in other experiments N was applied only to the first (Exp 3 and 4) or only cut (Exp 1-2). Experiment 8 compared 4 cutting regimes of Napier grass over a period of 3 years, also to investigate effects during dry periods. Cut number per regime varied from 2/3 to 5 cuts per year, dry seasons included. Reserved older grass may contribute to bridge dry periods. Exp 5 and 9 compared Napier varieties Bana and French Cameroons (=FC). Exp 9 continued during 2 years. In Exp 5, 8 and 9 only one N rate was used. In Exp 8 and 9 the number of cuts per year varied, depending on growing conditions, moisture supply in particular, and, in Exp 8, also on cutting regime. The design of Exp 10 is similar to Exp 1, but because it was conducted under extreme drought, results are mainly used in models to predict dOM.
In Exp 11 yield and quality of Napier grass grown in a mixture with and without Desmodium harvested at 2 grass heights (ages) was investigated over a period of 5 years (1985-1990). Exp 12 is a follow up of Exp 11, and compared the mixture of Napier/Desmodium with pure Napier, but now with application of fertilizer N. Exp 13 to 15 compare the use of surface applied or incorporated cattle manure (in a mixture of feces and urine) with the use of fertilizer N on Napier grass. In Exp 14 and 15 also combinations of manure and fertiliser N were included. Exp 13 continued for 5 years (1985-1990), and Exp 14 and 15 for 1-2 years.

Since the available results for morphology and chemical characteristics varied between experiments, various datasets were used to predict dOM and other characteristics, using sub-sets with similar measurements derived from a larger dataset (Chapter 2), depending on the objective. In prediction models for dOM emphasis is on datasets derived from Exp 1 to 9. Occasionally results from Exp 10 and 11 are included to predict dOM, also for validation. For models to predict DMY, LY, NY and CP or ash content, also results from Exp 13-15, without and with manure treatments were sometimes included (n=1802 for DMY). Model development was performed with the REML procedure of the statistical package GENSTAT.

Results of Exp 1 to 9 are discussed in Chapter 3, but also results of other experiments are sometimes included, among others in developing prediction models for dOM and other quality characteristcs, and for DMY, LY and NY. Results of Exp 11 and 12 with Desmodium mixtures are discussed in Chapter 4, Chapter 5 discusses results of Exp 13-15 with application of cattle manure. Results of scenarios are discussed in Chapter 6. Chapter 7 provides an overall discussion and Chapter 8 conclusions.

Results

Yield of DM, leaf and N of experiments/treatments with application of fertiliser only
Content of green leaf decreased with harvest age, while stem content increased. Content of dead leaf was minimal until about 6 weeks (Chapter 3.1, Table 2a). The subsequent increase varied, surpassing 30% in Exp 8 for very long growing periods, especially during the dry season. Dry matter yield and NY increased with cutting age and N rate. However, when comparing cutting regimes over similar, longer harvest periods, total leaf yield (LY) and, in line with LY, NY tended to peak at cutting ages of about 6-7 weeks, declining subsequently (Chapter 3.1 and 3.2, Figures 1c, 3a and 6).
Averaged over the first cuts of Exp 3 and 4 only, DMY varied from 2.5 to 13.8 Mg ha^{-1} (for CI of 6 to18 weeks and N rates of 0, 50 and 100 kg ha^{-1}; Table 2a). Averaged over the 6 and 12 week cutting regimes of Exp 6 and 7, total DMY, over a cutting period of 24 weeks, ranged from 8.7 to 20.9 Mg ha^{-1}, also depending on N rate. Average annual yields in Exp 8 varied from respectively 14.0 to 24.2 Mg DM ha^{-1} for respectively the 5 and 2/3 cut regimes, and NY from 169 to 139 kg N ha^{-1} (Chapter 3.1, Table 2b). Average daily growth rates (GR) were highest in Exp 4, at about 130-135 kg DM ha^{-1}day^{-1}, for the 15-18 week CI and an N rate of 100 kg N ha^{-1}, but protein content was very low at this age.

In prediction models for DMY, LY and NY for dataset A1 (Exp 1-4 and 6-7; variation in both CI and fertilizer N), and dataset A4 (Exp 1-9 and Exp13-15 without manure treatments) a rather good relation was found with age and N rate (Table A). The variation explained (=R^2) increased for larger datasets, in particular for NY, but the residual mean square (=MSres), also increased. The model for DMY in Eq 1.2.1 gives results for all experiments (Exp 1-15; dataset A5), including manure treatments (MNinc and MNs are N rates for respectively incorporated manure and surface applied cattle manure; Chapter 5 and 7.1). The contribution of NMs is just signicant at P<0.05 (P<0.001 for other parameters), in a model for NY, NMs is not significant anymore (results not given), possibly also due to residual effects (Chapter 5 and 7). If long duration annual Exp 11 and 13 in particular are also included, predicted yields tended to decrease, possibly due to a combination of (much) longer dry periods, relatively lower N rates and possibly a declining soil N supply in time (Chapter 7.1). Besides external N and moisture supply, also soil nitrogen supply is important (Chapter 7.1, Table 18)

Table A Relationship between DMY and LY (Mg ha^{-1}) and NY (kg ha^{-1}) and age (CI in days) and N application (kg ha^{-1}). Experiment and model number (=Eq), MSres, R^2, the F-statistic (the P value (for the poorest parameter) and sample number (=n) are also indicated. See further Chapter 3.1 and 7.1 (Table 3 and 17), Chapter 2 and text, also for abbreviations .

	DMY	**DMY**	**DMY**	**LY**	**LY**	**NY**	**NY**
	Eq 1.1	**Eq 1.2**	**Eq 1.2.1**	**Eq 1.3**	**Eq 1.4**	**Eq 1.7**	**Eq 1.8**
Exp	**1-4/6-7**	**1-9/13-15**	**1-15**	**1-4/6-7**	**1-9/13-15**	**1-4/6-7**	**1-9/13-15**
Const	-0.8929	3.975	6.138	3.513	3.924	72.78	79.12
CI	0.07832	0.02793	0.008727		-0.006739		-0.1056
1/CI		-99.16	-155.5	-75.17	-83.02	-1246	-1562
N	0.05799	0.06294	0.05831	0.02103	0.01763	0.5094	0.5556
CI*N							-0.001992
1/C*N	-1.693	-2.003	-1.941	-0.246	-0.2784		
MNinc			0.01331				
N*MNinc			-0.0008525				
MNs			0.007093				
MSres	0.43	2.04	1.54	0.09	0.21	57.3	96
R2	73	78	81	83	86	37	86
P<	0.001	0.001	0.05	0.04	0.001	0.001	0.002
n	326	1100	1802	255	915	326	725

In vitro organic matter digestibility and other quality characteristics

In vitro organic matter digestibility of Napier grass increased with contents of green leaf, leaf/stem ratio and crude protein (CP), and strongly decreased with contents of dead leaf, age and contents of crude (CF), neutral (NDF) and acid detergent (ADF) fibre and with acid detergent lignin (ADL). The decline in dOM increases with growth rate (GR). At the same age, effect of N on dOM is marginal, but at the same DMY, dOM is (substantially) higher with N because the same DMY is obtained at an earlier age with N. If corrected for growth rate, decrease in dOM was lower with N and during the (cold) rainy season. Nitrogen supply can have a positive effect on both yield and quality characteristics if growing conditions allow. Crude protein content at young age and high leaf contents is (very) sensitive for N supply (Figure 5e)

Prediction models for dOM with green leaf (L) content and the reverse of grass height (L+1/H) and, if including also dead (D) leaf, a model with 1/L+D+1/H, are the best "morphology" models (Table B and Chapter 3.3.3, Table 7). Models improved if age was also included. Models with age and leaf content (1/CI+1/L) predicted dOM almost as good as models derived from the 2 chemical chacteristics CP and NDF (expressed in organic matter; Chapter 3.3.3, Table 8a), but less well than by models including ADF or ADL content (Chapter 3.3.3, Table 8b, c). The combination of age with leaf predicts dOM slightly better than age combined with H. Height only is a poor predictor of dOM. However, age and H combined predicted dOM almost as good as age and leaf. Including leaf content as a parameter nearly always improves prediction models with age for quality characteristics, but grass H, if added additionally to leaf, is often not significant. More complicated models, including also growing season or temperature (T is often not significant in combination with season) and DMY often predict dOM (marginally) better, but or not suited for practical use.

Table B Relationship between in vitro organic matter digestibility (dOM) and crude protein (CP) contents (both in %) with contents of green and dead leaf (%) or grass height (H in cm) and age (CI in days). Experiments, MSres, R^2, P and n are also indicated. See further Chapters 3.3.3 and 7.2 (Table 7 and 19), Chapter 2 and text, also for abbreviations.

Eq	**dOM**	**dOM**	**dOM**	**CP**	**CP**	**CP**	**CP**
	Eq 10	**Eq 5**	**Eq 6**	**Eq 2.2.1**	**Eq 2.2.2**	**Eq 2.2.3**	**Eq 2.2.4**
Exp	1-9	1-9	1-9	1-9/13-15	1-9/13-15	1-9/13-15	1-9/13-15
Const	55.4	66.84	64.2	3.367	1.719	1.97	1.571
CI							
1/CI		375.6	376.2		250.4		146.3
Leaf	0.187			0.05938	0.3785	0.216	0.0526
1/Leaf		-212					
Dead%				-0.06435		-0.05103	
H							
1/H	171.2			116.6			
CI*H			-0.00019				
MSres	3.66	2.86	3.04	1.37	1.11	1.72	1.2
R2	37	54	54	44	70	42	60
P<	0.001	0.001	0.02	0.005	0.001	.0.001	0.001
N	155	155	155	504	504	573	573

The validation of models with leaf content and/or height with or without age for cutting ages from 4 to18 weeks results in a relative prediction error (RPE) below 10%, indicating satisfactory reliability, despite the fair variation explained by the model in Eq 10. If longer CI are also included, RPE is slightly higher.

Also quality characteristics CP, NDF and ash content were sometimes predicted rather well by morphology only (Table B and Chapter 3.1 and 7.2, Table 3 and 19), but the prediction improves if age and (sometimes) N rate are also included. The predicted leaf and ash content of the variety FC tended to be lower than of Bana. But no consistent difference in dOM between both varieties was established when corrected for differences in growth rate or yield. In prediction models ash content was lower in locations Kakamega and Kisi than in Naivasha.

The use of models in practical situations is discussed. For dOM, the use of the simple model L+1/H is probably most feasible, in particular to improve (calibrate) estimates for dOM in training sessions.

Results of Exp 11-12 with Napier/Desmodium mixtures

For the shorter CI of Exp 11, average annual DMY and NY of Napier with and without Desmodium were respectively 17.4 and 12.3 Mg ha^{-1}, and 286 and 96 kg N ha^{-1} (Chapter 4, Table 11). In the mixture with Desmodium, NY was lower when it was harvested at an older age. Once properly established, the mixture of Napier with Desmodium was able to control weeds well. Average Desmodium content was 57% after 6 years at the end of Exp 12. In Exp 12, DMY with Desmodium was comparable to an annual N application of approximately 200 kg N ha^{-1} when based on the difference method, and more when based on nitrogen yield. Derived from the difference in NY with and without Desmodium, respectively 93% and 87% of the annual yield of 201 and 164 kg Desmodium N ha^{-1} was apparently derived from symbiotic N fixation for cutting at a younger and older stage. Contents of CP and dOM of Napier in a mixture with Desmodium were about 1% higher than for Napier without Desmodium. Crude protein content of Desmodium in the mixture was about 10% higher than of Napier, but dOM of Desmodium and the Napier/Desmodium mixture were on average 13-14% and 7-8% lower respectively than of pure Napier grass.

Results of Exp 13-15 with use of cattle manure and fertiliser N

In experiments with manure application (Exp 13-15), annual DMY and NY without N varied respectively from 12 to 16.2 Mg DM and from 118 to 171 kg N ha^{-1} (Chapter 5, Table15). At the lowest application rate of manure, annual yields varied from 15.1 to 19.1 Mg DM ha^{-1}, and from 132 to 191 kg N ha^{-1}. Yields increased with manure and fertiliser N-application, and were higher if manure N was incorporated compared to surface application. Average yield increase over a 5 year period in Exp 13 was respectively 45, 24 and 27 kg DM kg^{-1} applied N for fertiliser (at the lowest N rate) and surface applied and incorporated manure. In Exp 14 and 15 effects of surface applied manure were (much) poorer, while effects of manure and fertiliser decreased at the highest application rate. In Exp 11 and 13, average cutting intervals increased during the last 2 years, due to drought, while NY also decreased.

Nitrogen utilisation

Averaged over N rates and cutting ages of Exp 1-4 and 6-7, the apparent nitrogen recovery (ANR) of fertiliser N was 53%, varying from 39% to 64% (Chapter 3.2; Table 5), excluding residual N effects for Exp 6 and 7. Average apparent nitrogen efficiency (ANE) of applied fertilizer N was 29.7 kg DM kg^{-1} applied N (variation 21 to 40.1 kg DM kg^{-1} N) for cutting ages up to 12 weeks, and 35 kg DM kg N^{-1} for cutting ages of 6 to 18 weeks. The variation in ANR and ANE was much larger for individual cutting intervals. Averaged over a 5 year period in Exp 13, ANR of fertiliser N was respectively 54% and 53% at the low and high N rate. Average ANR of surface applied and incorporated manure N was respectively 27 and 33% (Chapter 5; Table 15). ANR of fertiliser N tended to decrease during the last 2 years, while ANR of manure N increased, in particular for surface applied manure. In Exp 14 and 15, ANR of fertiliser N was respectively 51% and 45% at the lowest N rate, and ANR of incorporated manure 31% and 13% respectively. The ANR of surface applied manure N was lower in Exp 14-15, possibly also because manure was applied before weeding, possibly increasing N losses. The ANR of fertiliser and manure N tended to be lower at (relatively) high application rates, particularly for Exp 15. In Exp 12, ANR of fertiliser N was 52%. In Exp 6 and 7, residual effects of fertiliser N varied between a positive effect of 7.8% and a negative effect of 8.3%, with improved residual effects when grass was cut younger and for higher N rates.

Soil carbon content tended to increase with N supply, in particular from manure but also when derived from Desmodium, and tended to decrease without N input. However, these results were derived from a few soil samples only.

Scenarios to explore effects of nitrogen on potential milk yield

In a scenario approach effects of variation in cutting regime (5 to 16 weeks; Chapter 6, scenarios 1 to 8 in Table 6c) and N supply on predicted potential milk yield per ha from Napier grass only were explored, using models developed for DMY and quality characteristics. Nitrogen rates explored were: 0, 35 and 70 kg N ha^{-1} per cut and 0.5 and 1 kg N ha growing day^{-1} based on 210 growing days per year for 2 rainy seasons combined (155 days per year for 2 dry periods combined). An N application of 35 kg N ha^{-1} per cut, results in an annual N rate of 210 kg and 66 kg N ha for a 5 and 16 week cutting regime respectively. An application of 0.5 and 1 kg N ha^{-1} day^{-1} results in an annual N rate of 105 and 210 kg ha^{-1}.

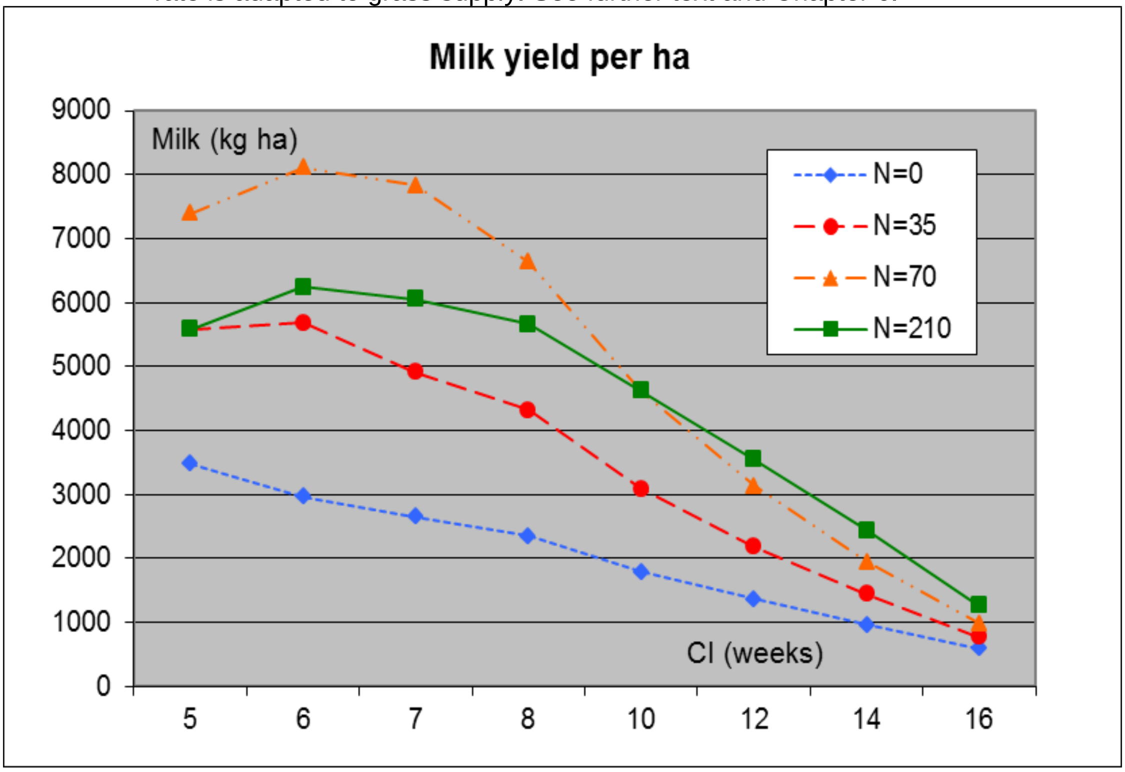
In some additional scenarios (9-12) cutting regimes are combined, older grass (or, for mixtures, Napier/Desmodium) being reserved for later cutting to bridge dry periods. In a scenario representing mixed farms, Napier grass was combined with maize stover and leaf from tree legumes. Potential milk production is derived from energy and protein supply and requirements for cows with a live weight of 400 kg.

The predicted potential effect of N on milk yield peaks at cutting intervals of 6-8 weeks. For an N rate of 0.5 ha^{-1} day^{-1} increase in milk yield varied from 15.2 to 3.5 kg kg^{-1} applied N, and for 1 kg N ha^{-1} growing day^{-1} from 13.1 to -10.6 kg milk kg^{-1} N, respectively for cutting regimes of 6 and 16 weeks (Chapter 6, scenarios 1-8 in Table 16c).

The predicted potential annual milk production without concentrate supplementation for N=210 (1 kg N ha^{-1} day^{-1} for a growing season of 210 days) peaks at 6200 kg ha^{-1} for a 6 week cutting regime and decreases to 1300 kg ha^{-1} for the 16 week cutting regime (Figure C; Chapter 6, Figure 14). For N=70 per cut, predicted milk yield peaks higher, because of a higher N supply, but is lower beyond a CI of 10 weeks because of a lower N supply. Requirements of fertiliser N decrease (substantially) if manure produced is applied to Napier grass, depending on manure management (Chapter 6 and 7).

For a combination of a 7 and 14 week regime (14 weeks to bridge dry periods), predicted potential annual milk yield without concentrates for pure Napier grass (at 1 kg N ha^{-1} day^{-1}) is 6700 kg ha^{-1} year^{1} (Chapter 6; scenario 9 in Table 16c), and slightly lower, at 6000 kg^{-1} ha, for a Napier/Desmodium mixture without N application (scenario 10). The potential for scenario 9 increases to17100 kg milk ha^{-1} year^{-1} with a supplementation of 4 kg concentrates per lactation day (scenario 11). In scenario 12, for a mixed farm with Napier grass and maize and 4 kg concentrates per lactation day, predicted potential milk yield is 11100 kg ha^{-1} (also for a Napier cutting regimes of 7+14 weeks). However, it should be noted that under practical conditions lower than “potential” yields are common, because of less favourable conditions, including for example unbalanced ratios or because cows are not able to produce more (see discussion).

Figure C Potential annual milk yield (kg ha^{-1}) from Napier grass, only using various N rates (0, 35, 70 kg N ha^{-1} cut^{-1} or 210 kg N ha^{-1} (1 kg N ha^{-1} growing day^{-1}) and cutting intervals of 5 to 16 weeks (age in weeks). Results are based on a growing season of 210 days. Stocking rate is adapted to grass supply. See further text and Chapter 6.



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1 Introduction

Demand for food of animal origin is increasing in developing countries (Upton, 2000). It has been observed that under smallholder conditions, as land becomes more limiting than labour, zero-grazing (cut and carry) tends to become more feasible than open grazing, because of the potentially higher forage productivity and utilisation (Humphries, 1991; Staal et al, 1998; Rufino, 2008). According to Ouma et al (2007), perspectives for dairy production based on zero-grazing and the use of Napier grass improve with market orientation, more favourable agro-climatic conditions (i.e. temperate zones in tropical highlands) and smaller farm size. Also forage characteristics are relevant (Stobbs, 1973; Dirven, 1977). Napier grass has become an important forage for smallholder mixed crop-livestock farmers in East African highlands changing to zero-grazing (Kariuki, 1998; Orodho 2005; Tessema et al., 2010). The popularity of Napier grass is attributed to its high yielding ability, provided that nutrient and moisture availability allow, its relative drought tolerance (Skerman and Riveros, 1990; http://www.tropicalforages.info/index.htm), and ease of manual cutting.

Nutrient supply depends upon naturally available soil nutrients and inputs from various sources such as animal and/or green manures, legumes and fertiliser (Mannetje, 1997; Sanchez et al., 1997; Smithon and Giller, 2002). It is important to optimize the use of nitrogen (and other nutrients), also on Napier grass, in order to reverse rapid soil degradation and declining soil productivity (Sanchez et al, 1997; Lal, 2006). This is all the more important because of high fertiliser prices in Africa (FAO, 2008; Morris et al, 2007) and environmental considerations that would minimize pollution (Steinfield et al, 2006; Van der Meer, 2008a, b). Manure is an important nutrient source for many smallholder farmers who cannot afford (or only limited amounts) of chemical fertilizer (Onduru et al 2008; Rufino et al, 2011). But under zero-grazing conditions animals do not excrete nutrients on pasture, and animals completely depend on humans. Therefore, the supply of nutrients to both animals and soil, requires more attention under zero-grazing. Smallholders tend to apply limited manure primarily on crops close to the homestead (Zingore et al., 2007), and less than required by Napier grass on zerograzing farms (Valk, 1991), thereby increasing the risk of nutrient depletion on grass plots. Forage and tree legumes can be cheap sources of nitrogen if conditions are favourable, but use in practice is subject to a number of constraints (Giller et al, 1997; Mwangi and Wambugu, 2003; Shelton et al, 2005; Mekoya et al, 2008), including land availability, phosphorus supply and suitable planting material. Increasing land scarcity and better market access for animal products will probably stimulate optimal nutrient use, also on grass.

A high milk production from forage can only be achieved if forage intake is not limited by supply or quality. In order to optimize animal production, both, forage yield and quality require attention. The main factors limiting intake are digestibility and (crude) protein content (Crowder and Chedda, 1982; Minson, 1990; Muia, 2000). Allowing animals to select on (green) leaves improves intake (Zemmelink, 2003; Abegaz et al, 2007), both leaf content and yield being important. Under practical conditions, without knowledge of chemical composition or other feed characteristics, a cutting height (=H) of about 60-100 cm is often recommended for Napier, for example in Kenya and Ethiopia (Muia, 2000; Zewdu et al, 2002). But because grass supply is often limited (Valk, 1991; Tessema et al, 2010), Napier grass is regularly chopped before feeding to minimize selection and hence rejected residues. Depending on the availability of crop residues and the length of the dry period, Napier grass may also be reserved, cutting at older age. This also depends on the feasibility to conserve forage or to adapt stocking rates and use of external supplements, including concentrates (Humphries, 1991). To balance nutrient supply and demand of animals throughout the year, both, Napier yield and quality need to be optimized throughout the year. Tools to reach this objective are variation in soil nutrient supply (from various sources) and cutting management, accounting for variation in socio-economic and agro-ecological conditions.

Effects of fertilizer N and age on yield, chemical composition and in vitro organic matter digestibility of Napier grass have been studied and/or reviewed before, in particular also in Eastern Africa. Yield increases with N input and age, while quality characteristics decrease at the same time (Vincente-Chandler et al., 1974; Crowder and Cheda, 1982; Kariuki, 1998, Muia, 2000, Zewdu et al, 2003). Results vary, also due to variation in experimental conditions and design. Analysing these effects for a series of experiments combined may help to understand some of the variation. Effects on leaf yield, N utilisation and the relationship between morphological characteristics and digestibility got less attention. Long(er) duration experiments with nutrient inputs from manure or legume N with and without fertiliser N on Napier grass are lacking or scarce.

The National Dairy Development Project (NDDP) in Kenya concentrated on smallholder dairy development through zero-grazing. The main objective of the project was to improve dairy production on smallholder (mixed) farms in the high potential districts of Kenya. Napier grass is an important forage for farms practicing zero-grazing. To improve the knowledge on Napier management and utilisation, and in support to this project, a series of 15 cutting experiments (Exp) was conducted between 1983 and 1991 on several sites in Kenya. This report reviews and discusses results of these experiments and provides results of a meta-analysis of in particular the relation between Napier morphology (contents of green and dead leaf and grass height) and Napier quality. Until now results were only reported in internal reports, and not in peer-reviewed scientific publications.

The most important management variables investigated in the experiments were variation in growing period (or cutting interval=CI) and rate and/or source of nitrogen (N). Parameters measured were effects on yields of dry matter (DMY), leaf (LY) and nitrogen (NY), nitrogen utilization and quality characteristics of Napier, in particular morphology (green leaf=L, dead leaf=D and grass height=H), chemical characteristics (crude ash and protein=CP, crude, neutral and acid detergent fibre =CF/NDF/ADF and acid detergent lignin=ADL) and in vitro organic matter digestibility (dOM). Nitrogen was derived from various sources: fertilizer and/or cattle manure and/or green leaf Desmodium (D. intortum, further referred to as Desmodium). Napier variety varied, depending on the experiment, and was also directly compared in 2 experiments.

An important objective was also to improve and support judgment of Napier quality for situations without laboratory facilities. Predictive models were developed for the relationship between in particular dOM and contents of green and dead leaf and/or grass height, without and with cutting age. In some models environmental parameters growing season and temperature (T) were also included. Results are compared with models based on chemical characteristics. Determination of parameters such as age, height and leaf content do not require complicated laboratory equipment. To improve Napier management, farmers may in training sessions improve their ability to use morphological parameters.
In a scenario approach, effects of variation in growing period of Napier and rate and source of N are explored at farm level, in particular effects on forage yield and on milk production per ha and per kg applied N.

The main objective of Exp 1-9 was to investigate the effect of variation in cutting management and application of fertiliser N on Napier production and quality characteristics. Only fertiliser N was used. In Exp 11 and 12 Napier grass was grown with and without the forage legume Greenleaf Desmodium (*Desmodium intortum*) to supply N. In Exp 13-15 N supply by cattle manure was compared to use of fertiliser N. Experiment 10, with a design similar to Exp 1, was conducted under extreme drought, and results are mainly used to validate models for quality characteristics (see below).

Chapter 2 discusses the methodology and details of Exp 1-9. Yields and morphological characteristics are discussed in Chapter 3.1, nitrogen utilisation in Chapter 3.2. Chapter 3.3 discusses organic matter digestibility and prediction models for dOM, first using morphological and environmental characteristics and subsequently morphological and chemical characteristics.
Chapter 4 discusses the use of Napier grass with or without Desmodium at 2 cutting stages (Exp 11), and in a follow up experiment (Exp 12), the use of Napier/Desmodium compared to Napier grown with fertilizer N. Chapter 5 presents a comparison of the effects of surface applied and incorporated cattle manure on Napier grass compared to fertiliser N (Exp 13-15). Exp 11 and 13 continued for 5 years, Exp 14 and 15 for 1-2 years. Methodology of Exp 11-15 is also discussed in Chapters 4 and 5, if not already discussed in Chapter 2. Chapter 6 discusses results of the scenario approach. Results are discussed generally in Chapter 7, followed by the main conclusions in Chapter 8.

2 Methodology

The two most important parameters varied in most experiments are: growing period/age (=CI or cutting interval) and rate and/or source of N input (N from fertilizer, manure or biological N fixation by Desmodium). However, both were not always included or combined in any given experiment. In Exp 5 and 9 for example, variety was included, but N rate not. In Exp 8 only cutting regimes were investigated and N rate was omitted with similar N application for all cutting regimes (at the start of the 2 rainy seasons only). In Exp 1, 2 and 5 only one single cut was harvested, but in other experiments harvests were made over a longer period, for example over a period of 24 weeks in Exp 6-7, and during 3, respectively 5 years in Exp 8 and 11. The experimental sites or location varied. Although most experiments were conducted in Naivasha in central Kenya, some were conducted in Kakamega and Kisii in western Kenya.

In Exp 1-9 only fertiliser N was used. The most important characteristics of Exp 1-9 are given in Table 1 (see for other experiments later). These include: location, year and season (rainy season=R, dry season=D; or S1 and S2, see later), and treatments (N rate, CI and/or variety). All experiments were designed as randomised blocks with 3-4 replicates as blocks. However, Exp 9 had only 2 replicates. The design of Exp 3-4 and Exp 6-7 was similar, both with multiple cuts (e.g. 4 cuts for the 6 week CI in Exp 6 (=4*6)) and 3 rates of fertiliser N. But there were also differences. In Exp 3-4, all N was applied prior to the first cut, in Exp 6-7, N was divided over all cuts. The total duration was respectively 18 and 24 weeks for Exp 3-4 and Exp 6-7. On a daily basis, N rates in Exp 3-4 were only slightly lower than those in Exp 6-7, but older (heavier first) cuts received less N per growing day (and per unit of yield increase). Nitrogen rates of 84 and 168 kg N ha^{-1} in Exp 6-7, are, if converted to daily rates, equivalent to respectively 0.5 and 1 kg N ha^{-1} growing day^{-1}. In reality, to optimise application regimes of manure and fertiliser, agro-ecological conditions (soils and climate) are important (see discussion later). Exp 3 and 4 in Naivasha started during the short rains (on respectively November 8 and 1, continuing into the dry season), Exp 6 in Kakamega and Exp 7 in Kisii during the long rainy season (on April 29 and June 11 respectively).
The objective of Experiment 8 in Naivasha was to relate various cutting regimes to practical on farm situations, including reservation of (older) grass to bridge dry periods. Multiple cuts were harvested during a period of 3 years (April 1985-88). The following cutting regimes (variety FC) were used: cutting at a target grass height of resp. 50, 100 and 150 cm (cutting regimes A, B and C) and cutting after 6 months followed by cutting at 100 cm (regime D). Regime D with a 6 month rest period was meant to promote drought resistance (through deeper rooting) and dry season yield (during the long dry period January-March). It was established after maize. A clearing cut was performed each year in April (at the start of the long rains). The N rate was 100 kg ha^{-1} year^{-1} for all regimes, given in 2 applications of each 50 kg N ha^{-1} during the start of the long and short rains respectively (except prior to the initial cut in April 1985 with only 25 kg N). Experiment 9 provided a comparison of varieties Bana and French Cameroons (=FC) and was conducted from 1984 -86 (starting on November 30th). In the other experiments only single cuts were harvested, investigating CI and N rate (Exp 1 and 2) or variety and CI (Exp 5). The N rate in Exp 9 was considered to be similar to Exp 8, but this data is not available anymore. The N rate used was derived and checked by comparing N yields with and without applied N with results from Exp 8 in particular (and other experiments in Naivasha!).

Table 1 Location, period and season (R=rainy, cold and D=dry, warm) and treatments per experiment (Exp 1-9): fertiliser rate (N in kg ha^{-1}), growing/cutting interval (CI in weeks and/or number of cuts; 3*6=3 cuts of 6 weeks old) and Napier variety used. Exp 5 and 9 investigated effect of CI and variety, Exp 8 compared 4 cutting regimes. See further text.

Exp	Location	Period	N rate	CI	Variety	Remarks
1	Naivasha	1984/R	0-75	3-6-8-10-12-14-17-20	Bana	Single cuts
2	Naivasha	1987/R	25-75	6-9-12-15	Bana	Single cuts
3	Naivasha	84/85/D	0-50-100	3*6-2*9-12+6-15+3-18	Bana	Total 18 wks; N cut 1
4	Naivasha	85/86/D	0-50-100	3*6-2*9-12+6-15+3-18	FC	Total 18 wks; N cut 1
5	Naivasha	1987/R	50	4-6-8-10-12-14	Bana+FC	Single cuts
6	Kakamega	1989/R	0-84-168	6*4-4*6-3*8-2*12	Bana	24 wks; N divided
7	Kisii	1990/R	0-84-168	4*6 and 2*12	Bana	24 wks; N divided
8	Naivasha	1985/87	100 year^{-1}	Variable CI and height	FC	2/3-5 cuts year^{-1}
9	Naivasha	1985/86	100 year^{-1}	Variable, total of 10 cuts	Bana+FC	5 cuts year^{-1}

Nitrogen was applied as calcium ammonium nitrate (26% N). Phosphorus was applied as single or triple superphosphate, potash as muriate of potash (150-200 kg K_2O ha^{-1}), both in quantities aiming to avoid shortages. The application rate was mostly around 75 kg P_2O5 and 150-200 kg K_2O ha^{-1}. But in Exp 8 annual application rate was 100 P_2O5 and 360 kg K_2O ha^{-1} $year^{-1}$ (possibly also in Exp 9; data not available anymore).

Experimental sites (location)
In Naivasha (altitude approximately 1900 m), experiments were sited on imperfectly to poorly drained, very deep, dark greyish brown, silty loam to clay soils developed on sediments of volcanic ash. In Kakamega and Kisii (Exp 6 and 7) in western Kenya (altitude approx.1600 and 1800 m respectively), experiments were sited on well drained, deep dark reddish brown friable clay soils (nitosols) with a humic top soil (Jaetzhold and Schmidt, 1983).
In Naivasha, experiments were all sited in the same (former) pasture field, for most (earlier started) experiments being ploughed first in August 1982, followed by subsequent Napier establishment. Due to drought, establishment after ploughing in 1982 was poor and was (partly) repeated, for some experiments after an intermediary maize crop (Exp 1, 3 and 8). Exp 4 was conducted on a fertile site, due to establishment immediately after ploughing of an additional pasture plot. Establishment was followed by one or more intermediary (clearing) cuts before the actual start of experiments (Annex 1). In Kakamega (Exp 6) and Kisii (Exp 7) sites had been cropped before grass establishment. The pH after ploughing of pasture in Naivasha in 1982 was 8.1. Soils in Kakamega and Kisii were moderately acid (Annex 1). Soil carbon (C) contents were initially respectively 1.7%, 2.9 % and 1.65% in Naivasha, Kakamega and Kisii respectively. Precipitation and temperature at the experimental locations and for Kiambu district of Central Kenya are given in Annex 2 (temperatures for Naivasha are long time averages). In Naivasha, situated in a semi-arid area, precipitation was supplemented by irrigation to simulate the precipitation level of about 1000 mm in Kiambu in Central Kenya. The coldest months are usually June-August. Sometimes irregular experimental sites, and/or poor water distribution contributed to experimental variation (Annex 3a). Average temperature over the growing period of all cuts of Exp 1-9 was 17.6 °C, and, upon inclusion of all experiments discussed 17.3 °C (see later for the complete dataset).
Napier was planted in rows 90 cm apart and at 60 cm within rows. All plots consisted of 4 rows of 7 plants (net plot size of 15.12 m^2), divided by 2 guard rows, also along the edges. When harvesting (using a sickle), grass was cut at a stubble height of about 5 cm.
After the last cuts of Exp 6 and 7 a residual cut was later made to determine residual effects of nitrogen application, after 4 and 10 weeks respectively (not given in Table 1). In Exp 3 and 4 residual effects of the first and only N application could be measured in subsequent cuts. In Exp 8 so-called “clearing” cuts were made between April 7 and 15 (being the last cut of the respective growing period/year and at the start of the rainy season), followed by fertilisation. In Exp 13-15, manure and fertiliser N were applied during the (beginning of) rainy seasons.

Measurements and chemical analysis
Grass height (H), fresh weight, dry matter contents (in duplicate) and contents of green leaf (further referred to as leaf=L), stem and dead leaf (=D) were determined per replicate, taking subsamples from a ridge of a larger sample. Determination of leaf and stem contents, and grass height was laborious, and therefore not always performed, in particular for later cuts.
Because of too high costs, chemical analysis was often not made for all replicates (and all parameters/cuts).Contents of crude ash, crude protein and dOM were mostly analysed for one replicate. Nitrogen content was calculated by dividing CP% by 6.25. But in Exp 6 and 7 contents of crude ash and CP were analysed for all replicates and dOM for two. In most experiments CF and NDF were determined in a single replicate (2 reps in Exp 7), but NDF was not determined in Exp 2 and not in all (later) cuts of Exp 3, 4, and 8. In Exp 7, ADF, fat, calcium and phosphorus were determined in 2 replicates. ADF was also determined in the first cut of Exp 4 and up to 12 weeks in Exp 6. The cell wall constituent’s crude, neutral and acid detergent fibre (CF, NDF and ADF) and acid detergent lignin (ADL) were analysed according to Van Soest, the in vitro organic matter digestibility (dOM) according to Tilley and Terry (1963). For details of chemical analysis see Annex 3b and Steg et al (1990).

Statistical analysis and sources of variation
Originally experiments were not designed with an overall statistical analysis in mind. A statistical analysis of individual experiments was being performed with the statistical package Genstat (Genstat Reference Manual, 13th edition) at an earlier stage. A few results from this earlier analysis are used in this report. The REML procedure of Genstat can account for differences in design and measurements between

experiments, and was therefore used for an overall meta regression analysis of experiments combined (see further later), with emphasis on in vitro organic matter digestibility (dOM). Experiment, replicate and plot and the interaction with cut number (within an experiment) were included as random factors. The random model used was (EXP/REP/VELD)*Cut_No. This comprises the random variation at the level of experiment, replicate, plot and cut number within an experiment, including interactions. But it should be noted that the random model can apparently not account for all variation due to differences in experimental design (in particular for the variation of models for CP if manure treatments are included; see further results and discussion).

Datasets to develop prediction models for dOM, and leaf content, grass height, CP and ash content and yields varied, depending on availability of morphological and chemical characteristics (see before) and purpose. Subsets were derived from larger datasets including all replicates (n=1066 for Exp 1-11; n=1802 for Exp 1-15). In Exp 1-111 dOM is determined, in Exp 13-15 not. Given n is for samples with determination of DM%, for other characteristics sample number is lower (for example n=386 for samples with determination of dOM for Exp 1-11 and n=1368 for CP% for Exp 1-15). For combinations of several characteristics sample number is still lower. Results from treatments with pure Napier grass from Exp 11-12 are included in regression analysis, but results from Napier/Desmodium mixtures not. Initially 2 datasets (A and B; n=155/255) were used, also to select models for dOM based on morphological and environmental parameters. For both datasets, besides contents green and dead leaf and grass height, contents of dOM, CP and ash are also known(for dataset A, cutting age is restricted to a CI of 4 to 18 weeks of Exp 1-9; dataset B contains all available samples of Exp 1-11). Subsequently, to compare with morphology, models based on chemical parameters were developed, stepwise including more chemical parameters, but from gradually smaller datasets because of incomplete analysis (see before). Those datasets used are described below. The dataset is available on request.

- Dataset A (n=155) is composed of samples from Exp 1-9 with a cutting age (CI) of 4-18 weeks, of which besides dOM, CP and ash content, and % leaf and grass height are known. To check for differences between cutting ages, in some models cutting age was also limited to 12 weeks (n=128), the shorter CI probably resulting in better growing conditions (for example due to relatively higher N availability per growing day at the same N rate).
- Datasets A1-A3 are composed of samples from Exp 1-4 and 6-7 only, while cutting age is limited to 4-18 weeks. For these experiments variation in N application is part of the experimental design. Dataset A1 (n=326) contains all replicates with known CP and ash contents (dOM not always), if leaf content is also known n is lower (n=255). Dataset A2 and A3 from Exp 1-4 and 6-7 (CI-4-18 weeks) are used to predict dOM. For dataset A2, dOM is also known (n=199), and for dataset A3 (n=165) dOM, CP, ash and leaf% are all known.
- Dataset A1 (n=326) has also been used to develop prediction models for DMY, LY (=leaf yield; n=255), NY (=N yield or uptake), CP% and ash% from cutting age and fertiliser N (Table 3a). Similar prediction models for samples from all experiments with fertiliser N application (CI of 4 weeks and older), consist of Exp 1-9 and Exp 13-15, but without manure treatments to avoid disturbing residual effects of manure application (dataset A4; n=1100, 915, 725, 725 and 692 for resp DMY, LY, NY, CP% and ash%). Samples from Exp 10 (seriously affected by drought), Exp 11 (no fertiliser N) and Exp12 are also excluded. To predict DMY from grass height for dataset A1 (H also known), n becomes 279, and for all samples of Exp 1-9 and 13-15 n=868 (Table 3). The results of prediction models derived from the whole dataset (Exp 1-15; dataset A5; n=1802 for DMY), including treatments with manure application, are discussed in Chapter 7.1.
- Dataset B (n=255) contains Napier samples from Exp 1-11 with known dOM, CP and ash content and leaf% and height, but now for all cutting ages of 4 weeks and older (including the samples from dataset A). For Exp 11 Napier samples from the Napier/Desmodium mixture are not included (see for Exp 11 Chapter 4). The design of Exp 10 is similar to Exp 1, but is mainly discussed in Chapter 7). Exp 11 and Exp 10 were both seriously affected by drought. Dataset B includes cutting ages up to half a year during and the long dry period in Exp 8, 9 and 11. For these reasons between sample variation is much larger than for dataset A (see also Annex 3a)
- Dataset C (n=386). In some models dataset C was also used, the dataset comprising all samples for which contents of ash, CP and dOM were known, but results for morphological parameters were partly missing. For dataset C1 (n=323) leaf content is also known, while grass height was not always available, and for dataset C2 (n=304) grass height is available, but not always leaf content.
- Dataset D (n=136) comprises samples from Exp 1-9, similar to dataset A, but for all cutting ages with known contents of leaf, dOM, CP, ash and NDF, but still without ADF.

- Datasets E, F and G (n=65, 57 and 15). These datasets enable a more detailed comparison of morphological and chemical parameters, and also include samples with known ADF content, however resulting in smaller datasets. Datasets E (n=65) and F (n=57) provide models for dOM based on respectively leaf content and height of Exp 1-4 and 6-7 (CI of 4-18 weeks), enabling a comparison with chemical parameters (CF, NDF and ADF). Dataset G (n=15; Exp 4 only) includes also samples with ADL content.
- Datasets H and I (n=132 and 123). Models based on age and/or leaf content or grass height, developed from results of Exp 1-7 (dataset H, n=123; n=119 if limited to ages of 4-18 weeks) were validated with results from Exp 8-11 (dataset I, n=132; n=102 limited to 4-18 weeks). Dataset I comprises long duration Exp 8, 9 and 11, including cutting ages up to 6 months (see previously), therefore cutting ages were sometimes restricted to18 weeks.
- In a few cases additional datasets were used (often related to datasets A-D), to predict green and dead leaf content of grass and grass height, using results from all replicates (higher sample number without known dOM content). This is indicated in the text by another value for n (and a short explanation).
- Harvest season (S1=rainy season and S2=dry season; see below), and average temperatures during the growing period of single cuts (T) and the temperature sum during the growing period (T-sum=age*T) were sometimes also included during model development.

It should be noted that results are derived from individual cuts. This implicates that results from follow up cuts include residual effects from preceding cuts. Residual effects are especially important for the prediction of yields and CP content after manure application, but also play a (less important) role for fertilizer application. Effects on N the prediction of dOM contents are small and often not significant at the same harvest age. See further results and discussion.

Model evaluation
The models were evaluated on the basis of the residual mean square (=MSres) and the variation explained (=R^2). MSres indicates the confidence interval, which should be low, whereas R^2 should be high. The standard error (se) of prediction is the square root of MSres. Only significant parameters (based on the F statistic; $P<0.05$ for most often $P<0.001$) were included in the final models. The indicated P value is for the parameter with the highest standard error used in a model. Complicated models with more than 4 parameters sometimes predict dOM slightly better, but these models are often not included in tables, because they are considered too complex for use in more practical situations. However, such models are sometimes given in an Annex.
Seasonal influences were indicated as S1 for cuts grown and mainly harvested during the colder and rainy season, including the short dry season (from the first cut in April, when harvested before April 15, to December 31), S2 for the long warm dry season (for cuts harvested between January 1 and the first cut in April, when cut before April 15). The use of both season and temperature is not without problems (see also Annex 2 and 3). The actual precipitation varies much between experiments, and experiments are affected by drought at different growth stages. Dry season growth results from residual soil moisture and incidental precipitation (including large showers). Variable soil fertility (productivity) results in sometimes large experimental variation, despite a blocking experimental design. More details on experimental variation and problems experienced are given in Annex 3a.

Results from models with different parameters and/or different datasets have been compared in graphs. But an additional analysis was performed for some models. The mean square and relative prediction error (MSPE and RPE) are sometimes used as criteria for the accuracy of prediction (Rook et al., 1991). MSPE is the sum of the square root of the measured values (M) minus the value (P) predicted from the validation model divided by the number of samples (n) in the dataset: MSPE = (M-P)^2/n. The relative prediction error (RPE) expresses MSPE as a % of the average of measured values (A): RPE=100*MSPE/A. Fuentes-pila et al. (1996), consider an RPE below 10% of the average as satisfactory, and an RPE above 20% as unacceptable. Prediction models for dOM with age and/or leaf or height in particular were validated. Models for dOM for dataset H, based on models similar to those for datasets A-D, were validated with dataset I. Datasets A-D partly overlap dataset I (dataset A for example for cutting ages of 4-18 weeks Exp 8 and 9). But, to compare RPE, some "morphological" models for these larger datasets were also "validated" with dataset I, because these models may improve prediction of dOM. Because of the limited number of samples, models based on datasets with more extensive chemical analyses (D-G), were not validated, since this was not the primary objective of this report.

In some experiments grass height was determined using two methods: measured with a stick or a stick with a PVC disk. In other experiments H was only determined using one of these methods, most frequently using only a stick. A good relationship was found between both methods of measurement: H_stick= - 5.2 + 1.0148 * H_disk (MSres=11.7; R^2=97). For prediction of dOM using height was not dependent on the method of measurement. Therefore only H determined with a stick was used to model dOM.

Nitrogen utilisation and calculation of the apparent nitrogen recovery and nitrogen efficiency
The apparent nitrogen recovery (ANR in %) and nitrogen efficiency (ANE in kg DM per kg N applied) are based on the increases in N yield (NY is CP yield divided by 6.25) and DMY in relation to a control without nitrogen application. For ANR this is expressed as: ANR=100*(NYx-NY0)/x, and for ANE as ANE=100*(DMYx-DMY0)/x. In these equations NYx/DMYx and NY0/DMY0 are the NY and DMY at fertilisation level x and 0 (control without N) respectively. Only harvested material is included, grass residues including roots not. In Exp 5 only average DMY is known and CP content is available for 1 replicate only, and, arbitrary, NY is derived from average DMY. Otherwise each cut is considered a separate entity. The percentage fertiliser equivalent (FE) of manure N was also calculated, derived from both ANE and ANR, as the ANR and ANE for manure divided by the ANE and ANR of fertiliser N. This was based on the lowest rate of fertiliser N only, also because effects of N were mostly more or less linear (see results).
The average annual N uptake (or NY) without N application is normally considered to be equivalent to the soil nitrogen supply (=SNS). Although cut number is included in the random model (see above), residual effects of previously fertilised cuts on yields of subsequent cuts cannot be excluded. This implies that effects of N are probably slightly underestimated (or overestimated in case of negative residual effects).

Several of the methodologies described were also applied in Exp 11-15, but the main characteristics of these experiments are presented in Chapter 4 and 5!
For details concerning methodology and results of individual experiments reference is made to Wouters (1985 and 1986 for Exp 1 and 3), Van der Kamp (1986: Exp 4); Kariuki (1989: Exp 2), Snijders et al. (1992a, 1992b and 1992c for Exp 13-15, Exp 6-7 and Exp 11-12), and also Schreuder et al (1993).

3 Results Experiments 1-9

3.1 Yield, morphology and chemical characteristics

3.1.1 Yield of dry matter, leaf and nitrogen

Dry matter yield (DMY) increased with cutting age and N rate (Table 2a, Figures 1, 2). Averaged over the first cut only of Exp 3-4, DMY increased with CI from 2.5 to 13.8 Mg DM ha^{-1}, depending on N rate. In Exp 6 DMY ranged from 7.5 Mg DM for the 4 week CI without N (results not given) to 20.9 Mg DM at the 12 week CI for N=168 (total harvest period of 24 weeks). Averaged over Exp 6-7, DMY ranged from 8.6 Mg ha^{-1} without N at the 6 week CI up to 18.8 Mg ha^{-1} at the highest N rate at a CI of 12 weeks (results not given). The leaf/stem ratio (LSR) and contents of CP and ash decreased with CI, while content of dead leaf increased (see further 3.1.3).The deviating content of 21.4% dead leaf for the 12 week CI in Exp 6 at N=84 is unexpected (see Annex 3a for experimental variation). Least Square Differences (LSD; $P<0.05$) for DMY in Exp 6 and 7 were respectively 0.8 and 1.2 Mg DM ha^{-1} for N rate and 1 and 1.4 Mg ha^{-1} for cutting age, and for CP respectively 0.4 and 0.7 % CP for N rates and 0.4 and 0.6% for CI. For other statistics see original reports (Chapter 2).
Annual DMY in Exp 8 increased if cut number decreased (from 14 to 24 Mg DM ha^{-1} $year^{-1}$ for cutting regime A and D), but NY tended to decrease (Table 2b, Figures 3a, b). Daily growth rates (GR; results not given separately) were highest for the (first) fertilised cuts of Exp 4 (approximately 130 kg DM ha^{-1} for the 12-18 week CI at N=100). On annual basis, average daily GR in Exp 8 varied from about 35 to 70 kg DM ha^{-1} (cutting regimes A and D respectively). Other yields are shown in the figures or as results of a regression analysis (Table 3a, b). Also quality characteristics are further discussed later.

Table 2a Dry matter yield (DMY in Mg ha^{-1}), ratio between green leaf and stem (LSR), and contents (%) of dead leaf, crude ash (ash) and crude protein (CP) for various cutting regimes and N rates (N0-N2), averaged (weighed) over Exp 3-4 (first fertilized cut only!) and Exp 6-7 (total of all cuts during 24 weeks). N rates for respectively Exp 3-4 and 6-7 are added.

Experiment		**Exp 3-4**					**Exp 6**		**Exp 7**	
CI (weeks)		**6**	**9**	**12**	**15**	**18**	**4*6**	**2*12**	**4*6**	**2*12**
N (kg ha^{-1})										
N0=0	**DMY**	2.5	4.8	6.3	8.8	9.7	8.7	10.6	8.5	11.1
N1=50/84		3.3	5.5	8.2	12.3	11.7	11.8	15.6	9.9	14.9
N2=100/168		3.6	6.7	9.6	12.1	13.8	12.5	20.9	12.9	16.6
N0=0	**CP**	12.8	8.4	6.1	5.9	4.3	9.4	5.7	8.7	6
N1=50/84		14.6	8.6	7.2	5.6	4.9	9.7	5.8	8.7	6.4
N2=100/168		15.1	10.0	8.0	6.7	5.0	10	5.9	10.1	6.5
N0=0	**ash**	20.3	20.3	18.3	17.6	15.3	20.1	16.8	18.8	17.3
N1=50/84		20.8	19.5	18.0	17.0	15.8	18.7	15.8	18.1	15.3
N2=100/168		19.0	18.4	17.6	16.7	14.8	18.2	14.9	16.8	14.3
N0=0	**LSR**	2.6	1.5	1.2	0.7	0.6	2.6	1.8	3.2	1.8
N1=50/84		2.5	1.4	1.0	0.7	0.6	2.5	1.7	2.7	1.9
N2=100/168		2.3	1.3	0.9	0.7	0.5	2.7	1.2	2.7	1.9
N0=0	**dead**	1.4	6.3	18.0	20.1	21.7	2.5	13.7	0.7	4.1
N1=50/84		1.9	6.9	21.0	18.4	19.8	1.7	21.4	0.7	6
N2=100/168		1.0	6.1	17.5	17.6	14.8	1.7	11.1	1	5.7

Table 2b Average annual cut number (rainy and dry seasons!), yields of DM and N (DMY and NY in respectively Mg and kg ha^{-1} $year^{-1}$) and average (weighed) contents of OM, CP and dOM (all in %) per treatment (A-D) for Exp 8. See further text, also for abbreviations.

Treatment	Cuts	DMY	NY	OM	CP	dOM
A	5.00	14.027	169.4	79.6	7.5	70.8
B	3.67	16.520	142.2	81.7	5.4	66.2
C	3.00	19.575	140.0	83.6	4.5	62.1
D	2.67	24.242	138.8	84.3	3.6	54.8

Green leaf yield (LY) peaked much earlier than DMY (Figure 1a). Effect of N on DMY increased with CI, the effect on leaf yield stabilised after a CI of 8 weeks (no N effect at a CI of 3 weeks!). If various cutting regimes are harvested over the same period, total leaf yield (LY) increased until a CI of about 6 weeks (Figure 1b, c), and started to decrease for a CI longer than 6-8 weeks (see also discussion). Figure 1c shows total LY (harvested over 18 weeks) for different cutting regimes (4-18 weeks), derived from a regression model for all replicates of Exp 1-9. Leaf yield topped at about 6 Mg ha^{-1} at a CI of 42 days (total of 3 cuts), deceasing to about 4.5 ton ha^{-1} if cut only once during 18 weeks. Leaf yield was

Figure 1a Average dry matter and leaf yield (DMY and LY) for Exp 1 (single replicate) plotted against cutting age (CI in weeks) for two N application rates (N=0 and N=75 in kg ha^{-1}).

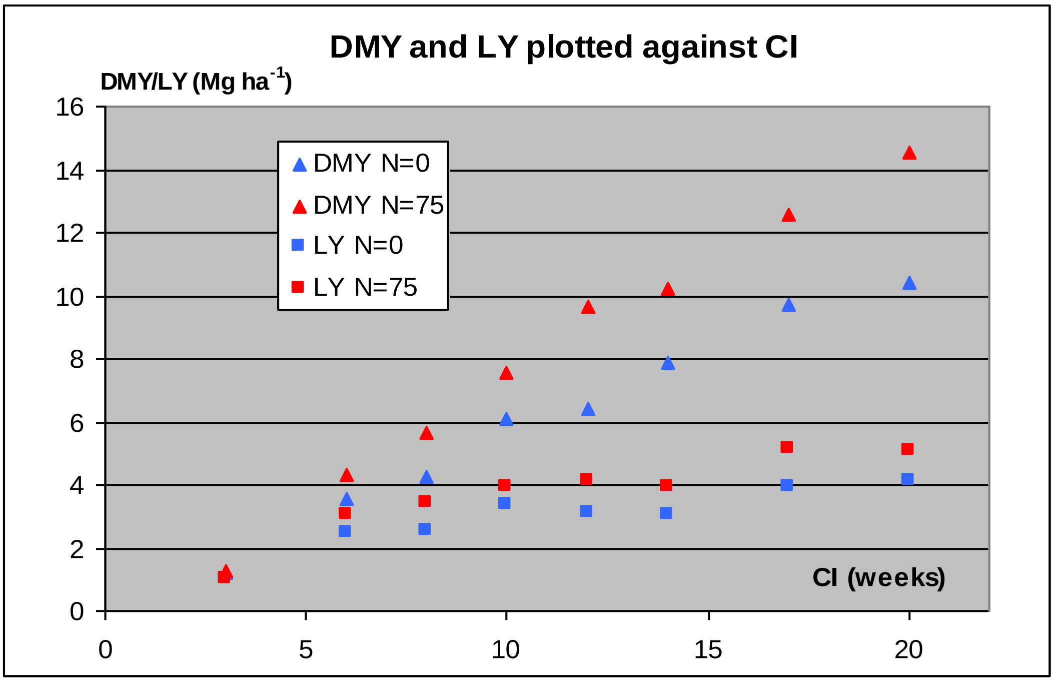
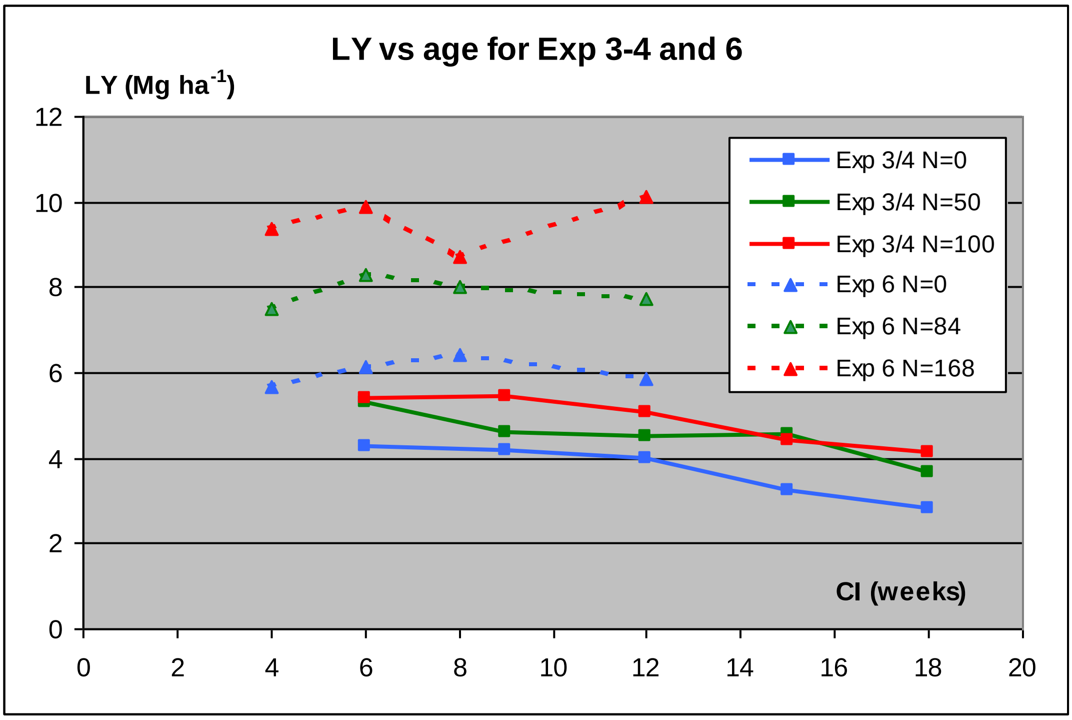


Figure 1b Total yield of green leaf per N rate for averages of Exp 3/4 and for Exp 6 plotted against cutting interval (CI) per cutting regime: totals for periods of respectively 18 and 24 weeks for Exp 3/4 and 6 (CI indicated for Exp 3-4 is for the first cut!). See further text.



substantially higher with N, but leaf content was about 5% lower with N if cut at the same age if modelled for the same dataset (results not given; for leaf% see further below).
Also nitrogen yield tended to top before DMY. For single cuts only, NY sometimes still increased at a long CI (Figure 2a, b). In Exp 1, NY increased with age (Figure 2a), but with N, in Exp 2, NY peaked at a CI of 12 weeks (Figure 2b). In Exp 3-4 and Exp 6-7, harvested over the same period, total NY tended to decrease for regimes with a longer CI (Figures 6a, b in section 2.2.2). In Exp 8, Dry matter yield was highest for regime D, but NY was highest for regime A with the shortest growing periods (Figure 3b). Nitrogen yield and utilisation are further discussed in Section 2.2.2.

Figure 1c Total leaf yield (LY over a period of 18 weeks) plotted against cutting regime for 2 N rates (kg N ha^{-1} day^{-1}; CI of 4-18 weeks). The graph is derived from a model for Exp 1-9 (n=544): LY (Mg ha^{-1}) =3.43 -76.64/CI + 0.01373*N (MSres=0.16; R^2=64; P<0.001).

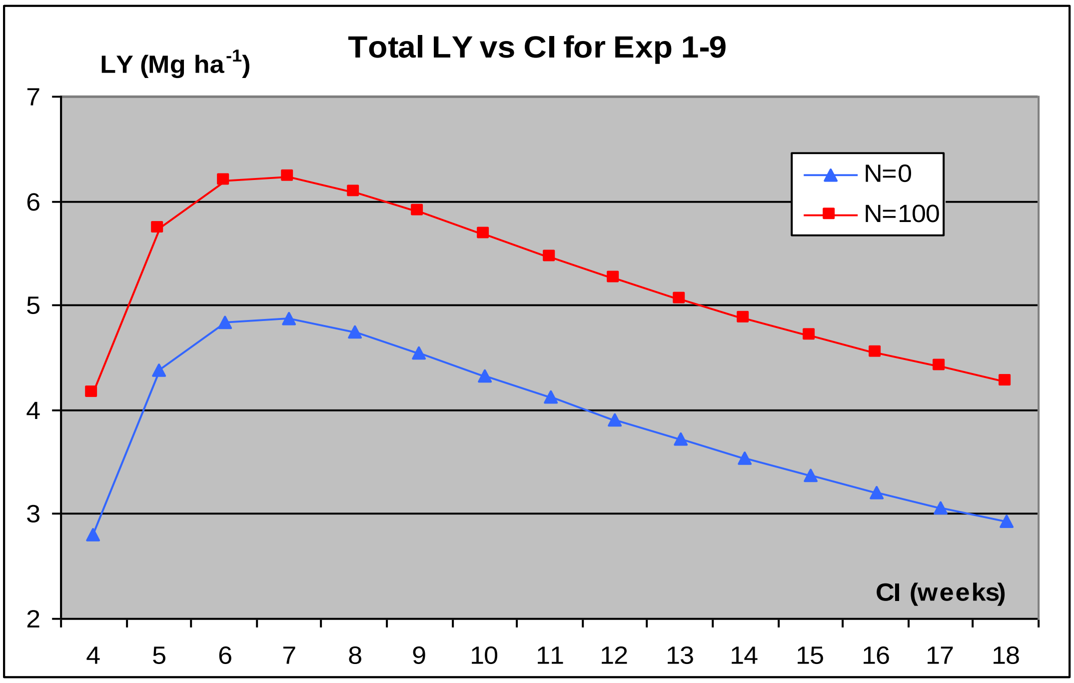


Figure 2a Average dry matter yield (DMY) and N yield (NY) of Exp 1 plotted against cutting age (based on 1 replicate!)

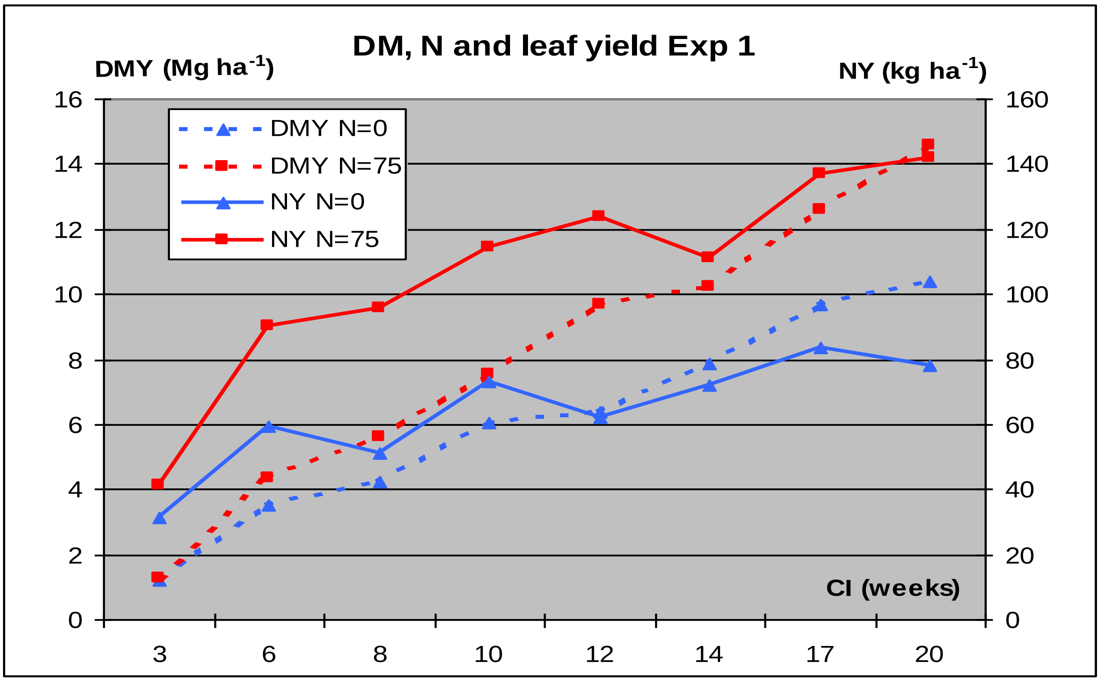


Figure 2b Average DM and N yield (DMY and NY) of Exp 2 plotted against cutting age (1 replicate!).

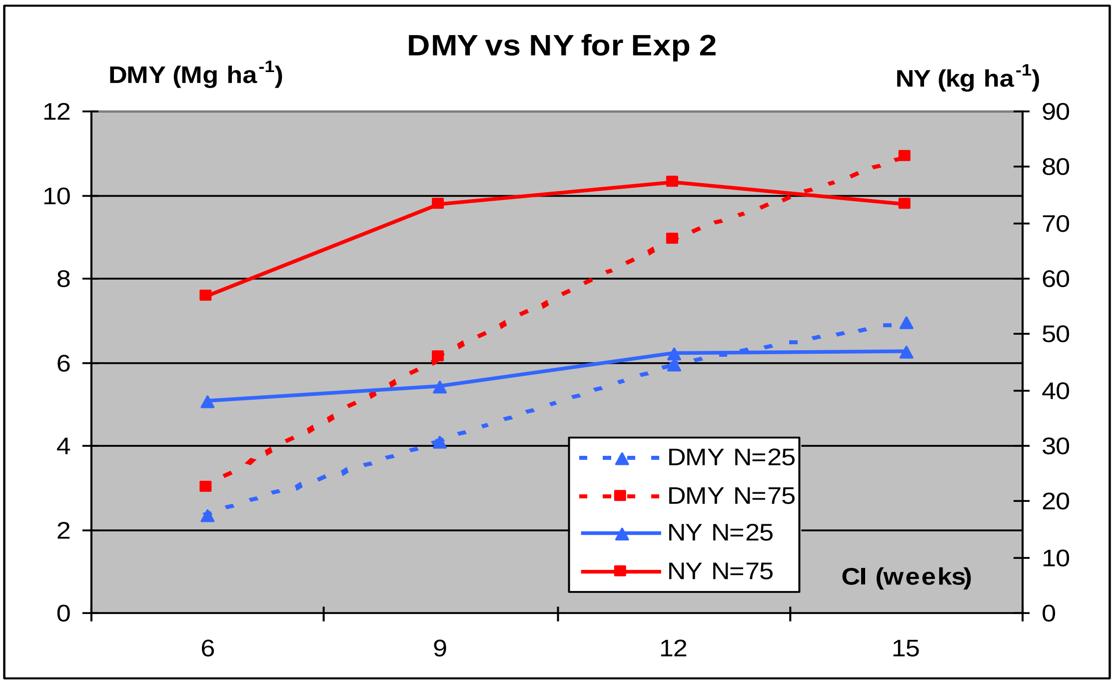
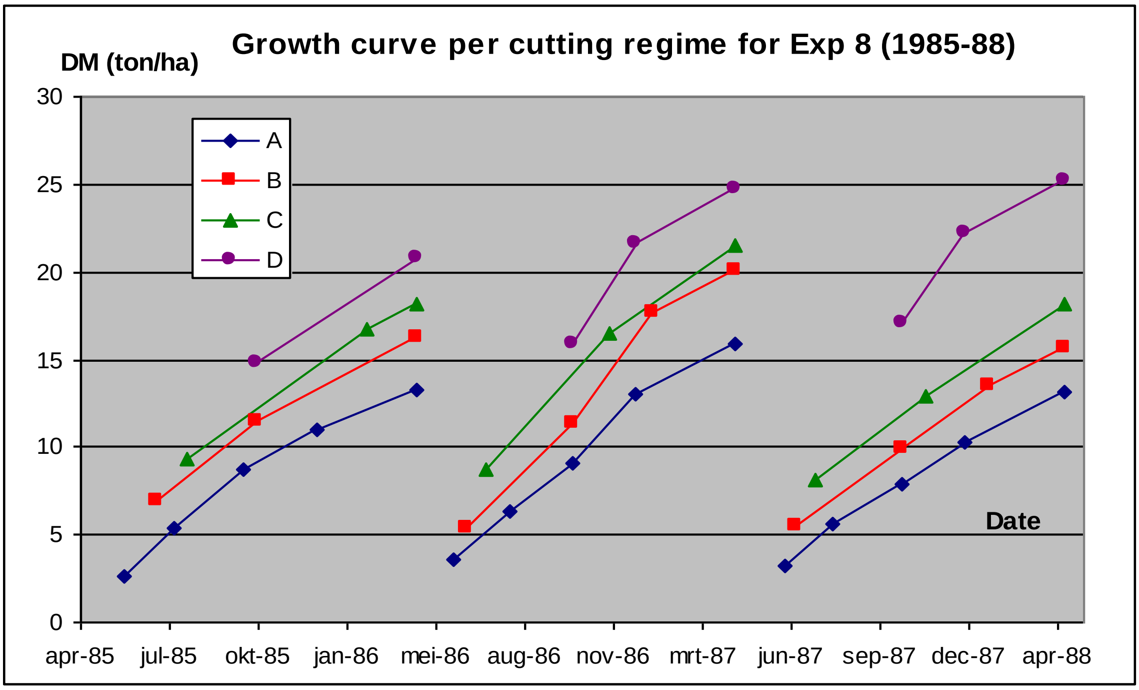


Figure 3a Cumulative DM yield (=growth curves for averages over replicates) per cutting regime (A-D) and year for Exp 8 (1985-88). The average CI was resp.10.4, 14.2, 17.3 and 19.5 weeks for regimes A-D (including long dry season!) Annual clearing (last) cuts were made in April (April 7 to15).



There was a rather good relationship between DMY and CI and N rate for Exp 1-4 and 6-7 (Table 3; Equation=Eq 1.1; dataset A1, n=326; N rate part of design, see Chapter 2). The predicted DMY for Exp 1-9 and 13-15 is given in Eq 1.2 (n=1100; n=779 for the relation with grass height). The standard error for the prediction of DMY in Eq 1.1 is 0.43 Mg DM (=square root of MSres), for Eq 1.2 both MSres and R^2 are higher. The model in Eq 1.1 indicates that the predicted average growth rate without N for Exp 1-4 and Exp 6-7 combined was 78 kg DM day^{-1} (derived from single cuts!), with a lag phase of about 11.4 days (0.8929 divided by 0.07832).

Figure 3b Cumulative nitrogen yield (in kg ha^{-1}) per cutting regime (A-D) and year for Exp 8 (1985-88; results from 1 replicate with known CP content). Annual clearing cuts for all regimes between April 7 and 15.

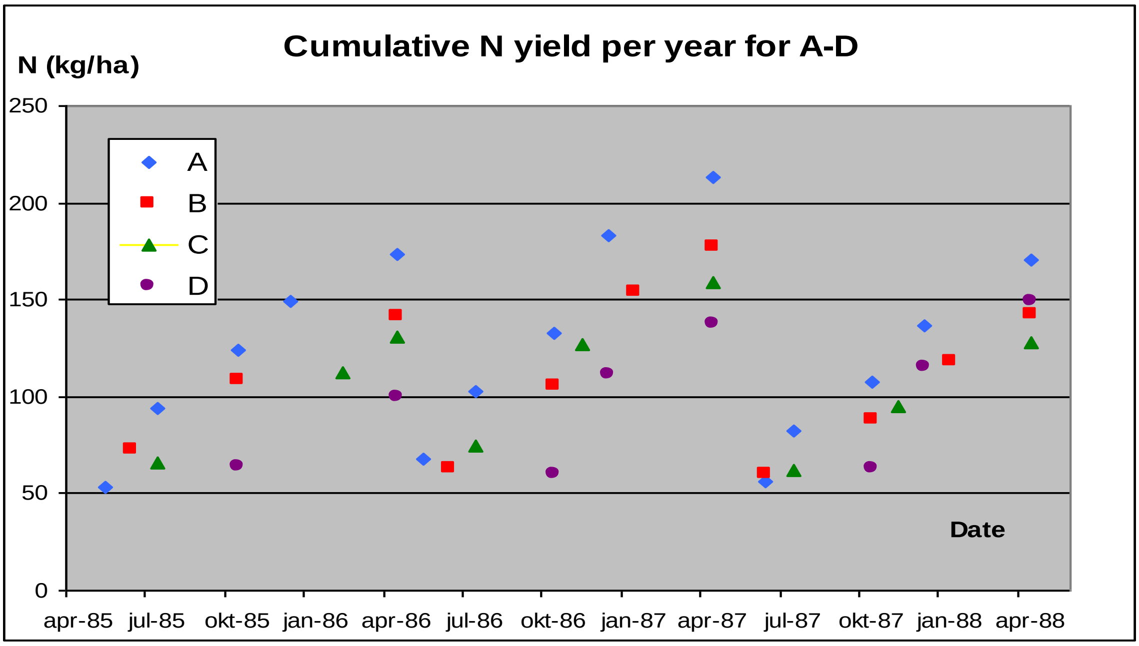


Table 3 Relationship between DMY and LY (Mg ha^{-1}), NY (kg ha^{-1}), CP and ash content (%), with age (CI in days), N rate (kg ha^{-1}) for Exp 1-4 and 6-7 (CI 4-18 weeks) and for all available samples (dataset A4). Model number (Eq) and n are also indicated. See further text, also for abbreviations, and Chapter 2. * *In Eq 1.5 and 1.6 DMY is derived from grass height (=DMY_H; H in cm; CI, CI*N stand for respectively H, H^2 and H*N; changes indicated in red/Italic).*

Model	MSres	R^2	Intercpt	CI	1/CI	N	CI*N	N*(1/CI)	Eq
DMY	**0.43**	**73**	-0.8929	0.07832		0.05799		-1.693	1.1
P<0.001			±0.77	±0.005		±0.007		±0.42	n=326
DMY	**2.04**	**78**	3.975	0.02793	-99.16	0.06294		-2.003	1.2
P<0.001			+0.626	±0.003	±12.69	±0.004		±1.997	n=1100
LY	**0,09**	**83**	3.513		-75.17	0.02103		-0.246	1.3
P<0.038			±0.19		±7.3	±0.003		±0.19	n=255
LY	**0.21**	**86**	3.924	-0.006739	-83.02	0.01763		-0.2784	1.4
P<0.001			±0.21	±0.001	±4.5	±0.0014		±0.086	n=915
DMY_H*	**0.26**	**66**	1.553	*0.02818*		*0.0002007*			1.5
P<0.001			±0.81	***=H***		***=H^2***			n=279
DMY_H*	**0.3**	**48**	3.345	*0.01349*	-82.59	*0.0002179*	*0.0001229*		1.6
P<0.001			±0.36	***=H***	±6.4	***=H^2***	*=H*N*		n=886
NY	**57.3**	**37**	72.78		-1246	0.5094			1.7
P<0.001			±11.6		+144	±0.03			n=326
NY	**96**	**86**	79.12	-0.1056	-1562	0.5556	-0.001992		1.8
P<0.002			±8	±0.037	±136	±0.05	±0.0006		n=725
CP	**1.2**	**74**	5.432	-0.01917	240	-0.0207		2.538	2.1
P<0.001			±0.86	±0.007	±20	±0.007		±0.37	n=326
CP	**1.26**	**74**	3.212		266.3	-0.02316		2.35	2.2
P<0.001			±0.236		±8.4	±0.004		±0.24	n=725
Ash	**1.41**	**43**	18.63	-0.0217	86.4		-0.000286		3.1
P<0.011			±1.42	±0.01	±31		±0.00005		n=326
Ash	**2.24**	**75**	20.58	-0.02998	104.7	-0.03285			3.2
P<0.001			±0.81	±0.0044	±16.76	±0.0025			n=692

According to Eq 1.1 the ANE increases from 24 to 41 kg DM kg^{-1} N if the CI increases from 50 to 100 days (from 23 to 43 kg DM kg^{-1} N for Eq 1.2). When cutting regimes are compared over a similar harvest period of 18 weeks, predicted DMY from Eq 1.1 increases relatively slowly from 1.3 Mg ha^{-1} at a CI of 4 weeks to about 9 Mg DM ha^{-1} at CI of 18 weeks for a N rate of 50 kg N cut^{-1} and from 1.2 to14.6 Mg ha^{-1} for a N rate of 1 kg growing day^{-1}. Predicted DMY is lower for 50 kg N cut^{-1} because the N rate growing day^{-1} is increasingly lower than for 1 kg N growing day^{-1} (see also Chapter 2). Predicted DMY (and LY and NY) is lower when derived Eq 1.2 for all samples, possibly due lower (soil) N and/or moisture supply if long term annual Exp 8, 9 and 13-15 are included (including also long dry periods; see discussion in Chapter 7.1). Including the square root of CI or season sometimes improve models slightly (results not given).

The LY is predicted well by Eq 1.3 and 1.4 (all samples; n=915). Predicted total LY over a harvest period of 18 weeks peaks at a CI of 6-7 weeks, decreasing subsequently, in particular if N rates per cut are the same. When derived from Eq 2 and 4, predicted leaf% decreases from 71 to 35 % for a CI of respectively 5 and 18 weeks (at 1 kg N ha day cut^{-1}; when derived from Eq 1.4). But leaf% is not realistic at the shortest 4 week CI and is probably better predicted directly from leaf content (see Figures 5c, d).

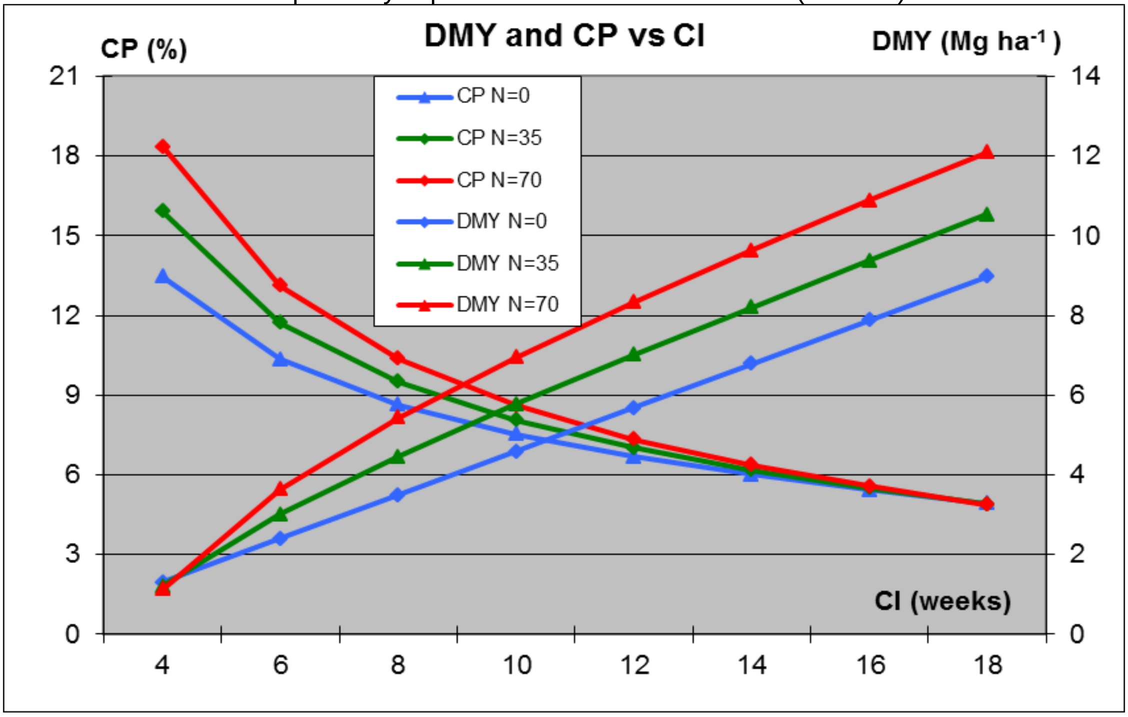
There is a rather good relationship between DMY and grass height (Eq 1.5 in Table 3). Derived from the model in Eq 1.5 (H and 1/H), predicted DMY increases by 58 and 78 kg DM ha^{-1} cm^{-1} increase in H between grass heights of respectively 50 to 100 and 100 to 150 cm. The relation improves, if age and N rate are added (MSres=0.22; R^2=79; results not given). For Eq 1.6 R^2 decreases (with age and N; n=868). Figure 4b shows that the relation between DMY and grass H becomes more variable if H increases, probably also due to differences between N rates (results not shown). Also plant density is probably important in models for DMY and grass H, but the planting arrangement was the same for all experiments (Chapter 2). Variation in DMY is expected to increase if variation in plant density increases (for whatever reason).

The model in Eq 1.7 (Table 3) does not explain the variation in NY well (MSres=57.3; R^2=37%), mainly due to a high residual variation at the level of experiments (Chapter 2).But in Eq 1.8 for all samples R^2 improves substantially (R^2=86). Derived from Eq 1.7, 50.9% of applied N would be recovered in harvested Napier. Residual effects of N are not included in models in Table 3 (see Chapter 2), implying that N effects may be higher (or lower), depending on cutting management and N rate (see further discussion). When cutting regimes are compared over a harvest period of 18 weeks, predicted NY peaks at a CI of 5-6 weeks, and subsequently strongly decreases by about 35% at A CI of 18 weeks (results not given). The models in Eq 1.7 and 1.8 predict an average NY without N application of respectively 96 and 83 kg ha^{-1} (averaged over all cutting regimes from 4 to 18 weeks over a harvest period of 18 weeks).

The model with age and N rate in Eq 2.1 (Table 3), explains 74% of the variation in CP%. The model for all samples in Eq 2.2 predicts a slightly lower CP%. Models are sensitive for N supply at a CI of 4 weeks in particular. Season is not significant if added to Eq 2.2. The models in Eq 3.2 predict ash content rather well. Predicted ash content is similar at younger ages, but higher at older age if derived from Eq 3.1 (than from Eq 3.2). The variation explained is slightly higher if variety and location are also included in Eq 3.2, ash content being lower for the variety FC (-2.4%) and in locations Kakamega and Kisii (respectively -5.2 and -4%; see further Chapter 3.3.4). Models for CP and ash% improve if leaf% is included (results given in Chapter 7.1) Crude protein and ash content are further discussed in Chapter 3.1.3 and Chapter 7.1.

Figure 4a shows the relation between both, DMY and CP content, and cutting age, derived from the models in Eq 1.1 and Eq 2.1 (for respectively for DMY and CP%). Content of CP strongly decreased up to a cutting age of about 10 weeks, in particular at the high N rate with high growth rates. Initially a higher N rate has a positive effect on CP content, but at older age, the effect on DMY dominates. The highest N application applied in experiments (100 kg N cut^{-1}; Chapter 2) increases predicted CP% to 20.5% at the short 4 week CI (results not shown). Predicted yield without N application is relatively high, because of a substantial contribution of soil N (see before and discussion).

Figure 4a Dry matter yield (DMY) and CP content plotted against cutting age (CI) at various N rates. Based on respectively Equations 1.1 and 2.1 in Table 3 (see text)



3.1.2 Morphological characteristics

Grass height increased with CI and N rate. If averaged over Exp 6 for example, H increased from 37 to 137 cm for a CI of respectively 4 and 12 weeks and from 111 to 162 cm for N rates of 0 and 100 kg N ha^{-1} (results not given in Table 2). Content of green leaf strongly decreased with CI and slightly with N rate (if cut at the same age!), while content of stem and dead leaf increased (Table 2; Figure 5b). Averaged over Exp 6-7, leaf/stem ratio (LSR) at N2 (N=168) decreased from 2.7 to 1.5 if CI increased from 6 to 12 weeks (derived from Table 2). Content of dead leaf was marginal until a CI of about 6 weeks and increased rather fast after a CI of about 9 weeks. In Exp 8 it surpassed 30% during the dry season for (very) long CI (results not given).

Models to predict grass H and contents of green and dead leaf from age, N rate and season (see below), are derived from datasets for Exp 1-9 (CI of 4-18 weeks; n=450 for H and n=562 for leaf; Eq 1.9 to 1.11 below) and for Exp 1-9 and 13-15 (dataset A4; n=868 for H and n=937 for green and dead leaf; Eq 1.9.1 to Eq 1.11.1).

Grass height (H in cm) = 120.6 -3058/CI +0.3477*N - 17.677*S2 (=minus 17.677 for dry season!) (MSres=114.1; R^2=52; P< 0.001 ; n=450 ; ***Eq 1.9****)*
Grass height (H in cm) =67.95 +0.4189*CI -1905/CI +0.5266*N -0.001798*CI*N +18.189*S2 - 0.3352*CI*S2 (MSres=297; R^2=54; P<0.002 ;***Eq 1.9.1****)*
Green leaf (%) = 71.57 - 0.3028*CI + 490.9/CI - 0.05003*N
(MSres=25.4; R^2=65; P<0.001 ; n=562 ; ***Eq 1.10****)*
Green leaf (%) = 61.39 -0.1822*CI +556/CI -0.1413*N -4.377*N/CI
(MSres=38.7; R^2=86; P<0.001 ; n=937 ; ***Eq 1.10.1****)*
Dead leaf (%) = -6.288 + 0.1821*CI + 3.72*S2 (MSres=17.42; R^2=60; n=562; P<0.002; ***Eq 1.11****)*
Dead leaf (%) = -2.897 + 0.1472*CI + 2.244*S2 (MSres=20.1; R^2=60; P<0.001; ***Eq 1.11.1****)*

Eq 1.9 indicates a curvilinear relation between grass H and age. Grass H is respectively 17.7 cm shorter during the long dry season (S2) if derived from Eq 1.9 and longer with N. The interaction of CI and S2 in Eq 1.9.1 indicates initially longer H during S2 (due higher temperatures?) and slower growth later (due to serious drought?). Green leaf % is lower with N and, if S2 is added to Eq 1.10, during the dry season (-2.8%), while dead leaf is higher (3.7%) during the dry season S2 (Eq 1.11; Figure 5c).

Models for various datasets result in similar changes in grass H (Figure 5a) and leaf content (Figure 5d; models not all given). But grass H tends to be shorter for dataset B and leaf content higher, probably because of lower growth rates (annual Exp 8-11 included, with long dry periods, older grass included and lower N availability. For leaf% of datasets A and B, N rate is not significant; possibly because of too large variation in among others soil N supply (see sources of variation in Chapter 2 and discussion).

Figure 4b Relation between DM yield (DMY) and grass height (H) for Exp 1-9

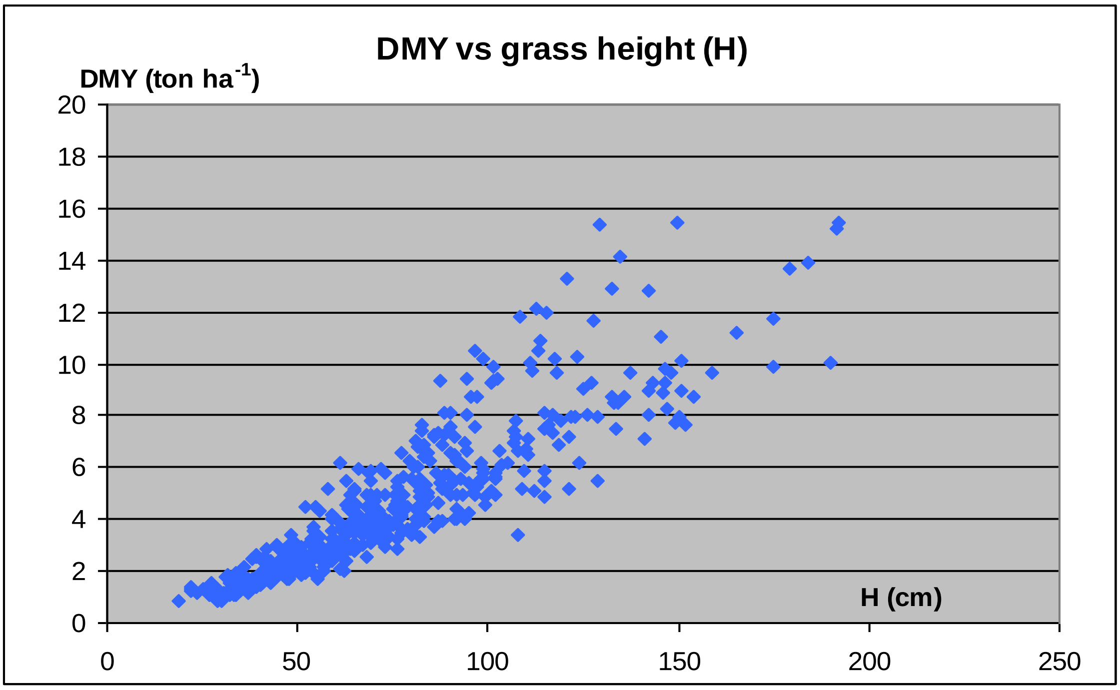


Figure 5a Grass height plotted against age (CI in weeks) for 4 datasets (A, B, C2 and for dataset A limited to a CI of 4-12 weeks, n=128). Curves are based on models similar to Eq 1.9, but without season (n=450, CI 4-18 weeks of Exp 1-9). The N application of 50 kg N ha^{-1}.See further text and for datasets Chapter 2.

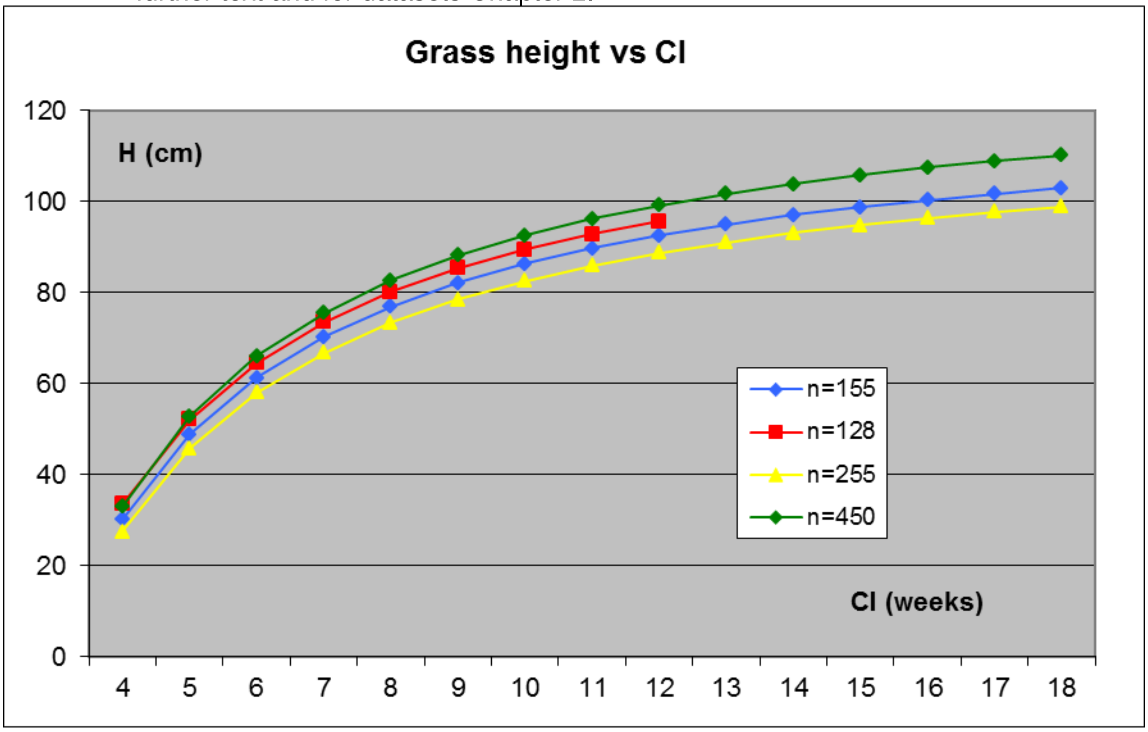


Figure 5b Relationship between content (%) of green leaf, stem and dead leaf and cutting age averaged over N rates for Exp 3-4 combined.

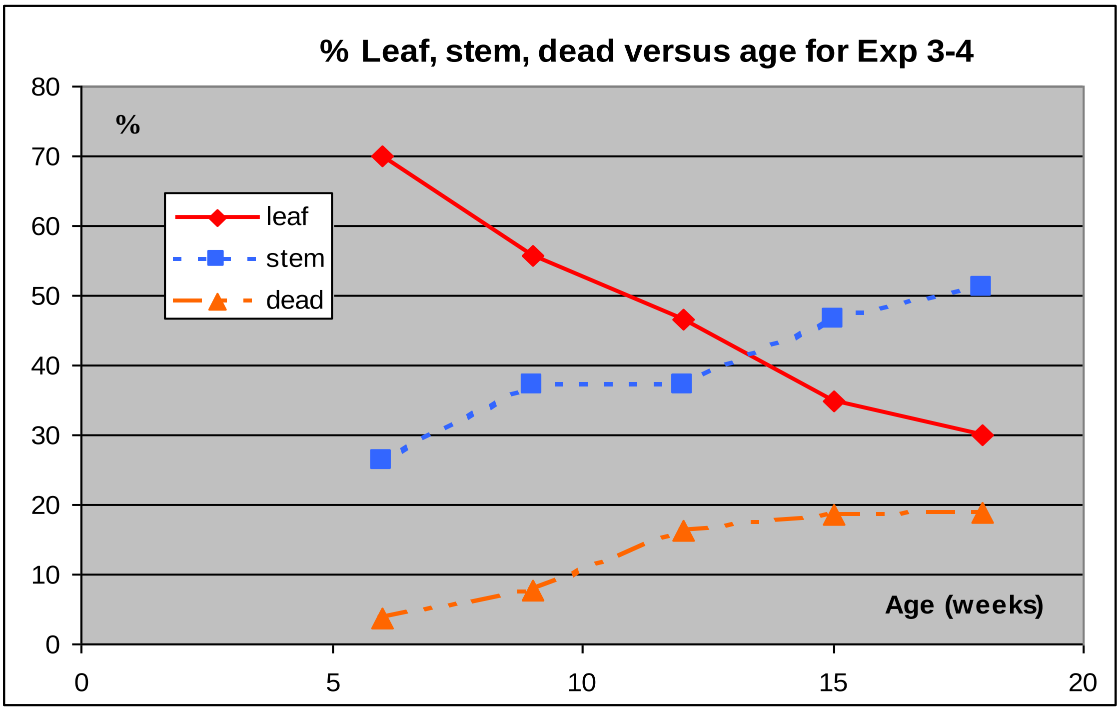


Figure 5c Content (%) of green (L) for 2 N rates (kg ha^{-1}) and dead leaf (D) plotted against cutting interval (CI) derived of models in Eq 1.10 and 1.11 for Exp 1-9 (rainy season S1: April-December; dry season S2: January-April; n=562). See further text.

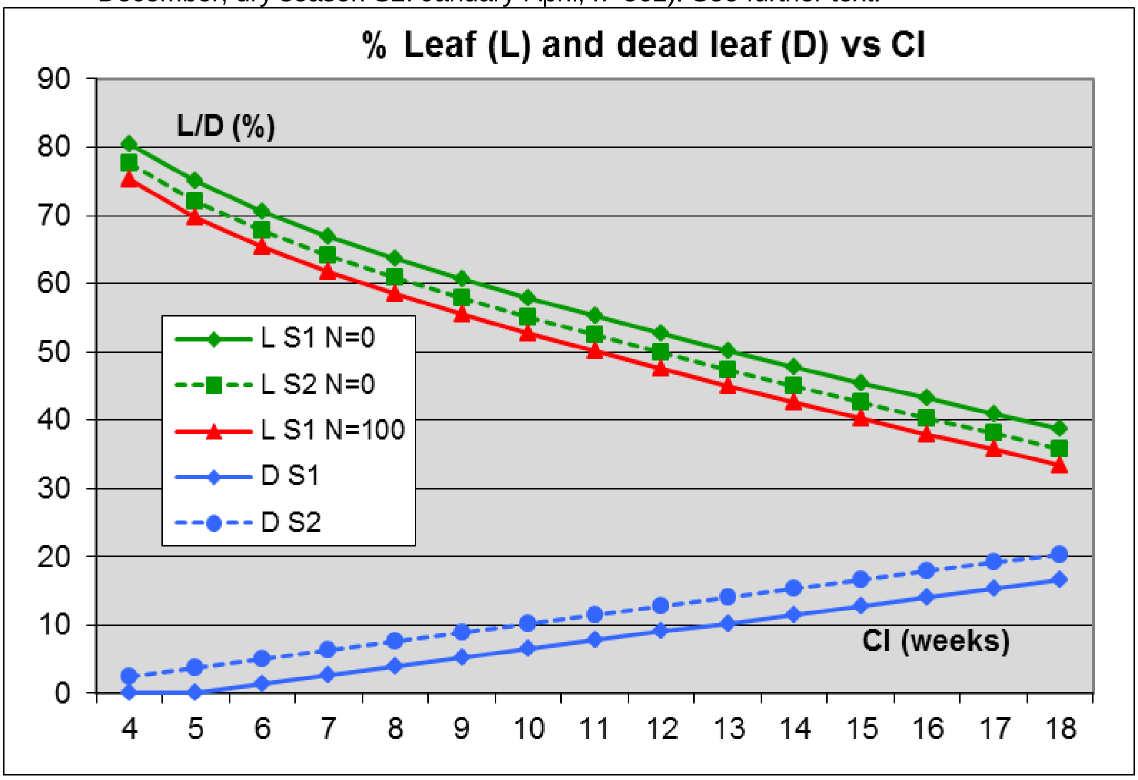


Figure 5d Relationship between predicted leaf content and age for various datasets: A, B, C1 (n=128 for CI of 4-12 weeks of dataset A) and n=908 for all samples of Ex 1-11 with known leaf content. Models similar to Eq 1.10, but without N rate and for n=128 also without 1/CI (not significant!). See further text.

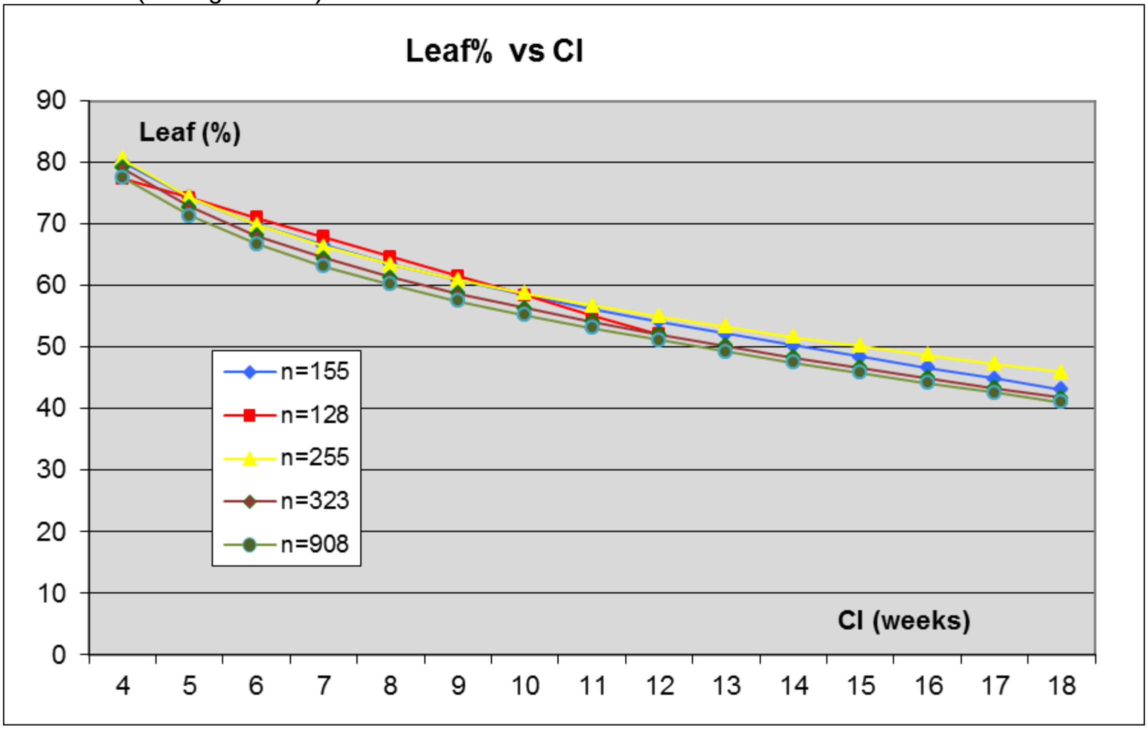
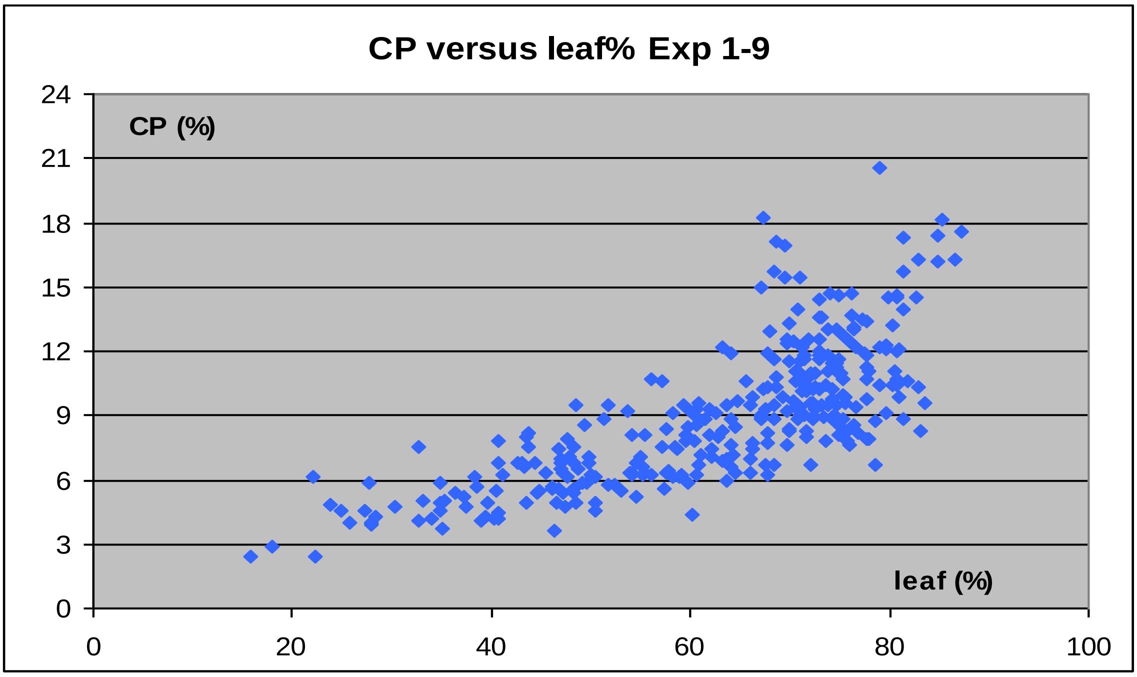


Figure 5e Relationship between content of crude protein (CP) and % green leaf for Exp 1-9



3.1.3 Dry matter content and some chemical characteristics

Average dry matter content of grass increased with CI and decreased with N rate, in Exp 6 (cold/wet season) for example by respectively by 1.4% and 0.8% (average of 15.4% DM; results not given). In Exp 4, DM% increased from about 12% at the 6 week CI to about 25% at the longest 18 week CI. Contents of DM and dead leaf both passed 30% during the dry season for some of the old cuts of cutting regime D in Exp 8 (results not given). In models for DM content for Exp 1-9 (CI 4-18 weeks), there was a reasonable relationship between DM% and content of dead leaf, but the relation improved substantially if CI and N rate were added (CI in days and N in kg ha^{-1}; see Eq 1.12 and 1.13 below). If season is added, content of dead leaf is not significant anymore (DM content 2.7% higher during the dry season).

DM (%) = 15.9+0.25*dead% (MSres=3.34; R^2=53; n=429; ***Eq 1.12***).
DM (%) =13.82 + 0.065*dead% + 0.058*CI - 0.053*N +0.00073*CI*N (MSres=2.47; R^2=64; ***Eq 1.13***).

The CP content strongly decreased with CI, till a CI of about 8-10 weeks and slower subsequently (Table 2). It increased with N rate (and soil N supply; results not given), in particular for shorter CI (Figure 4a), and with leaf content. The relation between CP% and green leaf% varied much at higher CP% (Figure 5e), probably due to a relatively large effect of variation in N supply (see also discussion). At a long CI (and low CP%) the effect of N was only marginal or invisible. The highest CP contents were measured in Exp 1 at the 3 week CI with N (18-20%), the lowest in Exp 8 for a CI of about 6 months (2.5-3%; Figure 5e, CI not shown). There was a negative relation of CP% with contents of stem and dead leaf (results not shown). Ash content strongly decreased with CI and (less) with N rate, and varied from about 15-25% within and between experiments (Table 2 and Eq 3 in Table 3), also due to increasing DMY (dilution; the model improved if DMY was added). Fibre contents and dOM are discussed in Chapter 3.3.

Chemical characteristics of green leaf, stem and dead leaf
Crude protein content was highest in green leaf and lowest in dead leaf, while ash content was highest in dead leaf and lowest in stem (Table 4a). Average contents of CP in leaf, stem and dead leaf were approximately 8, 5 and 4% respectively, and of ash content about 16, 14 and 23%.
In Exp 6-7, contents of calcium, phosphorus and potassium decreased with CI, and to a lesser extent with N rate (Table 4b). Phosphorus content was variable and sometimes low at the 12 week CI with N (see also Crowder and Cheda, 1982). Low P contents and an increasing N/P ratio with N (from about 6-7 without N to about 8-9 with N), may indicate less than optimal P supply. In Exp 6, Ca content was much higher in leaf than in stem, while K content was much lower in leaf (CI of 12 weeks). Green leaf and stem contained respectively 0.41% and 0.10% Ca, 0.09 and 0.09% P and 2.7% and 5.7% K. Dead leaf contained much less P and K (results not given). Also in Exp 6, leaf and stem fractions of 12 week old grass contained respectively 9.0 and 3.3% insoluble ash (silica) and 3.1 and 3.7% acid detergent lignin (average of 1 sample per N rate). Silica tended to decrease with N while ADL tended to increase. The high ash contents of dead leaf are possibly also due to relatively higher contamination with soil and higher silica content.

Table 4a Average content (% in DM) of crude and ash and protein (CP), of green leaf, stem and dead leaf for some cutting intervals of Exp 6 and 7 (results for 1 cut only and for 1 respectively 2 replicate for Exp 6 and 7; not weighed for dry matter yield)

CI	**N**		**ash**			**CP**	
(weeks)	**(kg $^{-1}$)**	**Leaf**	**Stem**	**Dead**	**Leaf**	**Stem**	**Dead**
Exp 4							
12	0	16.4	15.1	24.3	8.2	4.7	3.5
12	50	17.1	15	23	10	5	4
12	100	16.4	16.1	23.6	11.3	6.4	6.2
Exp 6							
8	0	18.9	16.6	26.2	9.9	4.9	
8	84	16	14.3	28.4	10.8	6.1	
8	168	15.9	15	27.1	11.7	6.8	
12	0	17.7	14.3	21.8	6.9	3.4	2.7
12	84	12.8	12	19.9	6.3	4.1	3.6
12	168	15.1	13.5	20.5	9.1	3.6	4.4
Exp 7							
6	0	18.3	15.8	19.4	9.4	5.4	
6	84	(18.1)	14.2	20.5	(9.5)	5.3	
6	168	15.8	14	19	12.5	7.2	6.4
12	0	18.5	14.6	24.8	7.9	4.1	3
12	84	14.2	12.6	21.7	8.6	4.3	3.8
12	168	14.8	12.9	21.2	9.1	4.7	3.6

Table 4b Average content of calcium (Ca), phosphorus (P) and potassium (K) in % of DM at different CI and N rates in Exp 6 in Kakamega and Exp 7 in Kisii

CI/N	**N=0**			**N=84**			**N=168**		
	Ca	**P**	**K**	**Ca**	**P**	**K**	**Ca**	**P**	**K**
Exp 6									
CI=4		0.2	5.1		0.22	5.3		0.22	4.9
CI=6		0.21	4.7		0.16	4.6		0.18	4.3
CI=8		0.16	4.1		0.14	4.6		0.15	4.4
CI=12		0.13	4.0		0.14	3.6		0.11	3.8
Exp 7									
CI=6	0.28	0.2		0.31	0.19		0.28	0.28	0.17
CI=12	0.25	0.16		0.21	0.11		0.21	0.12	

3.2 Nitrogen utilisation

A so-called three quadrants diagram can be used to explain the effect of N rate on the DM yield from the relation between N rate and N uptake (=N yield or NY) and the utilisation of applied N by grass (Van der Meer and Van Uum-Lohyuzen,1986). Figure 6a shows per CI, averaged over Exp 3 and 4, for increasing N rates (indicated by points!), the relation between N rate and N uptake (in quadrant IV, lower right hand corner), between N yield and DM yield (in quadrant I; upper right hand corner) and between N rate and DM yield (quadrant II; upper left hand corner). The utilisation of applied N (N-uptake divided by applied N; quadrant IV) and the relation between N uptake and DM yield (quadrant I) was more or less linear for the N rates used. This explains the more or less linear relation between N rate and DM yield in quadrant II. DM yields increased with CI, while the N yield tended to decrease (in particular for the 18 week CI), resulting in much lower N contents of grass (not shown separately). The cutting regime of 15+3 weeks deviates slightly, possibly due to a mistake.
The NY without N decreased with CI from 102 (at a CI of 6 weeks) to 67 kg N ha^{-1} (at a CI of 18 weeks), a decline of 34% (intercept with X-axis in quadrant IV of Figure 6a). Similar trends can be derived from Figure 6b (Exp 6), Figure 6c (derived from Eq 1.1 for DMY and Eq 2.1 for CP% in Table 3), and, for Exp 8 from Figure 3b. Figure 6b and 6c show quadrant I only. Yields are higher in Exp 6-7 than in Exp 3-4, because of a longer experimental period (24 resp. 18 weeks), and more favourable conditions (rainy season and higher N rate; Chapter 2).

Figure 6a Total dry matter yield (DM in t ha^{-1}) plotted versus N uptake (N in ha^{-1};quadrant I, upper left hand corner), and N application (N in ha^{-1} quadrant II) and N uptake plotted versus N applied (quadrant IV) per cutting interval (3*6, 2*9, 12+6, 15+3 and 18 weeks), averaged over Exp 3 and 4.

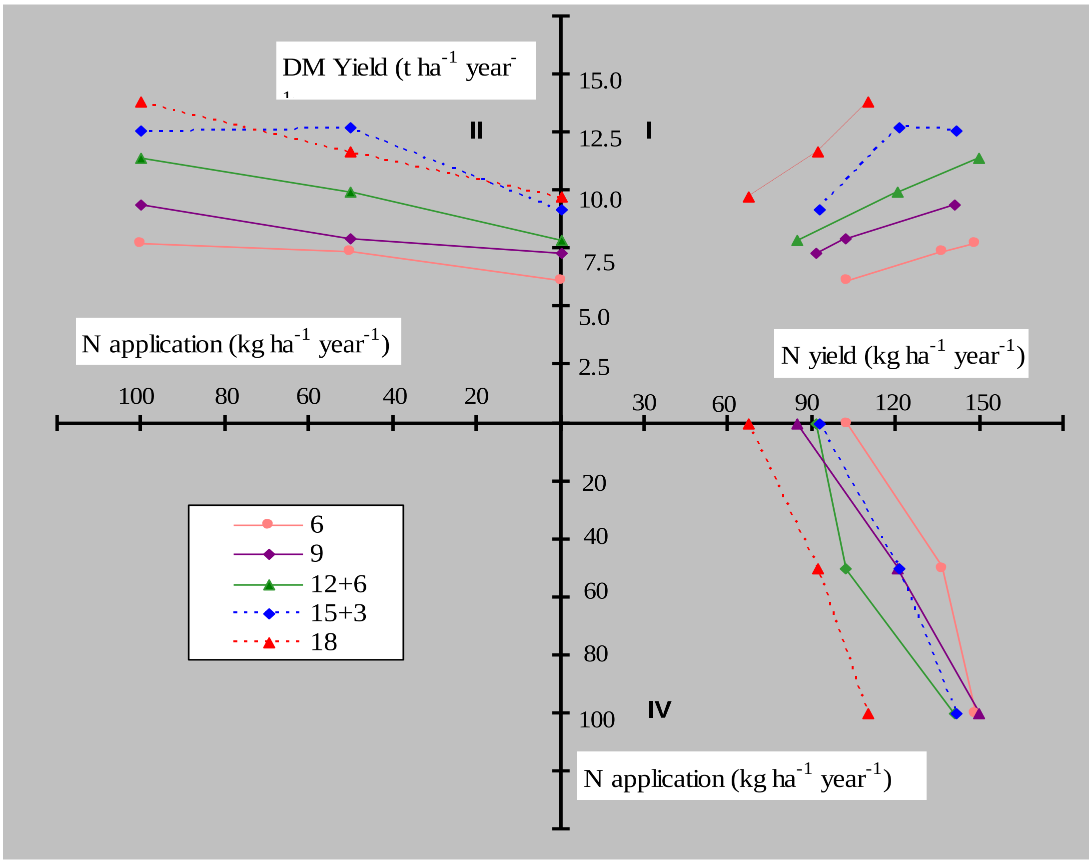
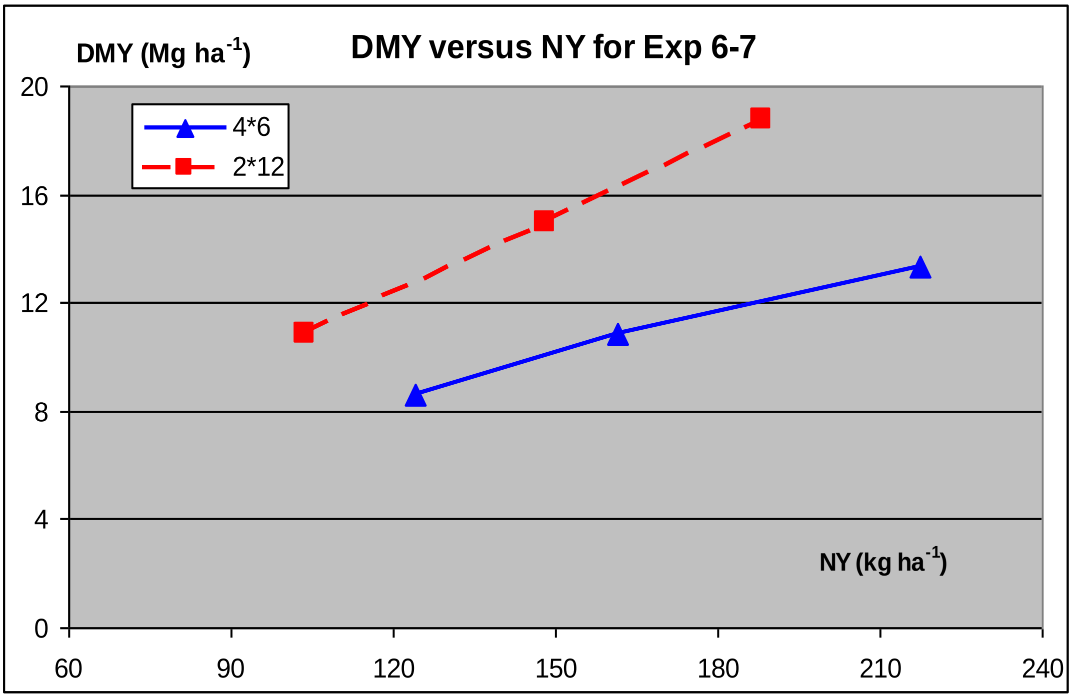


Figure 6b Average dry matter yields (DMY) for cutting regimes of 4*6 and 2*12 weeks plotted against nitrogen yield (NY) for Exp 6-7 at N rates of 0, 84 and 168 kg N ha^{-1} (NY increasing with N rate)



In Exp 8 annual NY (=SNS) increased from year 1 to year 2 (also because N application increased from 75 to 100 kg N ha^{-1} year^{-1}; see Chapter 2), but decreased during year 3, except for cutting regime D. When average over cutting regimes, NY in Exp 4 was much higher than in Exp 3 (Table 5), possibly because Exp 4 was established after ploughing of grass and Exp 3 after an intermediate maize crop. Averaged over Exp 6-7, NY decreased from 124 to 104 kg N ha^{-1} if CI increased from 6 to 12 weeks (results not given).

Figure 6c Relationship between total DMY (Mg ha^{-1}) and NY (kg ha^{-1}) at N rates 0, 35 and 70 kg N ha^{-}1 cut^{-1} (over a harvest period of 18 weeks) for cutting regimes of 18, 16, 14, 12, 10, 8, 6, 5 and 4 weeks (CI decreasing following the curves from left to right!). See further text, also for abbreviations.

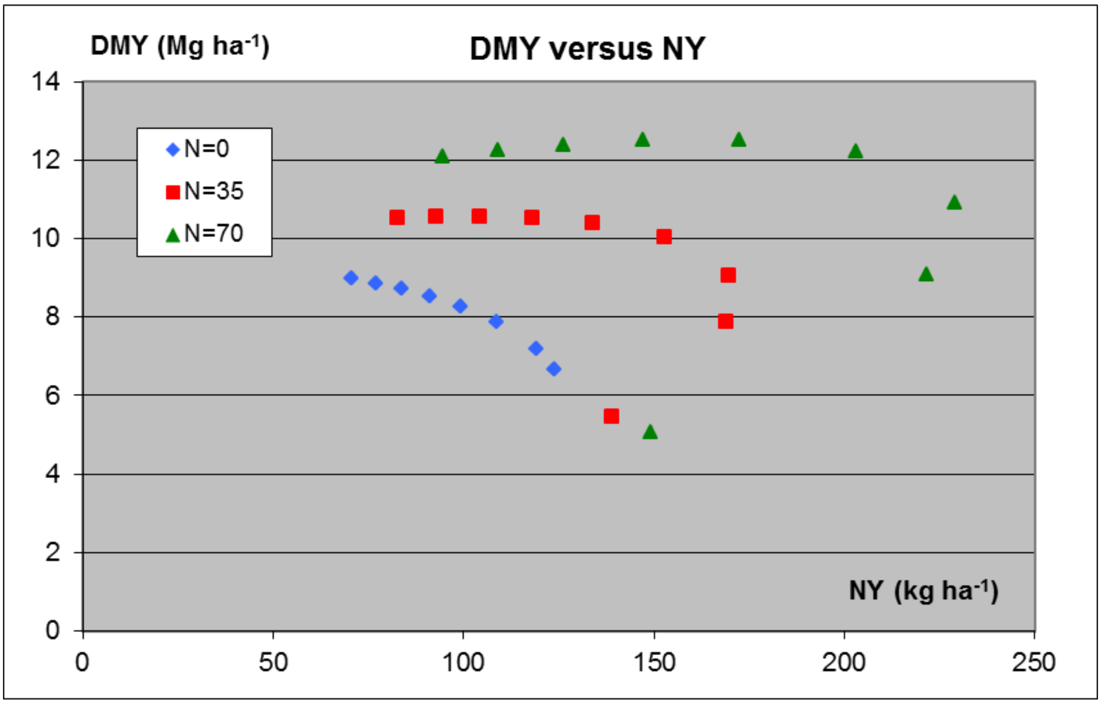
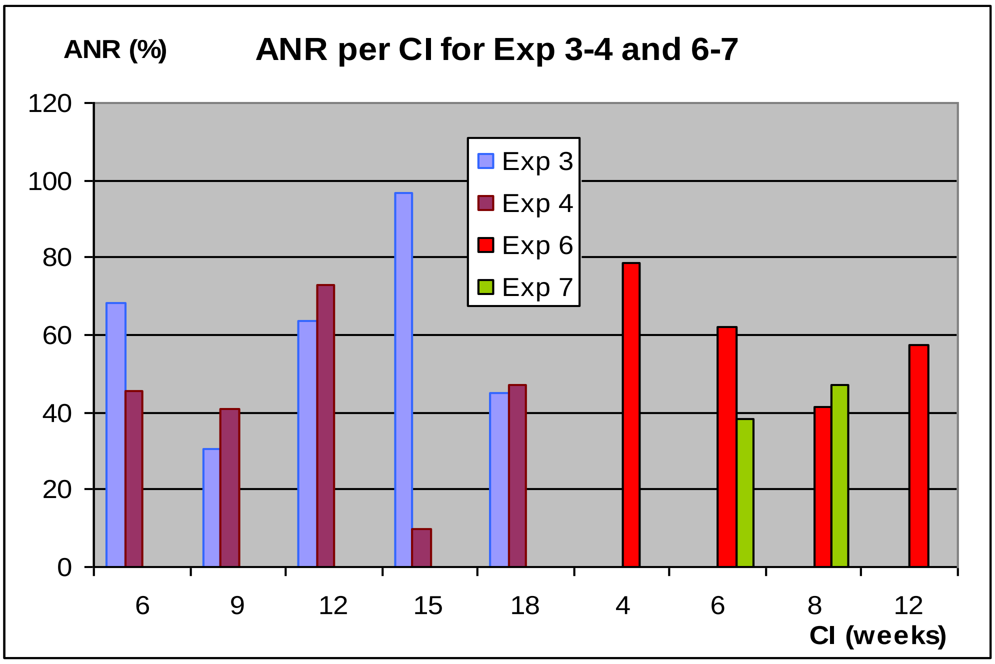


Table 5 Apparent nitrogen efficiency (ANE) and recovery (ANR) averaged over cutting intervals from 4-12 (Exp 1-7) and 6-18 weeks (Exp 1-4 only). Averages over experiments and N rates are also given (N1 and N2 are low and high N rates; in brackets for Exp 3-4 only!). Average N yield without N (=SNS) is also indicated (in Exp 2 SNS is derived from the N rate N=25).

Exp No	**N rate**	**SNS**	**ANE** (kg kg^{-1} N)		**ANR** (%)	
		kg ha^{-1}	**4/6-12 wks**	**6-18 wks**	**4/6-12 wks**	**6-18 wks**
1	**N1**=75	64	23	27.0	59,4	60.1
2	**N1**=75	43	37.9	48.0	54.7	54
3	**N1**=50	70	31.7	47.0	49.5	63.8
	N2=100		28,6	32.6	58.7	57.7
4	**N1**=50	105	21	29.1	57.7	43.1
	N2=100		19.5	26.5	48.6	43.4
6	**N1**=84	125	40.1		61	
	N2=168		36.8		58	
7	**N1**=84	112	28.3		39	
	N2=168		29.7		46	
Averages	**N1**		**30.3 (26.4)**	**(38.1)**	**53.6 (53.6)**	**(53.5)**
	N2		**28.7 (24.1)**	**(29.6)**	**52.8 (53.7)**	**(50.6)**
	N1+N2		**29.7**	**35**	**53.3**	**53.7**

Figure 6c relates total DMY to NY for Exp 1-4 and 6-7 (quadrant I) for a harvest period of 18 weeks, and is derived from the models in Eq 1.1 and 2.1 (Table 3a). When grass is cut older, NY tends to decrease (at N=0 from 126 kg N ha^{-1} for a CI of 4 weeks to 71 kg for a CI of 18 weeks), but for N=35/70 NY peaks at a CI 6 weeks. At the same time DMY tends to decline, but first peaks at a CI of 10/12 weeks for N=70 (lower DMY at a CI of 18 weeks). The derived N content (CP%) is highest for the 4 week CI (result not shown), similar to Figure 4a. Although Figure 6c depicts “lines” for N rates (and not for CI), the trend of a declining NY with increase in CI over 6 weeks is similar to Figure 6a and b, but a CI of 4 and 5 weeks is now also shown. See further discussion in Chapter 6.1.

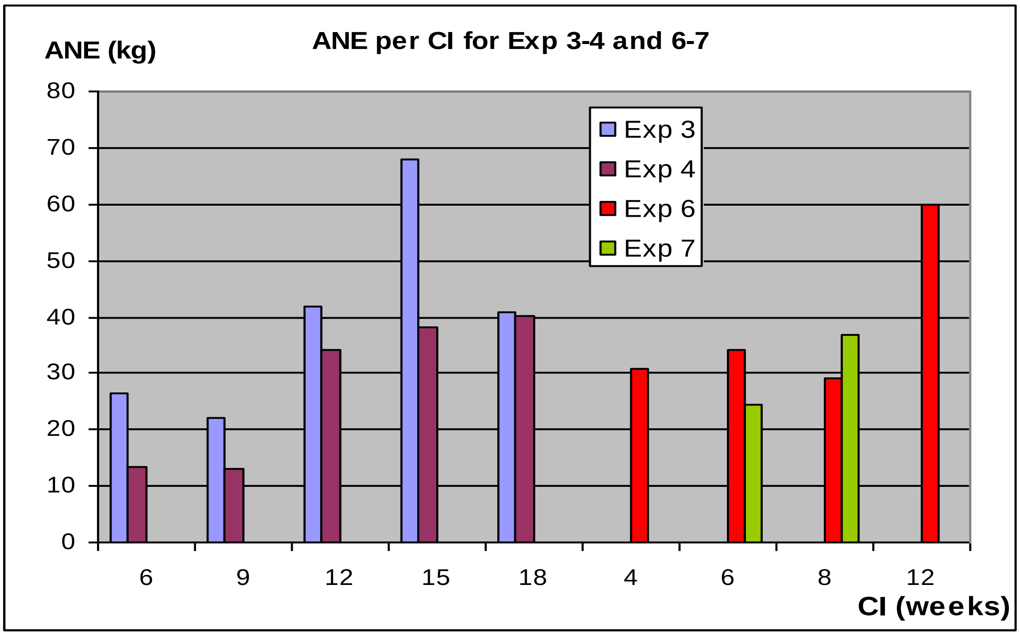
Figure 7a Apparent nitrogen recovery (ANR) per CI, averaged over N rates for Exp 3-4 and 6-7.



Apparent nitrogen efficiency and recovery
The apparent nitrogen efficiency (ANE) and recovery (ANR) of applied fertiliser N were respectively 29.7 kg DM kg^{-1} N and 53.3% if averaged over the 4/6-12 week CI of Exp 1-4 and 6-7 (Table 5). ANE varied from 19.5 to 40.1 kg^{-1} N and ANR from 39 to 64%. There was no clear effect of N rate or CI on ANR (Table 5 and Figures 6a and 7a). But ANE increased (substantially) with CI (Table 5 and Figure

7b). The ANR for combinations of individual N rates and CI varied even more, in Exp 6 for example from 40-84% (for respectively the 8 and 4 week CI at N1). From the models in Eq 1.7 and Eq 1.7.1 in Table 3, an ANR of respectively 47 and 59% (if CI and N rate are both set at for example 50 or 100; see before). At a cutting age of only 3 weeks in Exp 1, ANE and ANR were still low at respectively 1 kg DM kg^{-1} N and 13% (results not given in Table 5). There were some deviating values, also reflected in Figures 6a and 7a, b, possibly due to variation in soil productivity between plots (despite the use of blocks), and/or chemical analysis for 1 replicate only, but other sources of variation, including confusing of plots, cannot be excluded (Annex 3). In Exp 3 and 4, at the low N rate of the 15+3 week CI, ANR was respectively above 100 and below 0% (results not shown seperately).

Figure 7b Apparent nitrogen efficiency (ANE) per CI, averaged over N rates for Exp 3-4 and 6-7.



3.3 In vitro organic matter digestibility

3.3.1 Effect of morphological and environmental parameters on dOM

Green leaf and CP content enhanced in vitro organic matter digestibility (dOM). However, grass height, contents of stem and dead leaf, age, DMY and the temperature sum (T-sum; Chapter 2) over the growing period all had detrimental effects on dOM (Figures 8a-h; see for cell wall contents Section 3.3.2 and 3.3.3).

Figure 8a Relationship between dOM and contents of green (=L) and dead leaf (=D) for Exp 1-9.

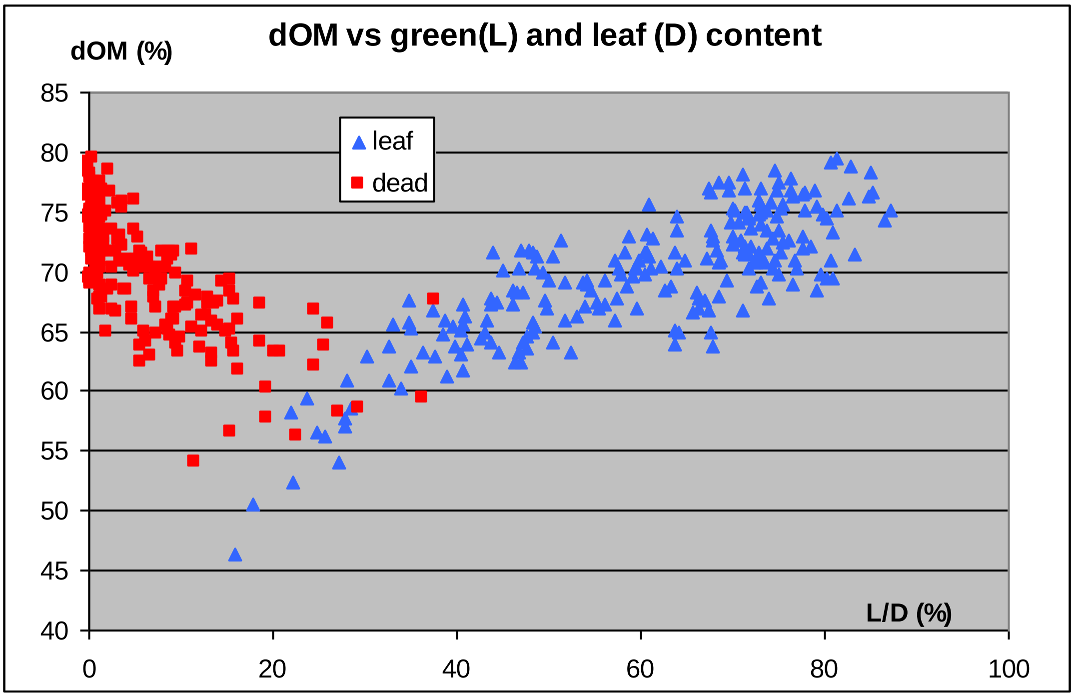
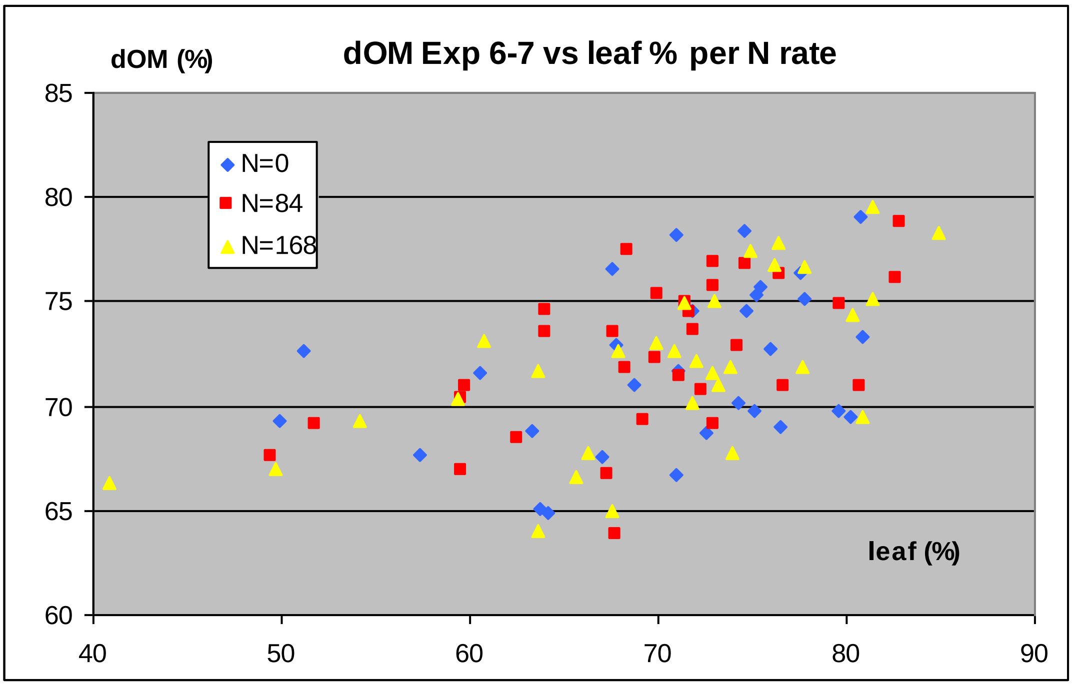


Figure 8b Relationship between dOM and leaf content per N rate for Exp 6-7.



In particular green leaf contents below about 30% resulted in rapid reductions in dOM, alongside increases in dead leaf content (Figure 8a). Green leaf contents above 80% were observed particularly for the 3 week CI of Exp 1, 3 and 4. Large variation in dOM occurred at similar levels of dead leaf content (in particular at contents above 15%; see also sources of variation in Annex 3).
At similar grass heights, dOM tended to be higher in Exp 6 (Figure 8c), probably because of higher growth rates (see discussion).

Figure 8c Relationship between dOM and grass height (H) for Exp 3, 6 and 7**.**

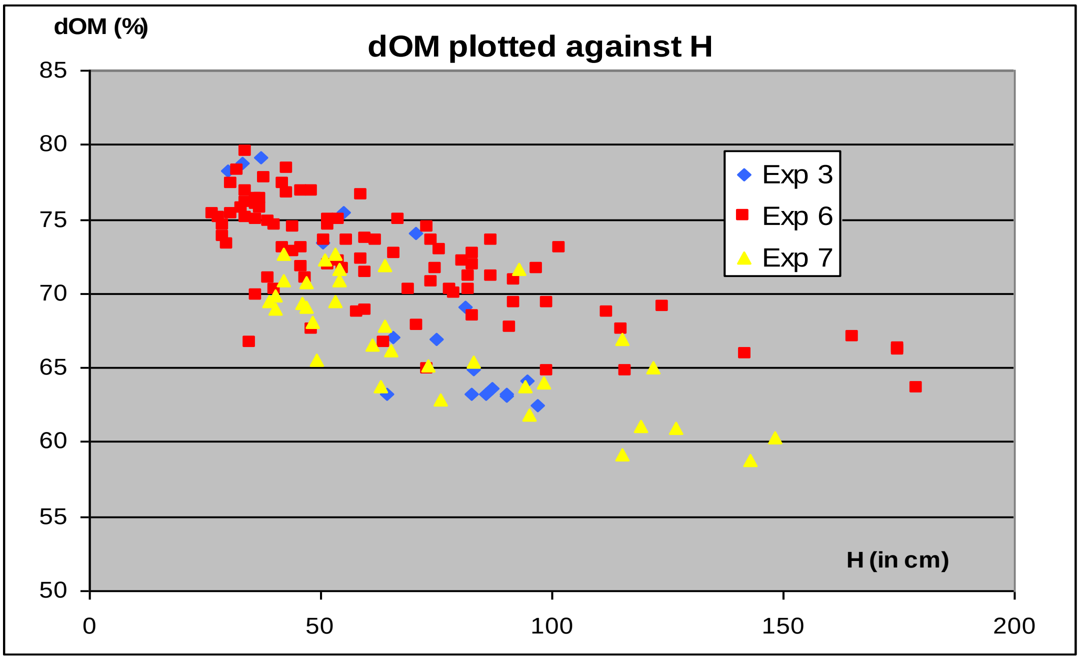
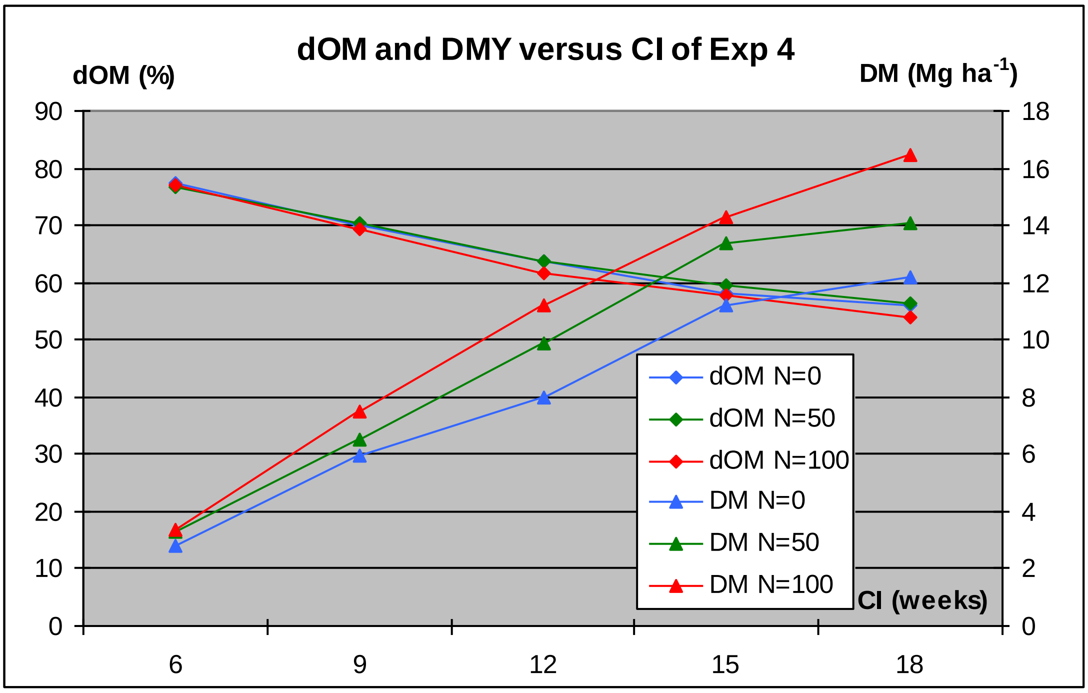


Figure 8d Effect of cutting interval (CI in weeks) on in vitro organic matter digestibility (dOM in %) and DM yield (ton ha^{-1}) for Exp 4.



There is no clearly visible effect of N application on the relationship between dOM and leaf% (Figure 8b) or CI, (Figure 8d), except for the 12 week CI in Exp 6-7 (Table 2; also showing a large effect of CI on LSR and DMY). However, at the same DMY, dOM was substantially higher with N (up to about 5%; Figures 8d-f), because similar DM yields are obtained at a (much) earlier age with N. At the 12 week CI in Exp 4 (Exp 4 having the lowest ANE; Table 5), dOM was similar without and with 100 kg N ha^{-1}, but DMY was respectively about 8 and 11 Mg ha^{-1} (Figure 8d). In Exp 4 dOM is higher at similar DMY as for Exp 3 (up to app. 10 Mg DM ha^{-1}), probably because grass was younger, due to a better soil N supply (Figure 8e; Table 5). From a CI of 9 weeks leaf% of Exp 4 was much lower (results not given).

Figure 8e Relationship between dOM and dry matter yield (DMY) for cut 1 of Exp 3-4 (CI 6-18 weeks)

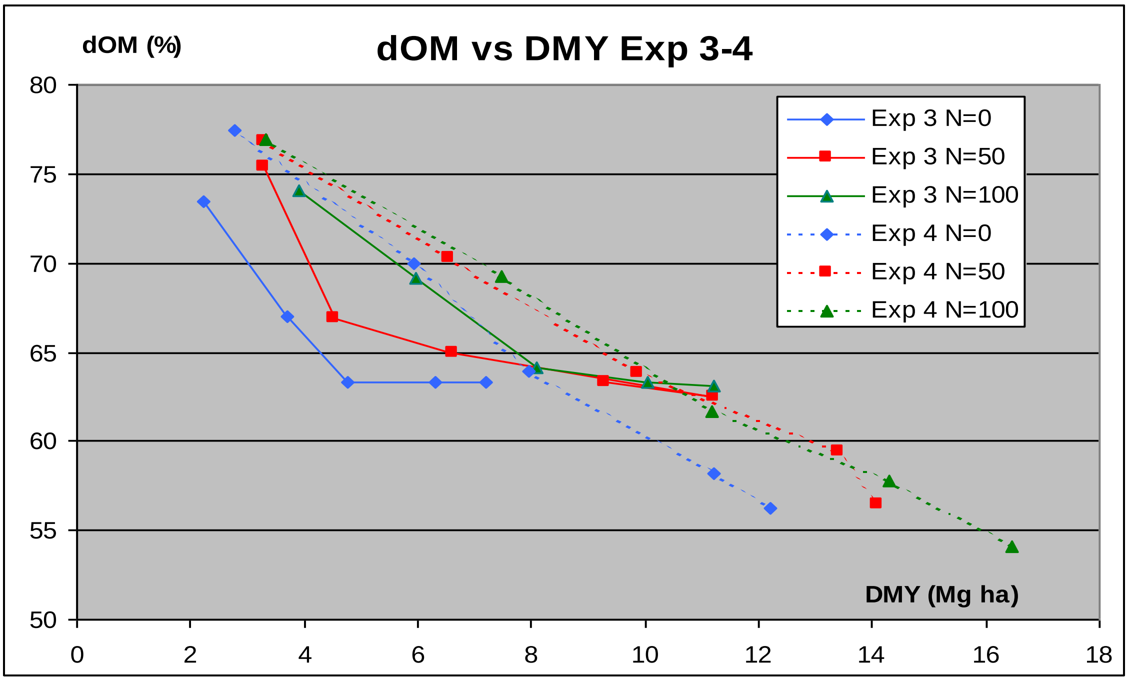
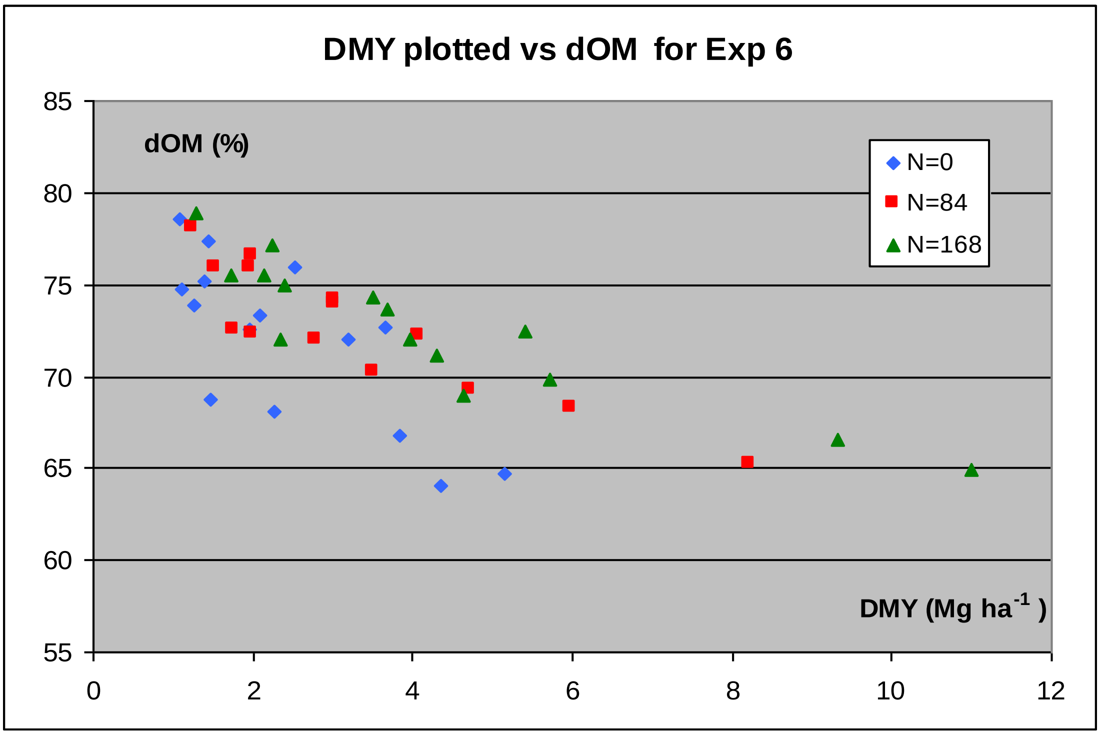


Figure 8f Relationship between dOM and dry matter yield (DMY) for all cuts of Exp 6 (CI of 4-12 weeks).



The negative effect of the T-sum (Figure 8g; and/or average temperature at the same CI, results not given; see for T effects later) on dOM may be (partly) due to a positive effect of temperature on growth rates (GR). Averaged over Exp 3, 4, 6 and 7, GR was 522 kg DM week^{-1} (Table 6a). The dOM and content of dOM in DM (DOM) decreased by respectively 1.04% units and 0.56% units per week. The weekly decrease in dOM was slightly higher with N (Table 6a). But if dOM was expressed per Mg increase in DMY, weekly decrease of dOM and DOM were substantially lower with N (respectively 29% and 44% for dOM at N=50/84 and N=100/168). When corrected for GR, decrease in dOM was 48% lower during the cold rainy season compared to the warm dry season (GR of respectively 656 and 389 kg DM ha^{-1} $week^{-1}$; see Chapter 2 for seasons). The same trend was observed for Exp 2 (results not given) and Exp 8 (Figure 8h). In contrast, at the same age, dOM tended to be slightly higher during the warm/dry season (results not shown).

Figure 8g Relationship between in vitro organic matter digestibility (dOM) and T-sum for Exp 1-9.

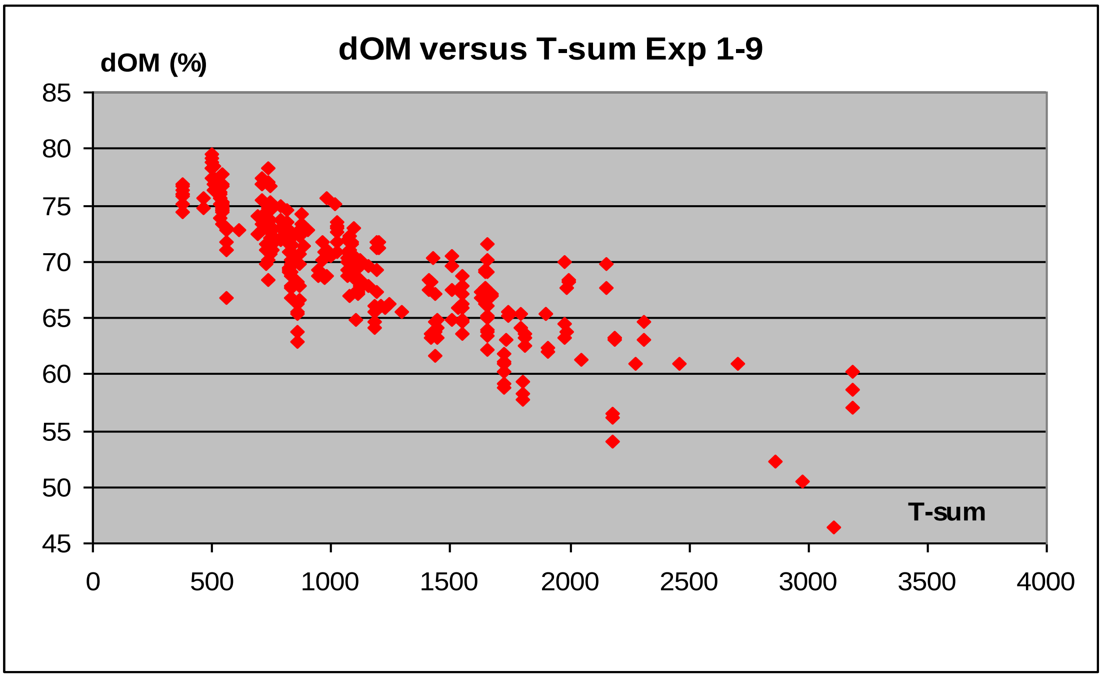
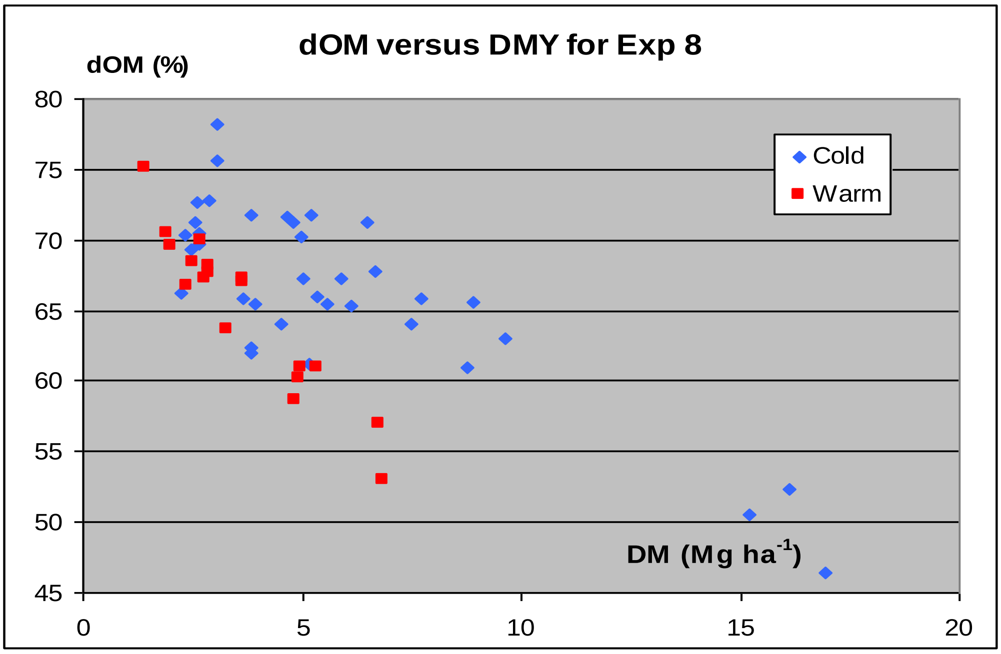


Table 6a Weekly (wk) growth rates (GR in kg DM $week^{-1}$) and decrease of in vitro organic matter digestibility (dOM in %) and content of digestible organic matter (DOM Mg^{-1} increase in DM yield) for Exp 3-4 and 6-7 at variable N rates and seasons, starting from a CI of 6 weeks (averages weighed over cuts per experiment, but not over experiments).

	N rate	**GR** (kg DM wk^{-1})	**dOM** % wk^{-1}	**DOM** % wk^{-1}	**dOM** (% Mg^{-1}DM)	**DOM** (% Mg^{-1} DM)
Exp 3 warm	**N=0**	162	0.74	0.38	4.57	2.32
Bana	**N=50**	205	0.83	0.44	4.05	2.17
6-18 weeks	**N=100**	313	0.67	0.37	2.15	1.19
Exp 4 warm	**N=0**	430	1.46	0.85	3.40	1.98
FC	**N=50**	512	1.41	0.81	2.75	1.58
6-18 weeks	**N=100**	710	1.58	0.93	2.22	1.31
Exp 6 cold	**N=0**	317	0.83	0.30	2.62	0.95
Bana	**N=84**	633	0.78	0.32	1.23	0.51
6-12 weeks	**N=168**	1183	1.18	0.60	0.84	0.43
Exp 7; cold	**N=0**	433	0.92	0.58	2.12	1.34
Bana	**N=84**	750	1.10	0.63	1.47	0.84
6-12 weeks	**N=168**	617	0.95	0.55	1.54	0.89
Averages:	**All**	**522**	**1.04**	**0.56**	**2.43**	1.30
	Warm	**389**	**1.11**	**0.63**	**3.19**	1.76
	Cold	**656**	**0.96**	**0.5**	**1.66**	0.84
	N=0	**336**	**0.99**	**0.53**	**3.18**	1.65
	N=50/84	**525**	**1.03**	**0.55**	**2.37**	1.27
	N=100/168	**706**	**1.10**	**0.61**	**1.73**	0.97

Figure 8h Relationship between dOM and DM yield per cut for Exp 8 (variety FC) for cold/rainy and warm/dry season cuts (warm season from January to April 15).



3.3.2 Effect chemical parameters on in vitro organic matter digestibility (dOM)

There was a negative relationship between dOM and contents of CF, NDF, ADF and acid detergent lignin (ADL; Table 6b, Figures 9a-e).

Table 6b Contents (% in DM) of crude fibre (CF), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), crude fat and in vitro organic matter digestibility (dOM) for various cutting regimes and N rates (N0-N2) averaged over Exp 3-4 (weighed over first cuts only) and Exp 6-7 (all cuts; not weighed!).

Experiment		**Exp 3-4**					**Exp 6**		**Exp 7**	
N kg ha^{-1} \ CI weeks		**6**	**9**	**12**	**15**	**18**	**4*6**	**2*12**	**4*6**	**2*12**
N0=0	**CF**	25.1	28.6	30.7	33.2	33.6	28.5	31.6	29.2	32.4
N1=50/84		24.4	29.1	30.8	33.2	32.7	29	34	30.3	34.6
N2=100/168		25.4	28.2	31.4	32.3	34.4	29.5	36.4	30.3	35.4
N0=0	**NDF**	57.8	63.5	66.4	66.4	67.4	57.9	64.3	60.1	64.5
N1=50/84		58.6	63.1	66.4	66.3	65.5	58.7	65.4	61.4	67
N2=100/168		57.8	61.4	65.2	65.2	66.1	59.5	66.5	61.8	68
N0=0	**ADF**	26.2	31.4	35.0	37.5	38.1	32.8	37.9	32.7	36.1
N1=50/84		25.0	31.5	34.8	37.4	37.2	33	39.5	33.5	38.5
N2=100/168		25.6	31.4	35.4	37.2	39.3	33.1	41	33.7	39.3
N0=0	**ADL**	2.4	3.1	4.0	5.0	5.3				
N1=50		2.4	3.0	3.8	4.9	5.5				
N2=100		2.4	3.1	3.9	4.9	5.5				
N0=0	**Fat**								1.9	1.7
N1=84									2.0	1.6
N2=168									1.8	1.5
N0=0	**dOM**	75.6	68.8	63.7	60.8	58.8	73.3	68.3	69.3	63.8
N1=50/84		76.1	68.9	64.2	60.6	59.2	72.4	67.7	69	62.4
N2=100/168		75.4	69.2	62.7	60.2	57.7	71.3	64.2	68	62.3

[1]

[1] ADF not available for Exp 3, ADL only for Exp 4, crude fat only for Exp 7!

Contents of CF for Exp 1-9 varied from 17.9-39.4%, NDF from 41.2-73% and ADF from 21.1-41.4% (results not given). The range in NDF and dOM and DM yields was higher in Exp 4 and 6 compared to respectively Exp 3 and 7. The higher GR in Exp 4 and 6 (Table 2) is possibly responsible for a more rapid decline in quality characteristics (results not given separately for Exp 3-4). Differences are smaller if corrected for DMY (Table 6a). Fat content decreased with CI and also tended to decrease slightly with N rate. Figure 9a shows the decline in dOM with increasing CF, NDF and ADF content in Exp 7. The variation in dOM explained by linear regression was lowest for CF and highest for ADF (see further section 3.3.3). Only linear components were significant. But ADF was only determined in some experiments. Figure 9b shows that in Exp 1-9, dOM decreased fast above NDF contents of 55-60%. This trend is less visible in Exp 7 with a smaller range in NDF contents.

Figure 9a Relationship between dOM of Exp 7 and contents (in DM) of crude fibre (CF), neutral detergent fibre (NDF) and acid detergent fibre (ADF) for all cuts and 2 replicates.

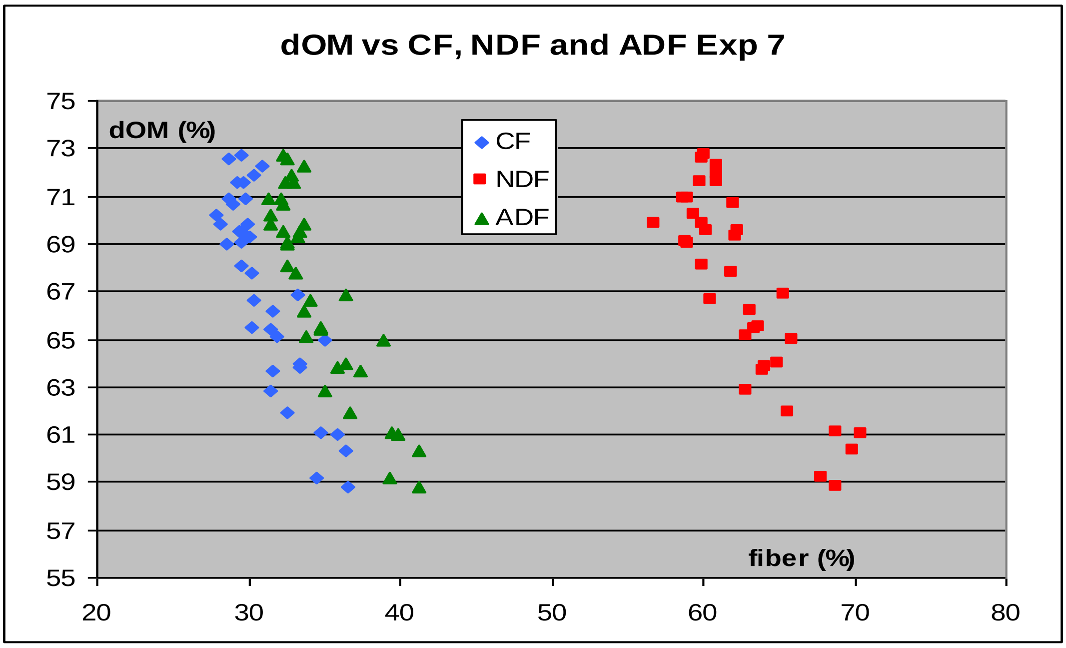


Figure 9b Relationship between dOM of Exp 1-9 and contents of neutral detergent fibre in dry matter (NDF DM) and organic matter (NDF OM).

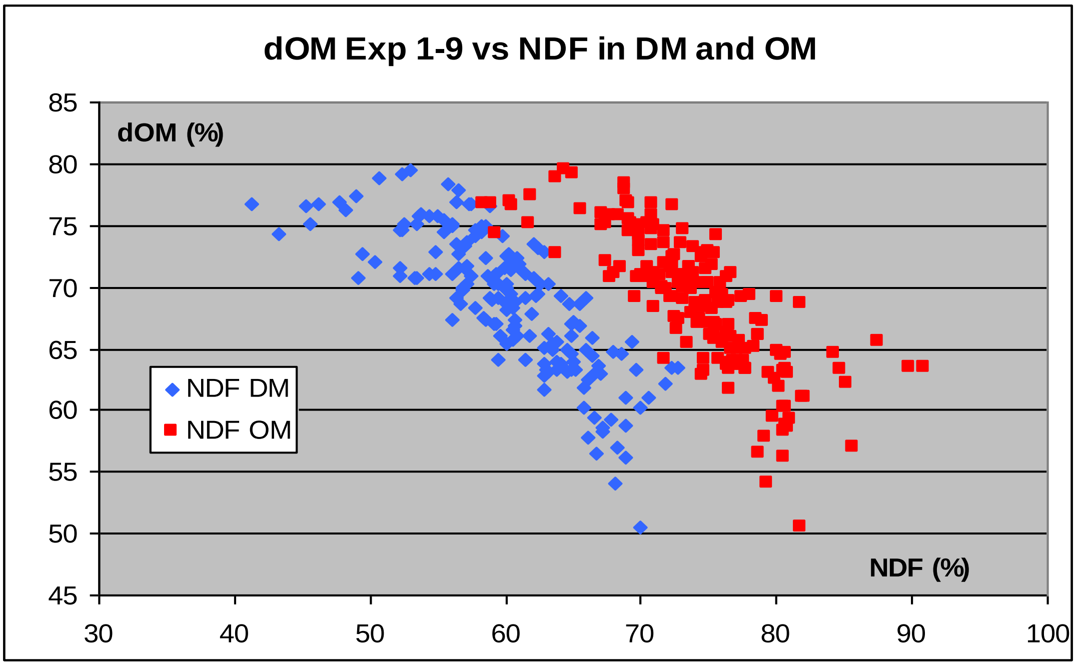


Figure 9c Relationship between dOM and contents of neutral detergent fibre (NDF in OM) for various cutting ages and N rates for Exp 3-4 (first cut only). NDF increases with CI (not separately indicated; N rates per CI often close!).

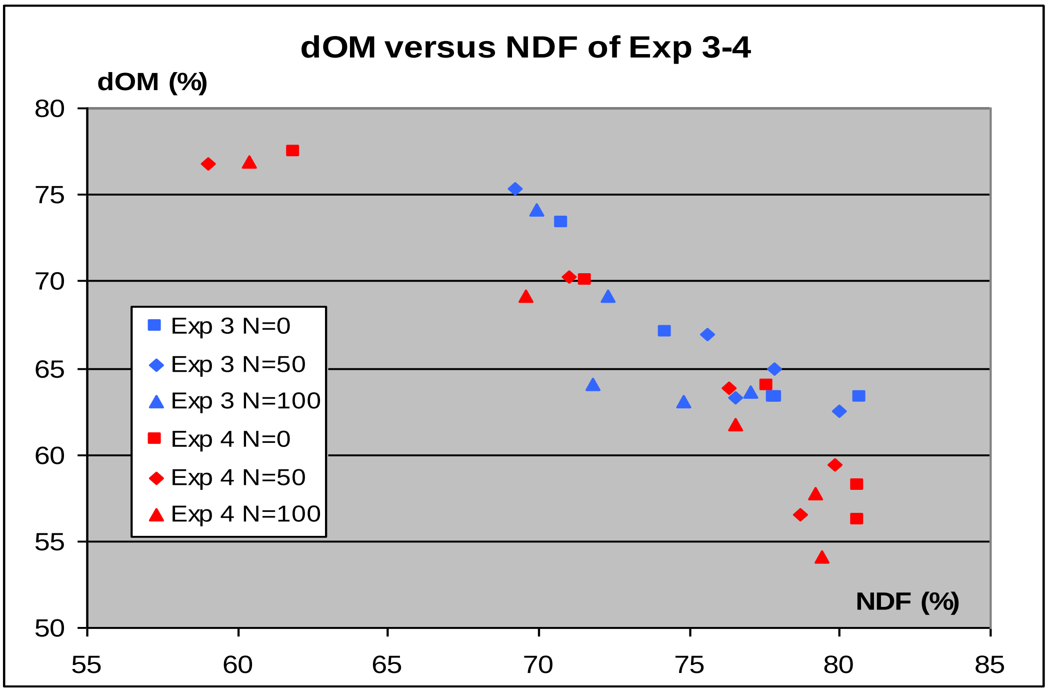


Figure 9d Relationship between dOM and content of ADF (in OM) per N rate for Exp 6 and 7. Results of Exp 6 are for 1 replicate and the first 12 weeks only. ADF increases with CI (CI not separately indicated)

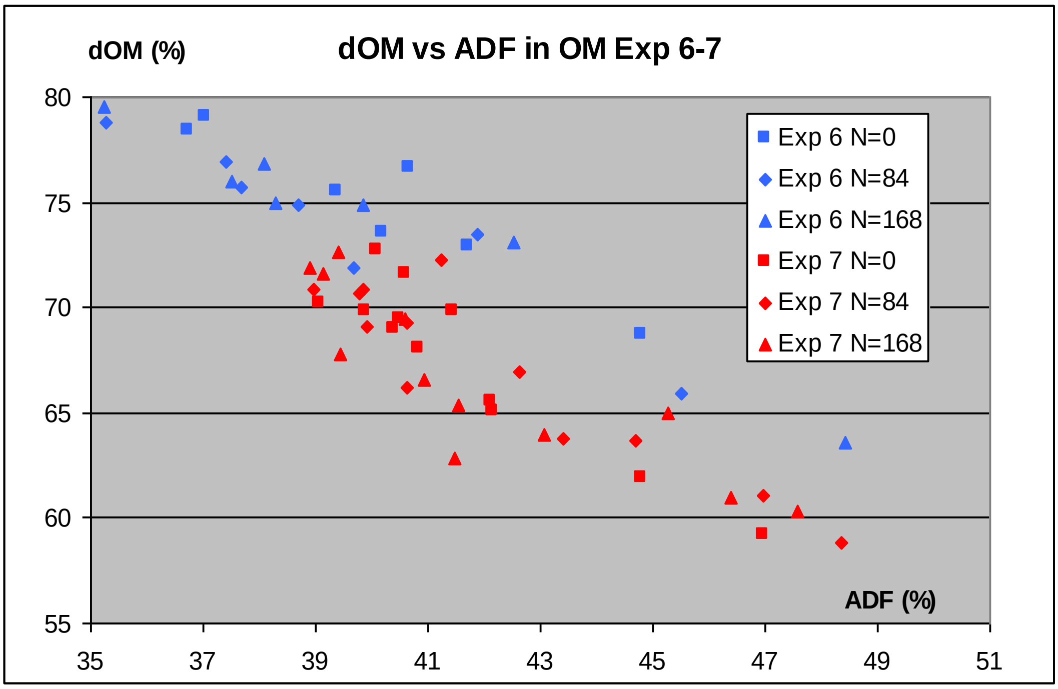
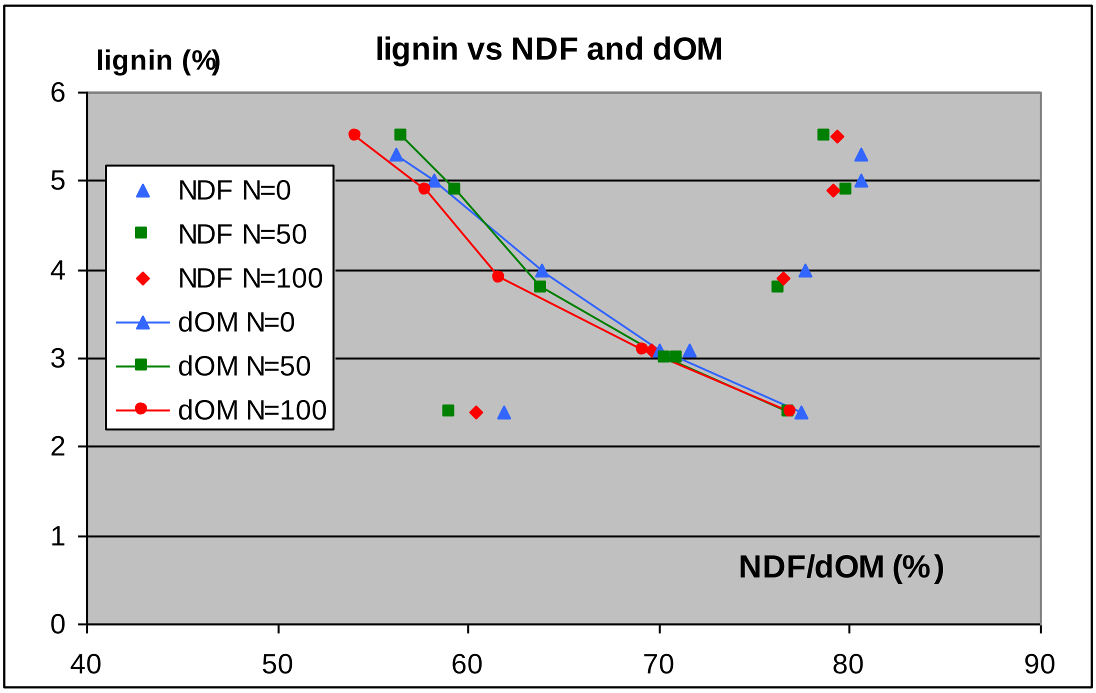


Figure 9c shows that at similar dOM, content of NDF tends to be slightly higher with N. At similar ADF contents, dOM tended to be higher in Exp 6 than in Exp 7 (Figure 9d), probably due to a higher GR in Exp 6. No clear N effect on dOM can be observed at similar ADF contents (results not given). In Exp 4, lignin content (in OM) tended to increase faster at higher NDF contents, while lignin content tended to be lower with higher N application (Figure 9e). There was a more or less linear decline in dOM with increasing lignin content. Relationships between dOM and morphological and chemical constituents are further discussed in Section 3.3.3.

Figure 9e Relationship between content of lignin and contents of NDF (in OM) and dOM for Exp 4



Leaf and stem digestibility
Table 6c gives contents of NDF and ADF and dOM of green leaf, stem and dead leaf (averaged over N rates) for a few experiments. Contents of NDF and ADF are higher in the stem than in (green) leaf, but surprisingly, dOM is higher in stem. Although dead leaf tissue is poorly digestible (lowest dOM), contents of NDF and ADF are not consistently higher than those found in stem tissue. At a cutting age of 9 and 15 weeks (Exp 2), grass leaf contains 3.7 and 5.2% sugar respectively, while the stem contains 3.9 and 7% sugar (averaged over N rates).

Table 6c Contents (% in DM) of OM, CP, dOM and dOM in DM of green leaf, stem and dead leaf at various ages for Exp 2, 4, 6 and 7 *averaged over N rates). Brackets indicate missing values for 1 of the N rates). A * indicates averages for Exp 6 and 7. See further text, also for abbreviations.

CI	**NDF**			**ADF**			**dOM**			**dOM in DM**	
(weeks)	**Leaf**	**Stem**	**Dead**	**Leaf**	**Stem**	**Dead**	**Leaf**	**Stem**	**Dead**	**Leaf**	**Stem**
Exp 2											
6							74.7	79.4		58.6	64.3
9	74.4	79.5	73.9	41.2	45.6	44.1	71.7	73.7	61.6	56.9	60.7
12							66.4	69.7	58	53.5	58.9
15	80.6	81.2	84.2	43.2	47.1	48.4	63.2	68.7	55.8	52.5	59.5
Exp 4											
12							59.8	62.3	55.8	49.9	52.7
18							(55.6)	54.3	47.8	(47.5)	48.1
Exp 6											
8							68.9	75	54.7	57.3	63.5
12	64.2*	68.3*		36.5*	41.5*		62.5	68.1	56.2	53	59
Exp 7											
6							67.4	73.6	(52.5)	55.7	62.8
12							58.2	64.9	53	49	56.2

3.3.3 Models for organic matter digestibility

A first exploration for the relation between dOM and morphology, environmental and chemical parameters is based on correlation matrices for several datasets. Results for dataset A are given in Annex 7. The exploration indicated a negative correlation between dOM and age, grass height, DMY, and contents of stem, dead leaf, CF, NDF, ADF and ADL, and a positive relation with contents of green leaf and CP. From the morphology parameters, leaf% showed the strongest relationship with dOM. The relation with the reverse of leaf (1/leaf) or height (1/H) was sometimes better, indicating a declining effect on dOM. The relation with stem% content was poorer than with leaf%. No significant relationship was observed between dOM and N application at the same age, but at the same age, DMY is higher with N (see before). dOM showed a strong positive correlation with CP% and a weak positive correlation with ash% (ash content decreases with age). The relationship between dOM and NDF was stronger than with CF. Both CF and NDF were positively correlated with age, T-sum, DM yield and stem content and inverse with contents of leaf, ash and CP. The relation between dOM and stem content or leaf/stem ratio was poorer than with green leaf and dead leaf, and therefore LSR was mostly excluded from further model development.
The correlation matrices indicate that the relationship between dOM and CP is more or less similar if expressed in either DM or organic matter (OM). But for other chemical parameters and combinations, expression in OM was often better (except for acid detergent lignin).Therefore all chemical parameters, except lignin, are expressed in OM, unless indicated otherwise (for reasons of comparison).
Subsequently, model development was first focused on the relation of dOM with environmental and morphology parameters for relatively larger datasets for which leaf content, grass height, ash and CP content are known (datasets A/B: n=155/255, see Chapter 2 and Chapter 3.3.3.1), not yet including other chemical parameters. In some cases also dataset C was also used (n=386). The relation with CP content was sometimes also included because analysis of CP content is more feasible than of other chemical parameters. Subsequently environmental and morphology parameters were compared with chemical parameters, first for dataset D (n=136, NDF and leaf% also known, but ADF not), and subsequently for datasets E (n=65; also ADF known), and dataset F (n=57; ADF, NDF, leaf and also H known). Finally dataset G was used (also ADL known; Exp 4, n=15). In the last part differences between varieties are discussed.

3.3.3.1 Models to predict dOM from morphological and environmental parameters (datasets A-C)

In overview, Table 7 shows that for dataset A (n=155; Exp 1-9, CI 4-18 weeks; Chapter 2), the model with the inverse of both age and leaf (Equation 5 with 1/CI and l/leaf) predicted dOM best (lowest MSres and highest R^2), while for models based on morphology only, Eq 10 with leaf% and the reverse of H was best (see also below). The standard error (se) for the prediction for dOM for Eq 5 is $\pm$1.69 (=square root of MSres). The variation explained is acceptable (R^2=54%), given the large variation in experimental design. The F statistic is below 0.001 for all model parameters (P<0.001; the se per parameter is given in Table 7).

dOM = 66.84 + 375.6/CI – 212/leaf (MSres=2.86 ; R^2=54 ; P<0.001) **(Eq 5)**
dOM = 55.4 + 0.187*leaf% + 171.2/H (MSres=3.66 ; R^2=37 ; P<0.001) **(Eq 10)**

Models with age only
The model in Eq 4 indicates that age predicted the variation in dOM for dataset A rather well. The declining effect of age on dOM is indicated by the inverse of CI (1/CI). Figure 10a shows that models with age for datasets A-C result in similar effects of cutting age on dOM. But for dataset A2 (Exp 1-4 and 6-7 only; n=199), initial dOM is slightly higher while the decline is stronger, probably because of larger variation in N rate and effects on growth rate and DMY (Eq 4.2). This probably also explains the improvement of the prediction if leaf content is included for some datasets; see below). Harvest season and T-sum are not significant if added to Eq 4, but season is if added for dataset A2 (Eq 4b.2 in Annex 8b), while temperature is not. Rate of N application and N provided by the soil (if used as a co-variant) are also significant if added to this model, provided that the DMY and interaction of DMY and age are also included (results not given). However, the prediction of dOM only improves marginally. But the prediction of dOM with age for dataset C (Eq 4b.1 in Annex 8b) improves substantially if the interaction of age and DMY is added (MSres=4.1; R^2=72%; results not given). However, DMY is difficult to determine. For larger datasets R^2 often improves while MSres declines, but this is not always the case, possibly because of the large variation in cutting ages and growing conditions (see further Annexes 8a and 8b for datasets B and C and Chapter 2).

Table 7 Models for the relationship between dOM and age (CI in days), % green or dead leaf, grass height (in cm) and DMY (Mg ha^{-1}) for CI of 4-18 weeks of Exp 1-9 (n=155; n=128 for CI of 4-12 weeks; n=199/165 for dataset A2/A3). See further text, also for abbreviations. *In Eq 5.3 and 6.1, CI*H stands for respectively season S2 and CI*DMY (both in red/italic).*

MSres	**R^2**	**Cst**	**CI**	**1/CI**	**leaf**	**1/leaf**	**dead**	**H**	**1/H**	**CI*H**	**Eq**
3.03	**52**	66.1	-0.035	349.7							4
P<0.001		±1.8	±0.013	±42.3							
3.18	**50**	68.14	-0.05987	296.4							4.1
P<0.001		±2.9	±0.027	±64							n=128
3.77	**72**	75.72	-0.1266	198.5							4.2
P<0.001		±1.79	±0.014	±44							n=199
2.86	**54**	66.84		375.6		-212					5
P<0.001		±1.6		±28.4		±57					
3	**50**	67.92		355.1		-270.8					5.1
P<0.001		±2.05		±33		±83					n=128
3.13	**70**	71.81		348.1		-400.2					5.2
P<0.001		±1.32		±28		±38					n=165
2.6	**69**	71.34		334.3		-344.5				*-3.699*	5.3
P<0.001		±1.32		±26		±39				*±0.77*	n=165
3.04	**54**	64.2		376.2						-0.00019	6
P<0.02		±1.3		±36.2						±0.00008	
2.91	**57**	64.6		364.2						*-0.0033*	6.1
P<0.001		±1.2		±31.2						*±0.0009*	
3.95	**30**	53.9			0.257						7
P<0.001		±1.6			±0.019						
3.94	**20**	77.97				-437.6	-0.1738				7.1
P<0.005		1.82				94	0.062				
3.99	**33**	40.16			0.377	372.5					8
P<0.03		6.25			0.055	166					
4.48	**9**	68.82						-0.041	212.9		9
P<0.005		±2.65						±0.017	±73.4		
3.66	**37**	55.4			0.187				171.2		10
P<0.001		±1.5			±0.024				±38.1		
3.84	**34**	70.34				-208	-0.207		245		11
P<0.02		±2				±88	±0.055		±34		

Models with age and leaf content A model with the reverse of both age (1/CI) and leaf% (1/L) improves MSres marginally for dataset A (compare Eq 4 and 5), but more for larger datasets including older cutting ages (Eq 5a and 5b in Annex 8a and 8b). Age, if added, is not significant anymore for dataset A. The model for 1/CI+1/L is slightly better than 1/CI + L or 1/CI + dead leaf (MSres=3.04; R^2=49; results not given). For dataset C1, the prediction of dOM is more or less similar for models with age or 1/L+D (Eq 4b1 and 7b1 in annex 8b). But if leaf content is added to age, the prediction of dOM improves substantially (Eq 5b).
Cutting age, N rate, % dead leaf, grass height, season, temperature (T), T-sum or DMY are not significant if added to Eq 5. But age, season, T (often not in combination with season!) or DMY are often significant if added to similar models for larger datasets with older cutting ages (Annex 8a, b). However, improvements are often only marginal. Predicted dOM is 1.14% lower during the dry season (S2) in Eq 5b2 (with leaf), but the decline is much larger in Eq 4b2 (age only; Annex 8b) and in Eq 5.3 (Table 7). Temperature is not significant if added to Eq 5.3. But adding CI, N rate, NY without N (as a co-variant) and growth rate improves MSres to 2.13 (results not given).
Figure 10b shows that there are only minor differences between models with 1/CI and 1/leaf for different datasets. Leaf % used is not shown, but is derived from a model for dataset C1 in Eq 5.5 below (dOM also known), but without N application, except for n=155 (dataset A; N=100 kg ha^{-1}). Leaf content decreases by about 4% if N application increases from 0 to100 kg N ha^{-1} (higher growth rate). The line for cutting ages of 4-12 weeks of dataset A (n=128; Eq 5.1 in Table 7) is not different from the

4-18 weeks CI (n=155). For dataset A2 (n=165), predicted dOM is slightly higher at young age (up to about 7 weeks), and slightly lower at old age, possibly due to higher N availability in Exp 1-4 and 6-7 (N not shown, but derived from the model in Eq 5.5 (N is significant for leaf%).

Leaf% = 69.71 - 0.2632*CI + 427.2/CI - 0.04039*N (MSres=31.5; R^2=77; P<0.003) ***(=Eq 5.5 ; n=323)***
H (cm) = 119.9 - 2879/CI + 0,216*N - 15.08 for S2 (MSres=182; R^2=48; P<0.001 ***(=Eq 5.6; n=304)***

Figure 10a Relationship between dOM and cutting age derived from models for 5 datasets (A-C: Eq 4-4.2 in Table 7 and Eq 4a, b in Annex 8a, b. See further text, also for abbreviations.

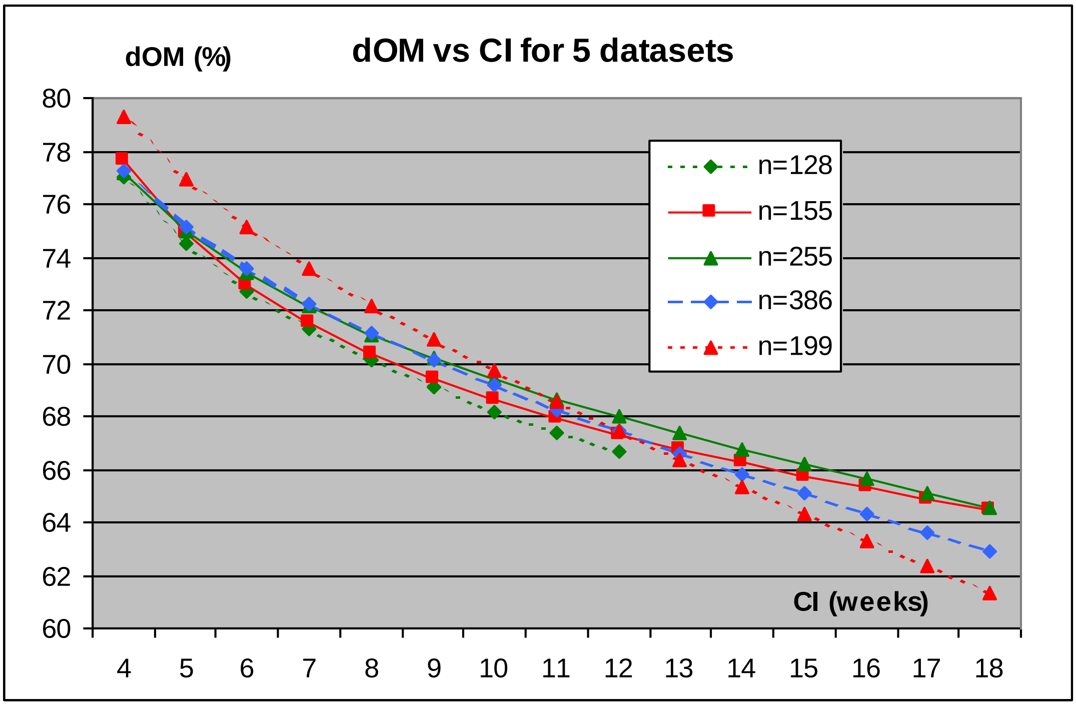
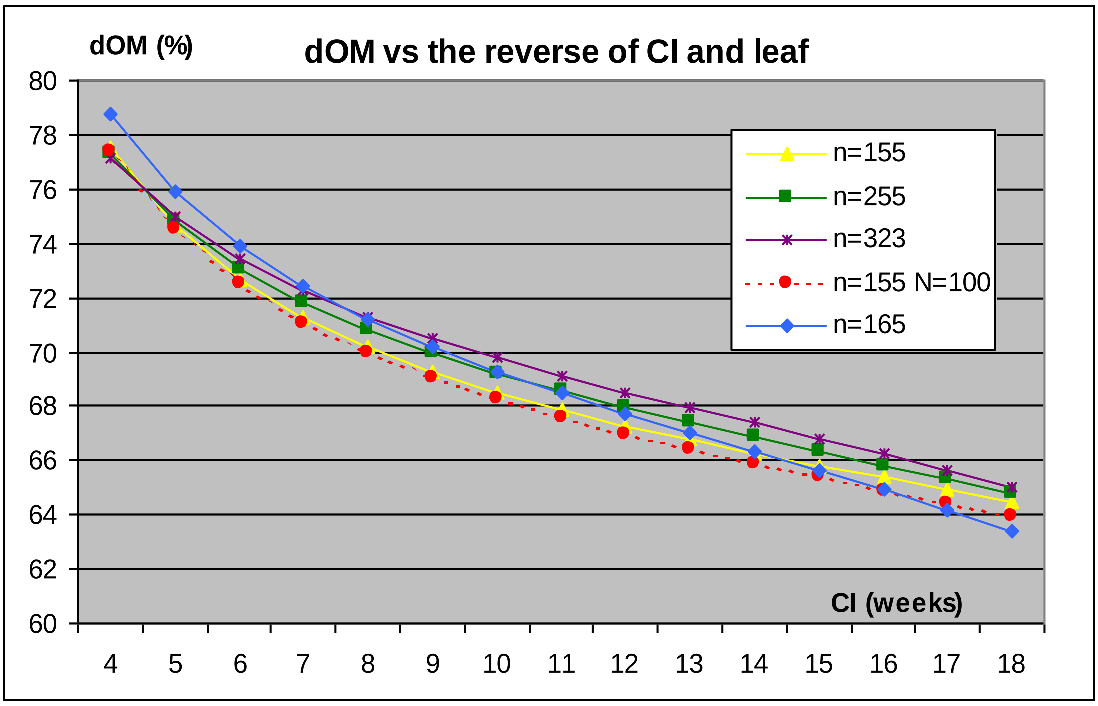
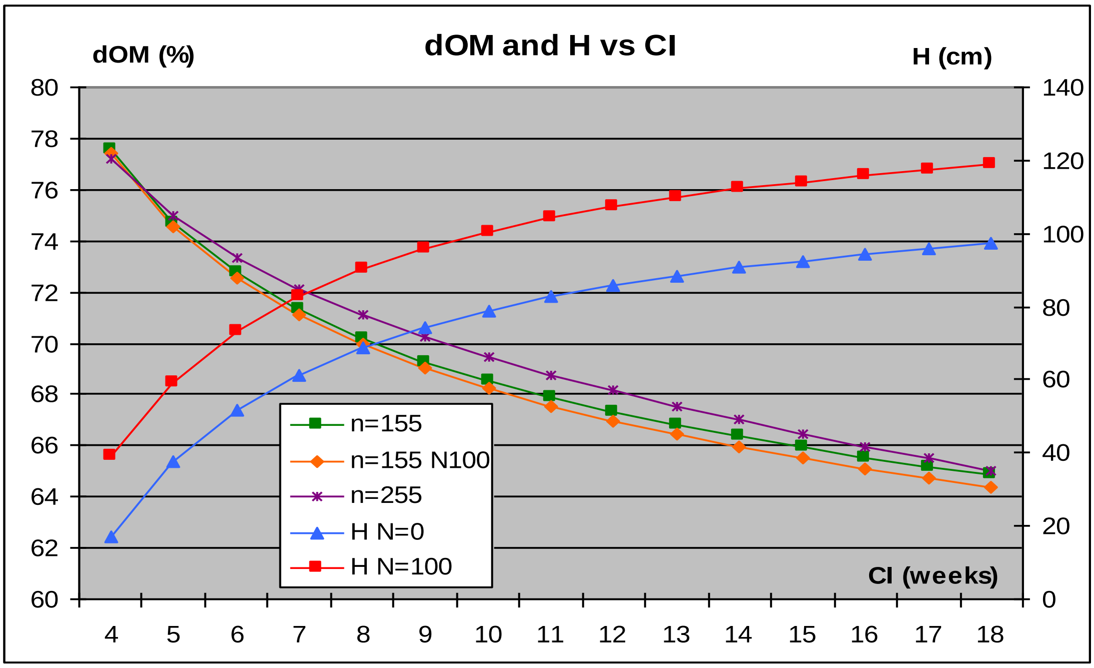


Figure 10b Relationship between dOM and age, derived from models with the reverse of both age (CI) and leaf % for 4 datasets (models in Eq 5, 5.1, 5a and 5b; Table 7 and Annex 8a, b). Leaf% (not shown) for respective ages is derived from Eq 5.5 for dataset C1 above. See further text.



Models for age and grass height
Age combined with grass height predicts the variation in dOM slightly less than age and leaf content for dataset A (Eq 5 and 6 in Table 7; Annex 8a, b). The interaction of age with DMY predicts dOM slightly better than the interaction with H (Eq 6 and 6.1 in Table 7), but for the larger dataset C2 results are similar (Annex 8 b). The interaction of age with H or DMY (Eq 6 and 6.1) implies that dOM decreases by 0.19% per 10 cm increase in H and by 0.33% per Mg increase in DMY at an age of 100 days (less at younger ages). Temperature, season and N and DMY are not significant if added to Eq 6, but are often for larger datasets (Annex 8a, b).
Figure 10c shows that differences in dOM for models for datasets A (without and with 100 kg N ha^{-1}) and dataset B are small, despite a substantial effect of N on grass height. Grass height is derived from the model in Eq 5.6 above for dataset C2 (n=304). Also if cutting age is limited to 4-18 weeks for dataset B, dOM is similar (maximum difference of 0.7% at an age of 12 weeks; results not shown).

Figure 10c dOM and grass height (H) plotted against age, based on models with age and the interaction of age and height (Eq 6 in Table 7 and Eq 6b in Annex 8b). Grass H is derived from Eq 5.6 above (dOM also known). See further text, also for abbreviations.



Models with only leaf or height and combinations of both
The variation explained is (substantially) lower for models with only leaf content (L) or H (without age). Leaf content (L or L+1/L in Eq 7 and 8) predicts dOM much better than height for dataset A (Eq 7 and 9 in Table 7; Annex 8a, b for datasets B and C). Grass height only is a poor predictor of dOM. Dead (D) leaf is not significant with L for dataset A, but it is with 1/L, also for dataset B and C (results not given). Models with L+1/L or L+D give similar results for dataset B (Annex 8a), but L+D predicts dOM slightly poorer for dataset C1 (Annex 8b). Results improve marginally if season (or T) are added to a model with L+1/L for dataset C1 (Annex 8b). The result improves substantially if DMY is added (results not given). Adding crude protein content (1/CP) or T to a model with H only improves results substantially (results not given).
Combinations of morphological parameters predict dOM better, the best model being Eq 10 in Table 7 (Eq 10a for dataset B). But the effect of differences in H on dOM, in addition to variation in leaf content, is limited (Figure 10d). For dataset A, dead leaf is significant with 1/L and 1/H (Eq 11 in Table 7), but not with L+1/H. The prediction of dOM is still slightly better for a model with L+DMY+DMY^2 (MSres=3.62; R^2=51). If season or T are added to models for dataset B or C1, the prediction of dOM improves marginally (Annex 8a, b). The dOM is respectively 1.09% lower during S2 (Eq 5a1), and 0.66% lower per ^{0}C increase in T (Eq 5a3). But T is not significant if added in combination with season in Eq 5a1. Complicated models sometimes explain (substantially) more of the variation in dOM, but such models are less easy to use under practical conditions (see further discussion).

Figure 10d dOM plotted against green leaf content for 2 grass heights (H=75 and 150 cm) for 2 datasets A (n=155) and B (n=255) (based on Eq 11 and 11a; see further text).

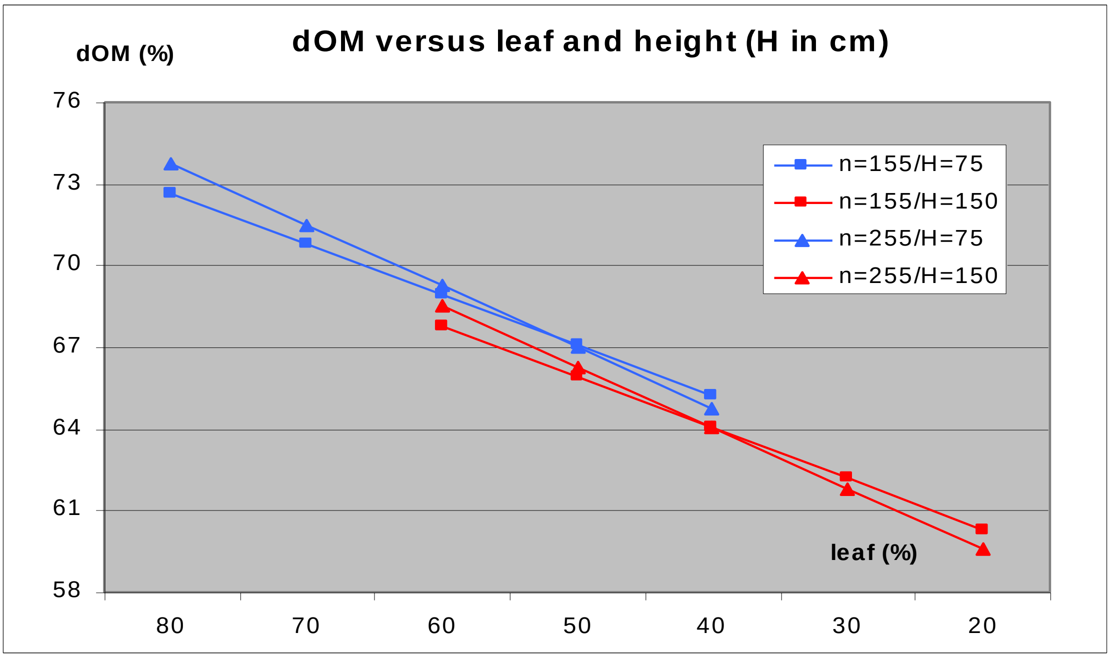


Figure 10e Relationship between dOM and age and contents of green (L) and dead (D) leaf, derived from models with L+D (Eq 7.1 in Table 7 and similar models for validation dataset H and I; n=123/132). L and D are derived from models including age (Eq 1.10 and Eq 1.11 in Chapter 3.1.2; n=562). See further text.

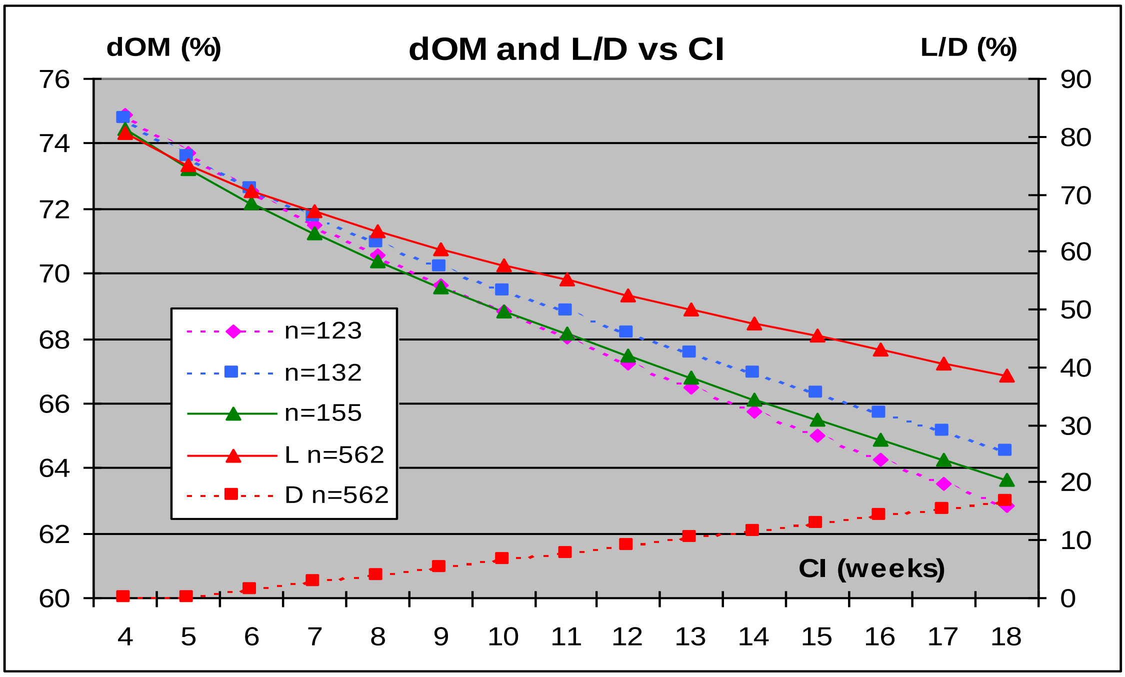


Figure 10e shows the difference in predicted dOM between morphology models with green and dead leaf for dataset A (dOM=56.6+0.222*L-0.0914*D; MSres=3.88; R^2=30) and similar models for validation datasets H and I (n=123 and 132; see further below; dead leaf not significant for dataset A, see before). Difference in dOM gradually increases to approximately 2% at a CI of 18 weeks. The model for n=132 has a slightly higher dOM, probably because of lower growth rates (similar to dataset B, see discussion before and Chapter 2). The difference between morphology models for dataset A is small, except for models with H only.

Validation of the most important models with age and morphological parameters
The mean and relative prediction error (MSPE and RPE) are sometimes used as criteria for the accuracy of prediction (see Chapter 2). An RPE below 10 is considered satisfactory and above 20% unsatisfactory. Results of the validation of dataset H (Exp 1-7) and a few other datasets with results from dataset I (Exp 8-11) are given in Table 7.1. Cutting ages used vary (for all CI of dataset I n=132, for CI of 4-18 weeks n=102).
Validation of the model with 1/CI+1/L for all CI of dataset H (n=123) results in a MSPE and RPE of respectively 7.49 and 10.9%, restricting CI to 4-18 weeks (n=119) improves MSPE and RPE (respectively 5.55 and 8.1%). Validation of the same model in Eq 5 (n=155; Table 7), results in a marginally higher MSPE and RPE (respectively 6.67 and 9.7%), but both are lower for the 4-18 week CI of dataset C1 (RPE=7.1%). Also models with 1/CI+CI*H result in satisfactory validation (RPE of 8.1 to 10.9% for datasets H to C2). For models with combinations of morphological parameters, RPE is more or less similar as for age and leaf (RPE of 8.4% for 1/L+D+1/L for n=155; see also Figures 10c and e). The RPE is higher for models with leaf only, but 1/L+D results in a satisfactory RPE for datasets B, C1 (n=255/323; RPE<10%). Models with H only are poor (results not given).

Table 7.1 Validation of models for datasets H (n=123/119), A (n=155), B (n=255), C1 (n=323) and C2 (n=304) with the measured results of Exp 8 to 11 (n=132 for all CI and n=102 if limited to 4-18 weeks). The validated models, cutting age of dataset I, the mean square prediction error (MSPE) and the relative prediction error (RPE) are given. See further text, also for abbreviations.

n	age	constant	1/CI	Leaf	1/leaf	dead	CI.H	1/H	MSPE	RPE
123	All	68.43	327.4		-242.4				7.49	10.9
119	4-18	67.44	376.6		-221.4				5.55	8.1
155	4-18	66.84	375.6		-212				6.67	9.7
255	All	70.58	306.1		-329.7				6.53	9.7
323	4-18	73.35	256.4		-414.7				4.89	7.1
323	All	73.35	256.4		-414.7				5.73	8.5
123	All	65.38	337				-0.00018		7.52	10.9
155	4-18	64.2	376.2				-0.00019		5.85	8.5
255	All	67.94	265.1				-0.00041		5.73	8.5
304	All	68.06	276.2				-0.00044		5.55	8.2
123	All	57.52		0.2158		-0.1815			11.38	16.5
119	4-18	58.83		0.1973		-0.2077			9.4	13.7
255	All	56.97		0.221		-0.106			9.3	13.8
323	All	56.43		0.2377		-0.1067			8.77	13
123	All	81.85			-619.3	-0.2422			6.42	9.5
155	4-18	77.97			-437.6	-0.1738			7.63	11.1
255	All	78.17			-446.7	-0.1054			6.46	9.6
323	All	79.55			-499	-0.1023			6.42	9.5
155	4-18	40.16		0.377	372.5				7.72	11.3
323	All	67.38		0.1427	-327.4				6.72	10
123	All	55.13		0.1971				151	7.36	10.7
119	4-18	54.89		0.1945				183.3	6.48	9.5
155	4-18	55.4		0.187				171.2	6.4	9.3
255	All	54.36		0.2238				107.6	7.46	11.1
123	All	74.25			-382.6	-0.2054		181	9.7	14.4
119	4-18	73.84			-348.3	-0.2163		216.1	6.6	9.7
155	4-18	70.34			-208	-0.207		245	5.78	8.4

Figure 10f and 10g are derived from models similar to respectively Eq 5 and Eq 6. Leaf content and grass H used in the models are derived from Eq 5.5 and Eq 5.6 for dataset C1 and C2 (see above; n=323/304). The lines for the standard errors in Figures 10f and g still overlap, also an indication of the reliability of this type of model (compare to Table 7.1). The predicted dOM tends to be slightly higher for dataset I (n=132), possibly because of less favourable growing conditions, in particular at younger harvest ages (e.g. lower N supply, see before and discussion). See further Chapter 3.3.3.2

Figure 10f Relation between dOM and age, derived from models with age and leaf (L in %), for datasets H (n=123; dOM=68.43 + 327.4/CI - 242.4/L; MSres=2.94; R^2=61) and I (n=132; dOM=72.38 + 314.7/CI – 371.1/L; MSres=5.18; R^2=66). Standard errors are shown via interrupted lines. See also Eq 5 in Table 7 and further text.

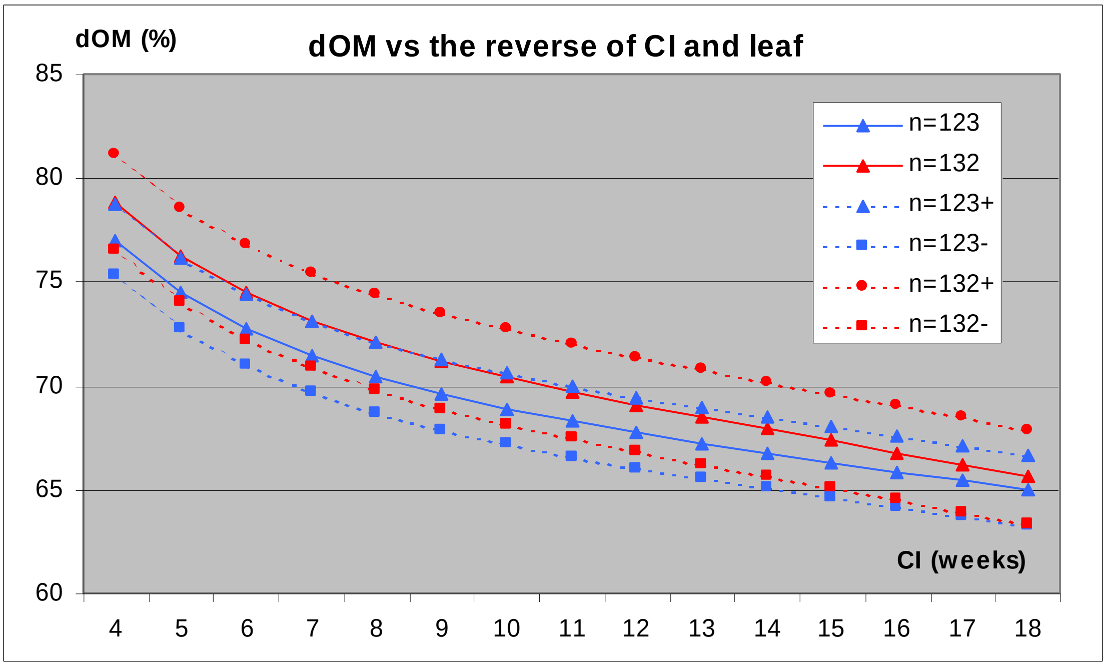
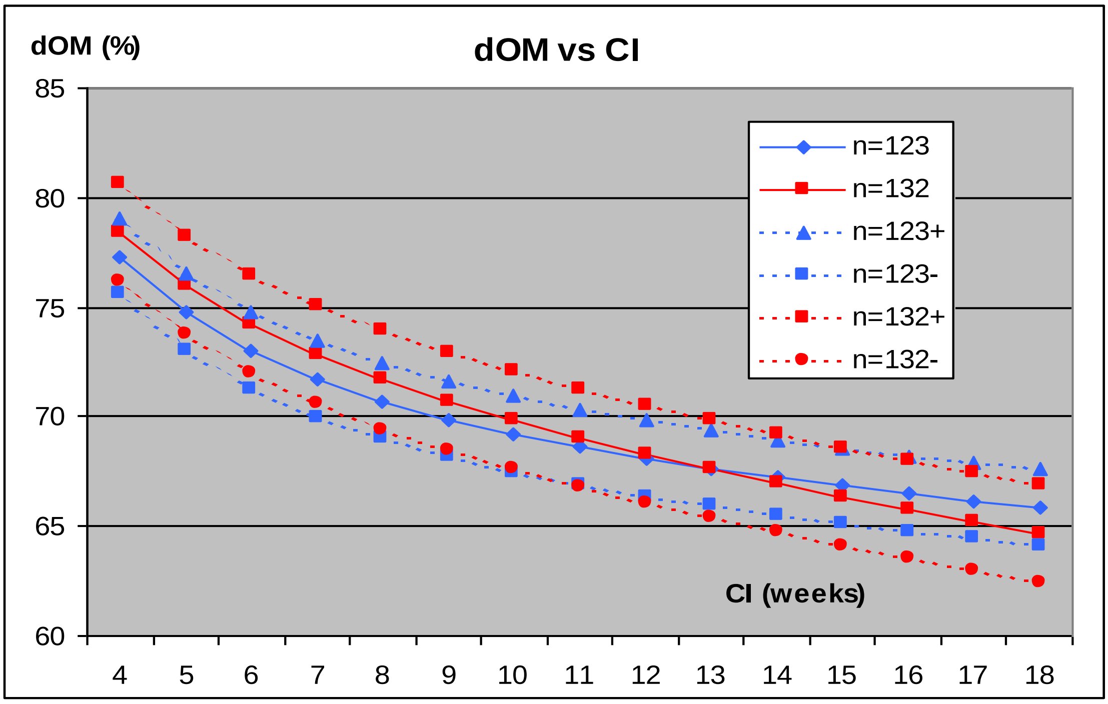


Figure 10g Relation between dOM and age, derived from models for age and grass height (H in cm), for datasets H (n=123; dOM=65.38 + 337/CI - 0.0018*CI*H; MSres=3.01; R^2=62) and I (n=132; dOM=68.66 + 278.8/CI – 0.00051*CI*H; (MSres=5.04; R^2=65). Standard errors are shown via interrupted lines. See also Eq 6 in Table 6 and further text.



3.3.3.2 Models for in vitro organic matter digestibility, morphological, environmental and chemical parameters (datasets D-G)

Models with CP and NDF

In overview, Table 8a shows that for dataset D (NDF also known), a model with the reverse of CP content and NDF in OM predict dOM best (Eq 19; less well if expressed in DM). But the variation explained is similar for models with age and leaf (Eq 13-15), while MSres is only marginally higher for a model with leaf content only (Eq 16). Similar to dataset A, the prediction of dOM improves if the reverse of leaf content is added to models with age. Adding leaf% improves the model in Eq 19 (MSres=2.65; R^2=85).

The difference between models with leaf or CP content only is small (Eq 16 and 17). A model with CP in DM performs marginally better (Eq 17.1). Adding 1/CP to leaf improves MSres (Eq 16.1), while 1/L is not significant anymore. A model with NDF alone predicts dOM less well (Eq 18). Also crude fibre alone is a poor predictor of dOM. But it improves the model in Eq 19 marginally (results not given). Also the model in Eq 17 improves marginally if CF substitutes for CP (MSres=3.03; R^2=77). Models also improve marginally if season or T is included. If T is added to leaf in Eq 16 variation explained increases, but MSres deteriorates (MSres=4.27; R^2=82), the effect of adding season is marginal. Adding T to Eq 19 improves MSres, but R^2 is poorer (MSres=2.75; R^2=74).

Table 8a Models for Exp 1-9 for the relationship between dOM and age (CI in days), % green leaf (in % of DM), CP and/or NDF (in % of OM, but Eq 17.1 in DM), based on dataset D for Exp 1-9 (n=136, unless indicated otherwise). Standard errors (P value), MSres and R^2 are also given. See further text, also abbreviations.

MSres	R^2	Cst	CI	1/CI	leaf	1/leaf	CP	1/CP	NDF	NDF^2	Eq
4.66	**75**	74.05	-0.1121	138.3							12
P<0.001		±1.75	±0.0107	±37							
3.7	**80**	74.04		226.8		-461.6					13
P<0.001		±1.37		±26		±35					
3.09	**82**	77.37		136.8		-277.5		-52.27			13.1
P<0.001		±1.44		±29		±47		±10			
3.42	**82**	75.78	-0.0448	160.9		-342.6					14
P<0.001		±1.44	±0.013	±32		±48					
3,14	**71**	74,42	-0,04176	245,3		-346,6					14.1
P<0.002		2,13	±0,02	±57		±54					n=125
3.36	**79**	68.87	-0.05961		0.1315	-173					15
P<0.007		3.28	±0.0123		±0.033	±63					
3.28	**70**	62.32			0.208	-258.6					16
P<0.001		±3.22			±0.031	±66					
2.76	**63**	66.99			0.1574			-68.16			16.1
P<0.001		2.3			0.023			8.4			
3.29	**71**	75.82					0.2384	-92.57			17
P<0.004		±2.22					±0.08	±9.88			
3.18	**72**	75.42					0.3451	-77.25			17.1
P<0.005		±2.53					±0.12	±9.28			In DM
4.77	**57**	73.16					0.3452	-70.65			17.2
P<0.001		1.44					0.06	5.7			n=386
4.4	**78**	20.79							2.274	-0.02202	18
P<0.003		±26.68							±0.75	±0.0052	
2.88	**80**	92.69						-65.97		-0.00315	19
P<0.001		±1.87						±8.19		±0.00043	

A model with age and grass H (1/CI + CI*H; similar to Eq 6 in Table 7) for samples with known NDF and grass H (n=141) predicts dOM only marginally less than Eq 13 with age and leaf (MSres=3.58 and R^2=75; model not given). But a model with H only (H+1/H) is much poorer (results not given) than leaf only (Eq 16.1). Therefore models with H are not given in Table 8a.

Figure 11a shows predicted dOM derived from models with leaf content only for dataset D (Eq 16; n=136) and 2 larger datasets. Leaf content is derived from the model in Eq 5.5 for dataset C1 given before (N application used is 50 kg ha^{-1}). Leaf content depends on age, therefore both are shown in Figure 11a. The relation between dOM and age and leaf is similar for the 3 datasets, despite differences in MSres and R^2 (see Annex 8a, b). Parallel with an increasing cutting age, leaf content declines from 78 to 40%. Figure 11b shows the relationship between dOM and NDF content expressed in either OM or DM. dOM strongly decreases beyond and NDF content of 50 and 60% in respectively DM and OM. This is concordant with the strong increase in lignin content at high NDF contents shown in Figure 9e.

Figure 11a Relationship between dOM and content of green leaf, derived from a models for various datasets with leaf content only (Eq 16 in Table 8a, n=136; Eq 7a1 and 7b in Annex 8a, b, n=255/323). See further text.

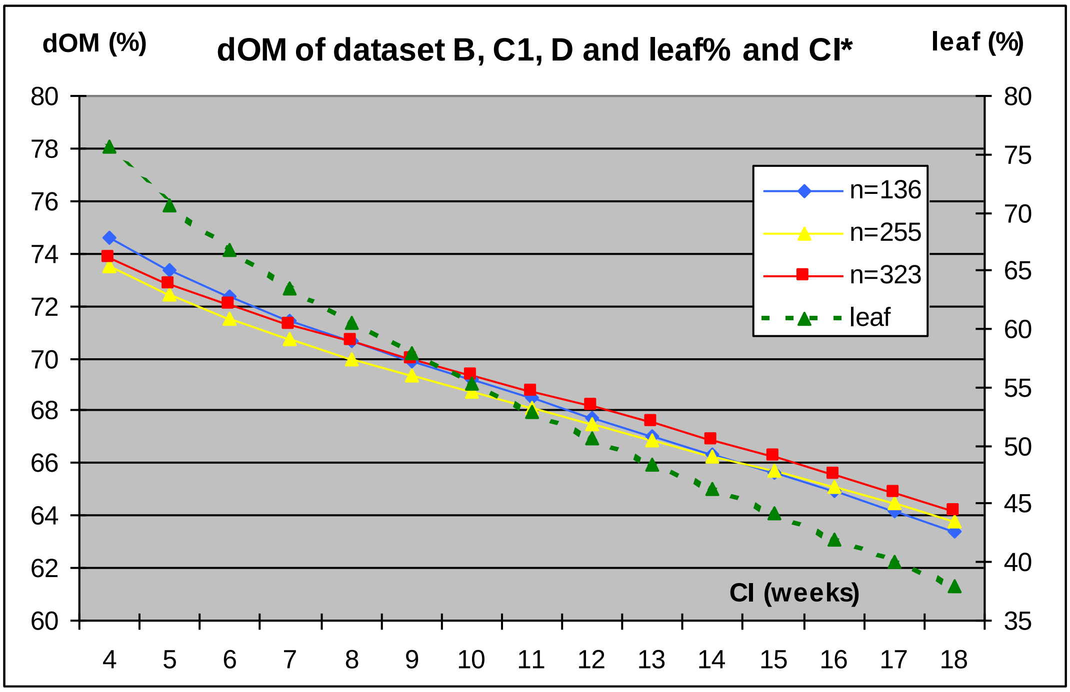
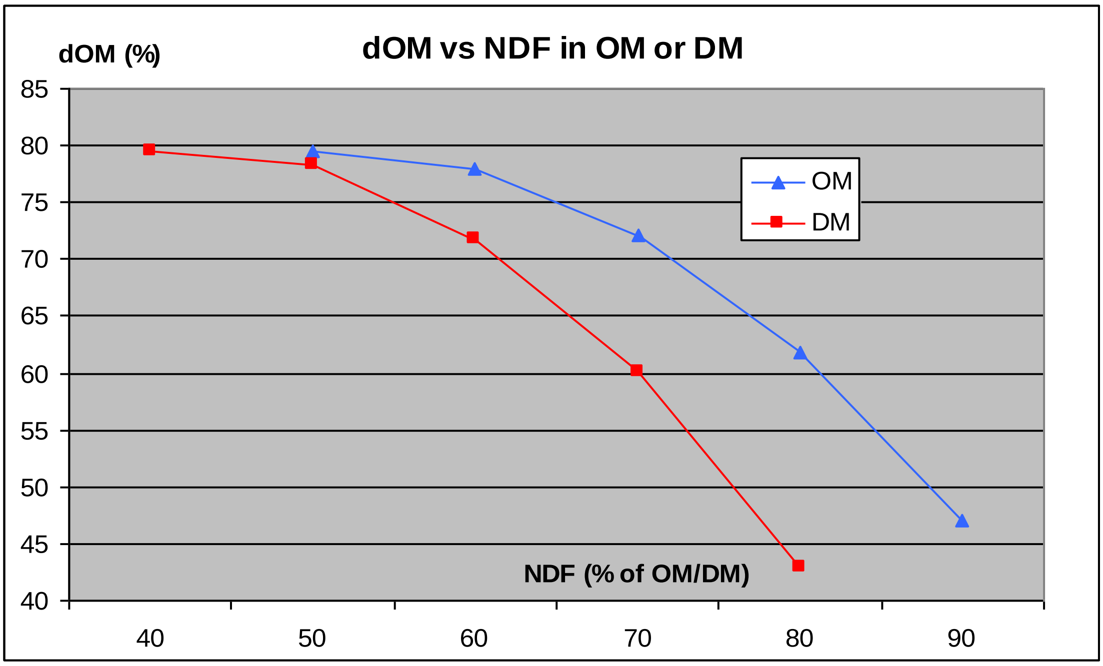


Figure 11b Relationship between dOM and content of neutral detergent fibre (NDF) in organic matter (=OM) or in dry matter (=DM) for dataset D of Exp 1-9 (n=136). See further text.



Models with NDF and ADF
Models for dOM based on more extensive chemical analysis, including NDF, ADF and leaf content are given in Table 8b (dataset E; n=65). In overview, a model with the reverse of CP and ADF results in the lowest MSres for the prediction of dOM (Eq 28). Eq 22.1 with the reverse of age and dead leaf *(leaf=dead leaf)* is (deviating from other datasets), slightly better than 1/CI+1/leaf (Eq 22). Although the combination of 1/CP and ADF results in the best prediction, it is difficult to validate these models because of the small datasets with known ADF (see validation before).

Table 8b Models for the relationship between dOM and age (CI in days), % green leaf and/or chemical composition (in OM) for experiments 1-4 and 6-7 (dataset E; n=65). The standard error of the regression coefficients, and MSres and R2 are also given. In Eq 22.1 leaf content stands for dead leaf. See further text, also for abbreviations.

MSres	R^2	Cst	CI	1/CI	leaf	1/leaf	1/CP	NDF	NDF^2	ADF	Eq
3.58	**82**	84.04	-0.208								20
P<0.001		±1.47	±0.012								
3.28	**85**	74.61	-0.156		0.099						21
P<0.02		±4.07	±0.023		±0.039						
3.49	**73**	72.75		339.2		-447.9					22
P<0.001		2.46		±57		±50					
2.98	**81**	63.75		458.9	*-0.3124*						22.1
P<0.001		1.93		77	*0.066*						*=dead*
4.55	**51**	63.8			0.1966	-307.9					23
P<0.008		±6.16			±0.06	±111					
3.19	**70**	82.34					-129.2				24
P<0.001		2.12					±8				
3.44	**78**	-40.83						4.166	-0.362		25
P<0.001		40						±1.13	±0.008		
3.04	**61**	132.1						-0.37		-0.88	26
		4.62						±0.12		±0.16	
2.56	**67**	112.1					-70.8	-0.4903			27
P<0.001		6.49					±13.63	±0.1			
1.97	**70**	107.7					-64.21			-0.7869	28
P<0.001		4.22					±11.1			±0.113	

Table 8c Models for the relationship between dOM and age (CI in days), green leaf and/or chemical composition (in OM, but ADL and in Eq 38.1 also ADF in DM). See further text, also for abbreviations.

MSres	R^2	Cst	CI	leaf	1/CP	NDF	ADF	ADL	1/ADL	T	Eq
2.61	**96**	86.51	-0.258								32
P<0.001		±2.04	±0.014								
1.84	**97**	72.45	-0.171	0.16							33
P<0.03		±5.79	±0.036	±0.06							
4	**94**	117.9			-62.2	-0.6223					34
P<0.001		9			21	0.148					
4.62	**93**	130.7					-1.617				35
P<0.001		4.87					0.119				
0.63	**99**	565,9					-0.7204			-27.6	35.1
P<0.001		48					0.107				
2.71	**96**	91.61						-6.79			36
		±1.55						±0.38			
0.97	**99**	39.65							90.77		37
P<0.03		±0.86							±2.97		
0.77	**99**	109.9					-0.709	-4.1			38
P<0.001		3.24					0.122	0.5			

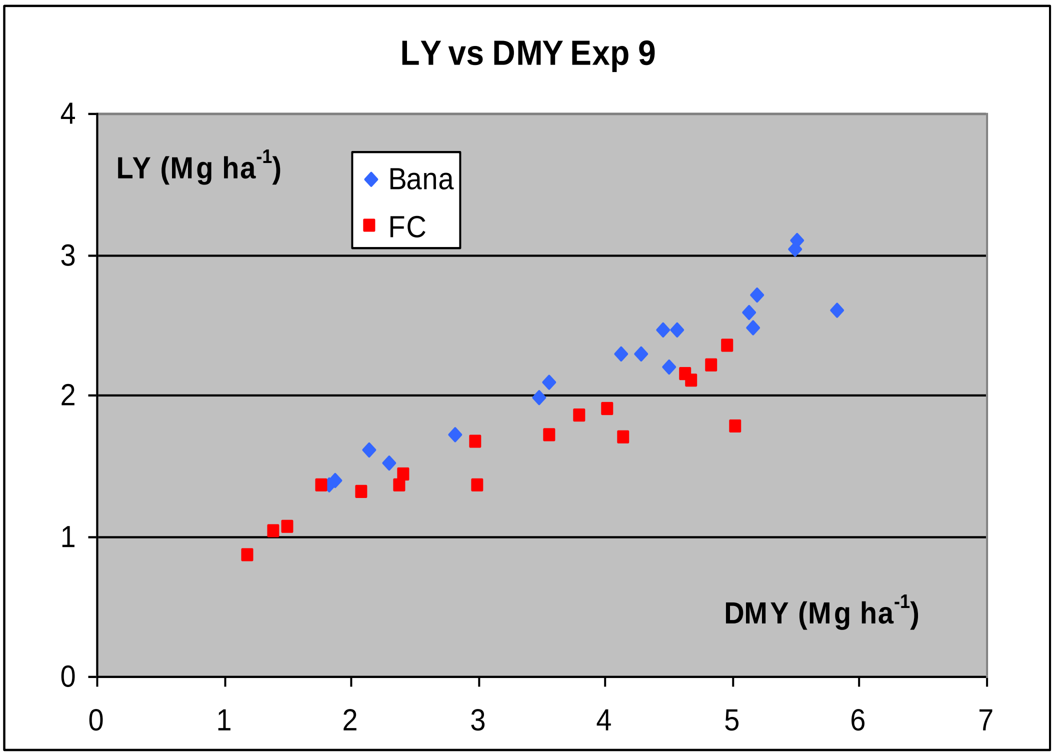
Results for dataset F (n=57; ADF and grass height known) are given in Annex 8c. In overview, the model with ADF is best (Eq 30). The variation explained improves if T is added (Eq 31). DMY is not significant if added, possibly because T accounts for difference in growth rate and DMY. The variation explained for the model with H alone is low (Eq 9c; 1/H is not significant), but if T is added, prediction of dOM is almost as good as for ADF (Eq 9c1). Generally, models with age and leaf content tend to explain more of the variation in dOM than models with age and H.

Models with lignin and ADF
Table 8c presents results for models for dataset F (n=15; first cut of Exp 4 only) with known ADF and ADL (ADL in DM). The model in Eq 38 with ADF and ADL is best. A model with the reverse of ADL also predicts dOM well, ADF not being significant anymore. The model with age and leaf is rather good as well (Eq 33), but MSres is higher. If added, T is not significant. But adding T improves the model with ADF substantially (Eq 35.1; see discussion before). If ADL is expressed in OM results are much poorer (results not given). For model with NDF or ADF only, MSres is much higher (Eq 34 and 35). The variation explained for the prediction of dOM for the models in Table 8c is high, but models consider only 1 replicate of Exp 4!

3.3.4 Differences between varieties Bana and French Cameroons

Averaged over all cuts of Exp 5 and 9, the only two experiments with a direct comparison of Bana and French Cameroons (=FC; Chapter 2), DMY was similar at respectively 4.15 and 4.14 Mg DM ha^{-1} (slightly higher for FC in Exp 5, results not given). In Exp 9, at the same DMY, leaf yield and NY of Bana tended to be higher (Figure 12a, b), in particular at higher yields (and older age; for Exp 5 leaf% is not known). In models for leaf content with CI and DMY (for all samples with known leaf content; n=886), predicted leaf% and stem% are respectively significantly lower and higher for FC than for Bana, in line with Figure 12a (for dead leaf variety is not significant). However, in models for CP content variety is not significant, despite the higher CP content of Bana which can be derived from Figure 12b.

Figure 12a Leaf yield of Exp 9 (Bana and FC) plotted against DMY at various cutting ages (CI not shown). See further text.



Average ash contents of Bana and FC (Exp 5 and 9) were resp. 22.5 and 19 %. At the same DMY yield, ash content of FC tended to be lower than for Bana (Figure 12c). In models for ash content with age, DMY, season and variety for Exp 1-11 and for dataset A4 (see chapter 3.1.1), predicted ash content is lower for FC than for Bana (2.8% for Exp 1-11; but variety is not significant if DM% is also included). Similar to the results for dataset A4, also a model for Exp 1-11 for ash, including location, variety and season, predicted a 3.1% lower ash content for FC, and 5.2 and 3.7% lower ash content in respectively Kakamega and Kisii compared to Naivasha (MSres=2.01; R^2=82; compare to Chapter 3.1.1). However, if leaf content is also included, location is not significant anymore.

Figure 12b Relationship between dry matter yield (DMY) and N yield (NY) for Exp 9.

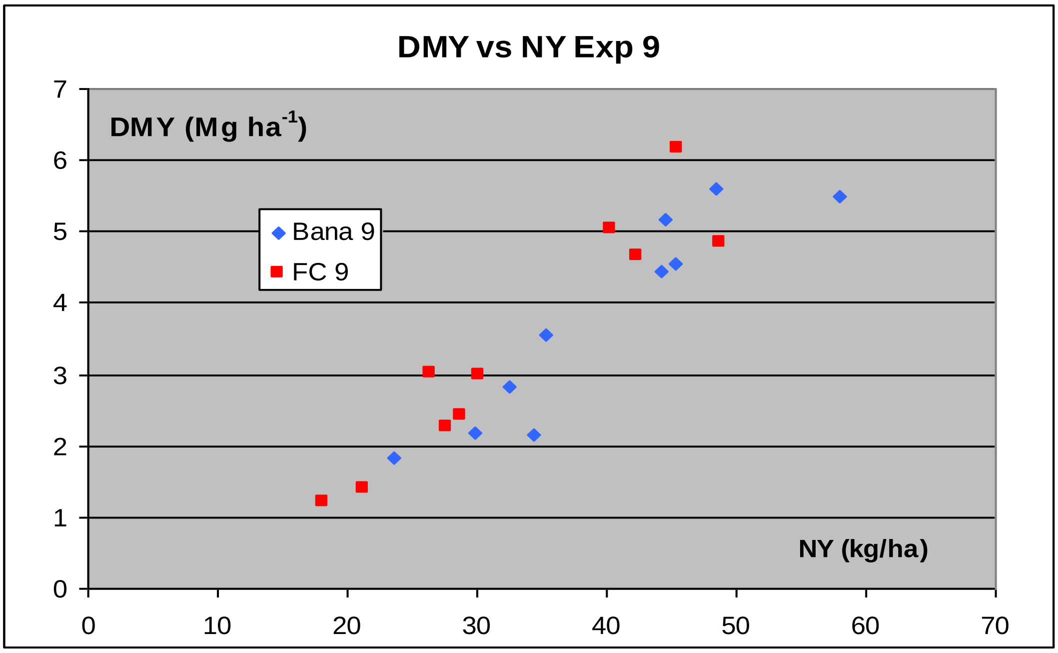
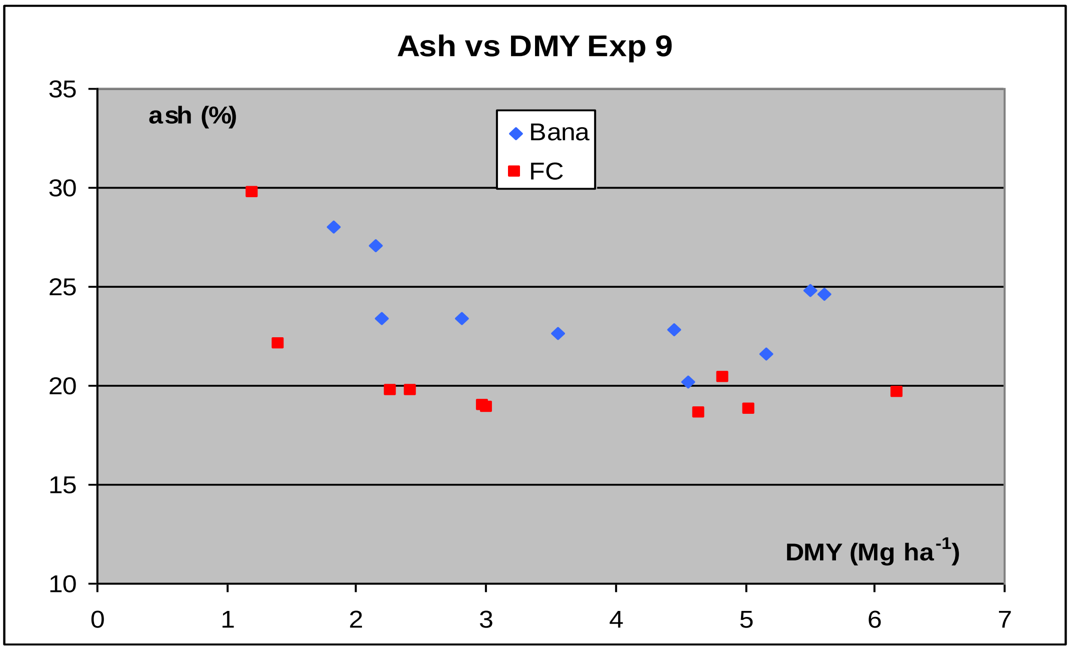


Figure 12c Relationship between crude ash % and DMY of Exp 9 for varieties Bana and FC.



In vitro organic matter digestibility of FC decreased faster than for Bana in Exp 5, in particular if expressed Mg^{-1} increase in DMY (decrease of resp. 1.71 and 1.48% ton^{-1}; see also Table 6a). If based on the content of in vitro digestible organic matter in DM (=DOM), the decrease was resp. 0.9 and 0.45% ton^{-1} DM for FC and Bana. But DOM tended to be higher for FC at the same DMY (Figure 12d), also due to the lower ash content of FC. At young age and similar NDF contents, dOM tended to be slightly higher for FC than for Bana, but with increasing NDF content, dOM of FC tended to decrease, resulting in lower dOM at high NDF contents (and long CI) than for Bana (Figure 12e).

Figure 12d Relationship between content of digestible organic matter in DM (=DOM) and DMY for Exp 9.

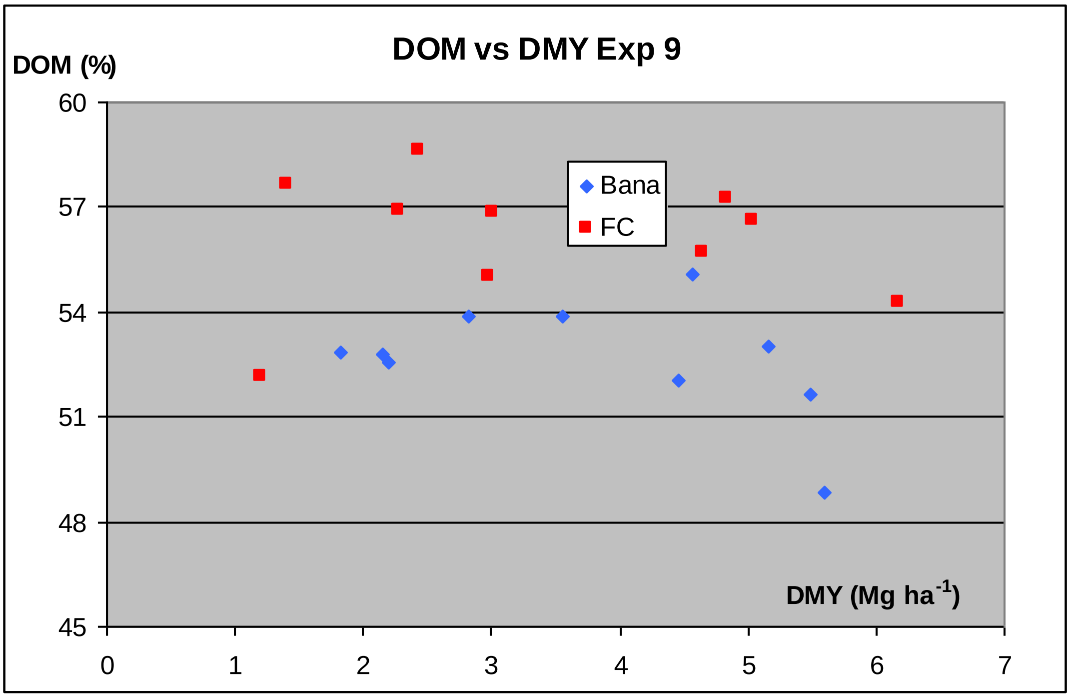
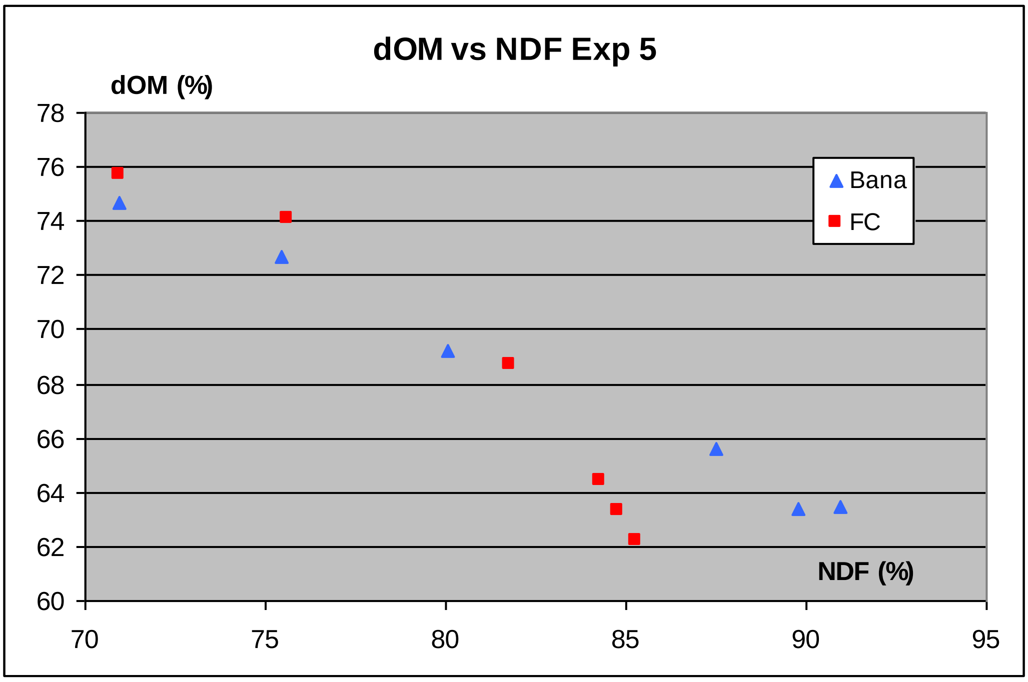


Figure 12e Relationship between (dOM) of the varieties Bana and FC and content of neutral detergent fibre (NDF in organic matter) for Exp 5.



In a model for dOM with age and variety for Exp 5 and 9 only (a direct comparison of Bana and FC), variety was not significant. In a model for dOM for dataset C (CI of 4-18 weeks; n=343) with CI, DMY, variety and the interaction of variety and CI (variety/CI), variety is nearly significant (P<0.054; P<0.004 for interaction). Derived from the model, dOM of FC is 2.1% higher than of Bana at young age (50 days), but 0.9% lower at 100 days, possibly due to a faster decline of leaf content and faster aging of FC (see Figure 12e and discussion). Without the interaction, dOM of FC is higher. Variety is just significant (P<0.03) in a model with age and leaf content for dataset C1, but not anymore if DMY is also included (results not given). In a model for dOM with all samples with known NDF content ($NDF+NDF^2$; n=203), predicted dOM of FC is significantly lower than of Bana (2.8% lower for FC;

compare to Figure 12e), but not anymore if 1/CP or ADF are also included. In a model for ADF content (also including DMY), ADF of FC is lower (n=84). These “conflicting” results may also be due to differences between datasets, not allowing a direct comparison of models.

4 Mixtures of Napier grass with and without Greenleaf Desmodium

4.1 Methods

Both Exp 11 and 12 were conducted in Naivasha. The main objective of Exp 11 (1985-1990) was to investigate the effect of a mixture of Napier (variety French Cameroons) with Desmodium in comparison with pure Napier on yield and quality (Table 9). Both treatments (pure Napier=N and Napier/Desmodium=ND) were aimed to be cut at (average) grass heights of 60 cm (short=s) and 90 cm (long=s). Desmodium was planted in November 1984 at 45 cm between rows, Napier grass (variety FC) was planted in February 1985 by means of root splits in the rows with Desmodium at a spacing of 90 cm between rows and 60 cm within rows. During part of 1988/99 there was a period with an extreme moisture deficit because of a failing irrigation system (Chapter 2). Average cutting ages were long (14 and 17 weeks for s and l) because of longer periods between harvests during 1988/99 and the normal (long) dry seasons.
Experiment 12 was a follow up of Exp 11, conducted on the same site, but all cuts were now made at the same grass height of about 90 cm. One of the original pure Napier treatments was now fertilised with 200 kg fertiliser N ha^{-1} year^{-1}, to investigate the contribution of Desmodium to N uptake. For methods of harvesting and sampling see Chapter 2. Desmodium was cut with a sickle, slightly higher than grass at a height of 5-10 cm. Chemical analysis for crude ash and protein was made per replicate, but analysis for dOM was performed for 1 replicate only.

Table 9 Treatments and period, rate of fertiliser N per year, grass height at cutting, total cut number and average cutting interval (CI) for Exp 11 and 12. See further text, also for abbreviations.

Exp 11 (1985/90)	N kg ha^{-1}	Height (cm)	Total cut number
N-s	0	60	18 (CI of 14 weeks)
ND-s	0	60	18 (CI of 14 weeks)
N-l	0	90	15 (CI of 17 weeks)
ND-l	0	90	15 (CI of 17 weeks)
Exp 12 (1990/91)			
N	200	90	5 (CI of 13 weeks)
ND	0	90	5 (CI of 13 weeks)

4.2 Results

Soil carbon content was higher with Desmodium and when grass was cut longer (Table 10). But compared to the indicative initial C content (1.7%; see Annex 1) soil carbon decreased for all treatments, probably because the initial content was already lower at the start of the experiment, 3 years after sampling and ploughing of pasture, and because variation was insufficiently included during initial sampling (see Chapter 2).

Table 10 Results of soil analysis (0-20 cm) at the end of Exp 11 in 1990 for contents of carbon (C), nitrogen (N), C/N ratio, pH, phosphorus (P), calcium (Ca), and average annual soil nitrogen supply (SNS in kg ha^{-1}). See further text, also for abbreviations.

Treatment	C	N	C/N	pH	P	Ca	SNS
	%	%	ratio		ppm	meq %	
N-s	1.33	0.19	7.0	7.5	44	15	96
N-l	1.43	0.16	8.9	7.4	40	18	94
ND-s	1.41	0.17	8.3	7.1	40	19	
ND-l	1.52	0.21	7.2	7.2	28	20	

Annual DMY in Exp 11 varied from 12.3 to 17.4 ton DM ha^{-1} (Table 11), yield of ND mixtures being substantially higher. The annual NY was much higher with Desmodium (respectively 94 and 286 kg N ha^{-1} without and with Desmodium), the highest NY being for the short cut mixture (ND-s=287 kg N ha^{-1}). Grass height was resp. 71 and 75 cm for pure Napier and the ND mixture if cut short CI, and 94 and 96 if cut longer. Crude protein contents were low, due to long CI (Table 9), and much higher for the ND mixtures. Both, CP and dOM contents of Napier were approximately 1-2% higher for Napier in the ND

mixture. Contents of dOM were much lower in Desmodium, resulting in a dOM which was 13-14% lower in the ND mixture compared to pure Napier for both cutting heights.
The Desmodium content of the mixture was about 50%, being slightly lower for the long cutting interval. During 1988-1990 average Desmodium content was similar, but Desmodium content tended to decrease slightly during long dry periods. It was marginally higher (57%) during Exp 12, varying from 45-65% between cuts (results per cut not given).

Table 11 Annual yields of dry matter (DMY) and nitrogen (NY) of pure Napier grass (N) or Napier in a mixture with Desmodium (D) cut at different heights (H; short=s; long=l). Contents of Desmodium in the mixture (%D in DM; in brackets 1985-88 only), crude protein (CP), ash and dOM of Napier and Desmodium and Least Square differences (LSD for P<0.05) are also given. See further text, also for abbreviations.

Treatment	**H**	**DMY**	**% D**	**CP**	**Ash**	**NY**	**dOM-N**	**dOM-D**
Exp 11								
N-s	71	12.3		4.9	17.8	96	67.2	
N-s in mixture	75			6.2	17.6		68.7	
ND-s		17.4	51 (52)	10.3	14.3	286	60.9	54.1
N-l	94	13.3		4.4	16.7	94	64.9	
N-l in mixture	96			5.4	16.3		65.8	
ND-l		16.2	48 (49)	9.1	13.5	237	67.4	50.3
LSD		2.3		0.8	0.8			
Exp 12								
Control		11.3		5.1	16.9	91		
N=200		20.2		5.4	15.9	173		
ND		19.6	57	10.6	13.6	329		

In the follow up Exp 12, ANE and ANR of fertiliser N for pure Napier grass were respectively 56 kg DM kg^{-1} N and 52% (results not given). For the short and long cutting heights respectively of Exp 11, 93% and 87% of the annual NY of 201 and 164 kg Desmodium N ha^{-1} respectively (results not shown in Table 11) is derived from symbiotic N fixation if based on the difference method (derived from Snijders et al., 1992b).
In the follow up Exp 12, ANE and ANR of fertiliser N for pure Napier grass were respectively 56 kg DM kg^{-1} N and 52% (results not given). The DMY of Napier/Desmodium approached the yield of Napier fertilised with 200 kg N per ha at respectively 19.6 versus 20.2 ton ha^{-1}. The NY was much higher with Desmodium than Napier fertilised with 200 kg N (respectively 329 and 173 kg N ha^{-1}). Based on the difference in NY between the control without N and Napier/Desmodium, estimated annual biological N fixation by Desmodium was 238 kg N ha^{-1}.

5 Effects of slurry application on yields and nitrogen utilisation

5.1 Methods and slurry composition

The objective of these experiments was to investigate the effect of cattle manure (as slurry, a mixture of faeces and urine), either surface applied (=Ms) or incorporated (=Mc) into the soil, in comparison with application of fertiliser N on yields and N utilisation. Table 12 gives an overview of the experiments conducted, including rates of applied fertiliser and manure N. Besides a control without manure, two rates of fertiliser N were used (N1 and N2). In Exp 14 and Exp 15, also two rates of incorporated manure were applied (Mc1 and Mc2). Treatment Mc1 was also combined with both fertiliser rates (Mc1N1 and Mc1N2) in these experiments. Exp 13 and 14 were conducted in Naivasha, respectively from 1985 to 1990 (total of 1812 days) and from 1990 to 1992 (total of 615 days). Exp 15 was conducted in Kakamega from 1990-1991 (total of 363 days). During part of 1988/99 there was a period with an extreme moisture deficit during Exp 13 in Naivasha because of a failing irrigation system (Chapter 2), resulting in extra long cutting ages, besides increases in average cutting ages caused by normal dry periods.

Table 12 Rate and method of manure and fertiliser application (kg N ha^{-1} year^{-1}; manure N=Nm, fertiliser N=Nf) per treatment. Total number of cuts (No cuts) and average cutting interval (CI in days) are also given. See further text, also for abbreviations

Experiment	**Exp 13**		**Exp 14**		**Exp 15**	
No cuts / CI	24 / 76		7 / 88		6 / 61	
N application	**Nm**	**Nf**	**Nm**	**Nf**	**Nm**	**Nf**
Treatment						
Control	0	0	0	0	0	0
N1	0	113	0	74	0	151
N2	0	159	0	148	0	302
Ms1	135	0	105	0	159	0
Mc1	135	0	105	0	159	0
Mc2	-	-	210	0	318	0
Mc1N1	-	-	105	74	159	151
Mc1N2	-	-	105	148	159	302

Annual rates of fertiliser N for N1 and N2 were respectively 125 and 175 kg N ha^{-1} year^{-1} for Exp 13, and 100 and 200 kg in Exp 14. In Exp 15 total rates were higher (see below). The annual application of slurry manure in Exp 13 (Ms1 and Mc1) was 55 Mg wet slurry ha^{-1} year^{-1}. The rate was meant to represent the manure production at a stocking rate of about 2.5 cows ha^{-1} (LW per cow about 500 kg). In Exp 14 the planned manure rate was 60 Mg manure ha^{-1} year^{-1} for Ms1/Mc1 and 120 Mg for Mc2. In reality N rates from manure varied slightly, because of variable DM contents of manure. Manure and fertiliser were normally distributed over 2 cuts, one during the long and one during short rains. In Exp 15 more cuts were fertilised and manured, accounting for the higher precipitation and longer growing season in Kakamega (Chapter 2), resulting in higher annual rates. Surface applied slurry was distributed in a small band between Napier rows. Slurry for Mc was incorporated in furrows between Napier rows, and raked in within a few hours after application. Slurry was applied after weeding in Exp 13, and before weeding in Exp 14 and 15.

For methods of harvesting and sampling see Chapter 2. Samples of all replicates were analysed for contents of crude protein and ash. In Exp 15, two clearing cuts were excluded from results because of unintentional grazing after the second cut (dung pats were removed), resulting in 6 cuts being used for further analysis.

Slurry was sampled (several samples per application), and composition was analysed. But content of DM and ammonia N were only determined from 1988 onwards, and not in all samples. Average contents of nitrogen, phosphorus and potassium (K) in slurry manure (Table 13) varied from respectively 1.9 to 2.2%, 0.03 to 0.08% and 0.21 to 0.5%. Content of ammonia N varied from 18 to 33% of total N (if determined!). Content of OM matter was relatively lower in Naivasha slurries, while the C/N ratio was higher compared to Kakamega slurries (Exp 15). For comparison the composition of some solid manures in Africa (Onduru et al, 2008) and slurry and solid manure in the Netherlands (Anonymous, 2009) is also given.

Table 13 Average contents (%) of dry matter (DM) and organic matter (OM), and (in DM) contents nitrogen (N), estimated C/N ratio (based on 55% C in OM), % ammonia N (NH3-N), phosphor (P), potassium (K), calcium (Ca) and magnesium (Mg) for manure slurries used in Exp 13-15 (DM and NH3-N not in all samples!).

	DM	OM	N	C/N	% NH3-N	P	K	Ca	Mg
Experiment 13 (n=9)	12	6.3	2.2	13.3	26	0.5	4.1	1.0	0.58
Experiment 14 (n=5)	11.2	6.1	2.1	14.0	22	0.71	4.3	0.89	0.63
Experiment 15 (n=6)	7.7	5.6	2.2	18.1	33	0.39	2.7	0.39	0.52
Solid manure Africa*			0.2-2.5			0.1-0.8	0.3-3.3		
Slurry Netherlands	8.6	6.4	5.1	8	50	0.81	6.0		0.15
Solid Netherlands	24.8	15	2.6	13	19	0.72	2.93		

5.2 Results

Results of soil analysis show that the initial pH of 8.1 after ploughing of pasture in 1982 (Annex 1) decreased substantially to between 7.2 and 7.6 at the end of Exp 13 in 1990, depending on the treatment. The initial soil carbon (C) and N contents of respectively 1.7% and 0.17% decreased without fertiliser N, probably also because experiments started much later (see before). However, contents increased with fertiliser N and in particular with manure (for Mc1 to 1.95% carbon and 0.23% N).

Table 14 Results of soil analysis (layer 0-20 cm) in 1990 at the end of Exp 13 for carbon (C), nitrogen (N), C/N ratio, pH, phosphorus (P), calcium (Ca), and average annual soil nitrogen supply (SNS in kg ha^{-1} ; SNS=N yield without N).

Experiment/treatment	C	N	C/N	pH	P	Ca	SNS
	%	%	ratio		ppm	meq %	
Exp. 13 (1990)							
N=0	1.17	0.15	7.8	7.2	32	23	118
N1+N2	1.84	0.18	10.2	7.5	32	20	
Ms1	1.93	0.23	8.4	7.5	44	25	
Mc1	1.95	0.23	8.5	7.6	40	24	

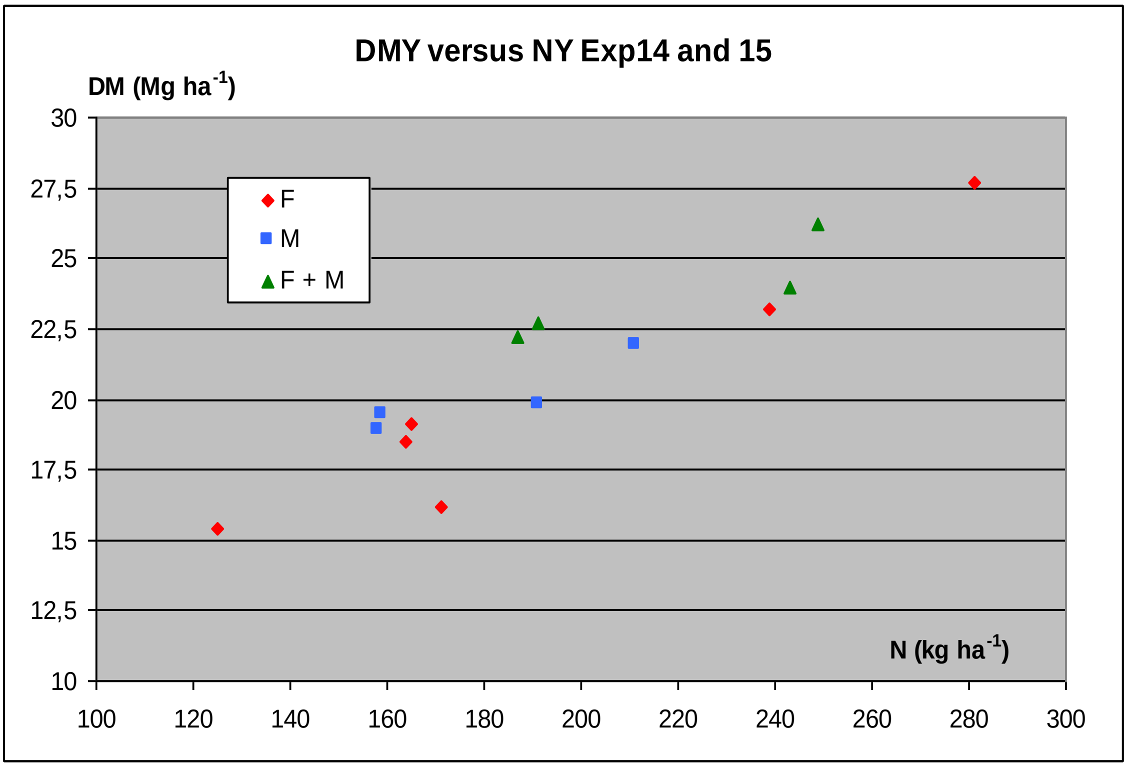
Annual DMY and NY for Exp 13-15 varied from respectively 12 to 27.7 ton and 118 to 281 kg N per ha (Table 15). Yields increased substantially with fertiliser and less with manure N. In Exp 14 and 15 increases were relatively lower for the high N rates, especially for manure N, but also for fertiliser N. In Exp 14 and 15, yields were highest for the combinations of fertiliser and manure, except in Exp 15 for N2. Highest yields were obtained in Exp 15 in Kakamega, probably mainly due to a higher NY without N, higher N rates and better growing conditions (Chapter 2 and Table 14). Contents of CP were low, due to long average CI, in particular during the last 2 years of Exp 13 (see Table 15 and before). Both, fertiliser and manure application tended to increase crude protein (CP) content of grass, but not significantly.
The apparent nitrogen efficiency of fertiliser N (ANE) varied from 25 to 46 kg DM kg^{-1} N, the ANR from 27 to 54%. The highest values were calculated for the lower fertiliser rates. The ANE of incorporated manure varied from 18 to 23 kg DM kg^{-1} manure N and ANR from 13 to 33%. For surface applied manure ANE varied from 0 to 24 kg DM per kg manure N and ANR from 3 to 27%. In Exp 13, ANR values for manure N increased during the last 2 years 1988 to 1990 (Table 15), probably due to residual effects, in particular for surface applied manure. At the same time ANR of fertiliser N decreased, probably due to drought and resulting increase in cutting age (Table 15). When for Exp 14 and 15 the ANE and ANR values for combinations of manure and fertiliser N are calculated (McN1 and McN2; given in red), using the ANE and ANR values for N1 and Mc1, results are more or less additive or MCN1 of Exp 14 (ANE and ANR of respectively 36 kg DM kg^{-1} N and 39% for MC1N1 and of 28 kg DM kg^{-1} N and 29% for Mc1N2). However, for McN2 of Exp 14 and for Exp 15, derived ANE and ANR are higher, indicating a less efficient N utilisation for the fertiliser-manure combinations (ANE and ANR of respectively 35 kg DM kg^{-1} N and 30% for Mc1N1 in Exp 15).
The fertiliser equivalencies FE of incorporated manure N varied from 39 to 80% (derived from ANE) and from 29 to 61% (derived from ANR). The lowest values were for the high manure rates of Exp 14 and 15. The FE for surface applied slurry manure varied from 0 to 53% derived from ANE and from 7 to 50% derived from ANR, the high values being for Experiment 13.

Table 15 Annual yield of dry matter (DMY in Mg ha^{-1}) and nitrogen (NY in kg ha^{-1}) and CP content (%) for Experiments 13-15. The apparent nitrogen efficiency (ANE in kg DM kg^{-1} applied N) and recovery (ANR in %) and the fertiliser equivalent (FE in %) of manure N and the LSD (P<0.05) are also given. Between brackets results of Exp 13 for 1985-88 only. *In red/Italic results for Exp 14 and 15 when using ANE and ANR values from N1 and Mc1.* See further text.

Treatment	**DMY**	**NY**	**CP**	**ANE**	**ANR**	**FE (ANE)**	**FE (ANR)**
Exp 13 (24 cuts; average CI of 76 days, 100 days from 1988 to 1990)							
Control	12	118 (147)	6.2				
N1	17	180 (216)	6.6	45	54 (56)		
N2	18.8	214 (246)	6.7	43	53 (57)		
Ms1	15.1	155 (197)	6.4	24	27 (22)	53 (46)	50 (39)
Mc1	15.6	162 (160)	6.5	27	33 (31)	60 (55)	61 (55)
LSD	4.1		0.7				
Exp 14 (7 cuts, average CI of 88 days)							
Control	15.4	125	5.0				
N1	18.5	164	5.4	41	51		
N2	19.2	165	5.3	25	27		
Ms1	15.4	132	5.3	0	7	0	14
Mc1	18.9	158	5.2	33	31	80	61
Mc2	19.5	159	5.0	19	16	46	31
Mc1N1	22.7	191	5.2	40 *(36)*	36 *(39)*		
Mc1N2	22.2	187	5.2	27 *(29)*	24 *(29)*		
Exp 15 (6 cuts, average CI of 61 days, excluding 2 grazed cuts)							
LSD	2.9	33	0.4				
Control	16.2	171	6.6				
N1	23.2	239	6.3	46	45		
N2	27.7	281	6.4	38	37		
Ms1	17.9	175	6.1	11	3	24	7
Mc1	19.8	191	6.0	23	13	50	29
Mc2	21.9	211	6.1	18	13	39	29
Mc1N1	24.0	243	6.3	25 *(35)*	23 *(30)*		
Mc1N2	26.2	249	5.9	22 *(31)*	17 *(26)*		
LSD	3.1	35	0.6				

The NY without N (SNS) was higher in Kakamega than in Naivasha (respectively 118, 125 and 171 kg N ha^{-1} for Exp 15, 13 and 14). See further discussion.
Figure 13 shows the relation between DMY and NY (similar to quadrant 2 in Figure 6) for various rates of fertiliser N and incorporated manure N of Exp 14 and 15. The DMY at the same NY tends to be higher with manure N, also for the combinations with fertiliser N. This difference was hardly or not visible in Exp 13 (results not shown).

Figure 13 Annual dry matter yield (DMY) plotted against N yield (NY) of Exp 14 and 15 for N from fertiliser (F), incorporated manure (M) and the combination (F+M) at various N rates.



6 Scenarios for use of N from manure, fertiliser and Desmodium at farm level

On smallholder (mixed) farms in East Africa use of fertilizer N (and manure use) is often restricted to food and commercial crops, an important reason being the comparatively high costs and at times non-availability of fertilizer. Also on intensive farms, forage from Napier grass often comprises less than 50% of the roughage supply. In the highlands grass strips can also contribute to soil conservation or the cultivation of otherwise less productive road sides (Gosh et al, 2009). Forage legumes are grown in limited quantities on some farms, with variable success, its management and use being more demanding (see Chapter 7.3).

To explore the potential to improve soil and animal productivity a scenario approach will be used. Because Napier grass is the subject of this study, scenarios with Napier grass get most attention. But in some scenarios also other forages and crop residues are included, more reflecting mixed farms. Crop residues are represented by maize stover. In the scenarios cutting regime and nitrogen utilisation vary, using N from various sources (fertiliser, manure and N derived from Desmodium). To develop the scenarios, the models for DMY, and for ash, CP and dOM content from Tables 3 and 7 are used. The models are copied in Table 16a. However, to calculate potential stocking rates (SR) per ha for N=210 (in Table 16c; SR is DMY divided by annual DM demand per cow plus young stock), and manure and milk production, DMY is corrected downwards to an average annual soil N supply of 100 kg N ha^{-1} $year^{-1}$ if averaged over cutting regimes given in Table 16c. The models in Table 16a are derived from short during experiments only, and result in a high SNS if used to predict annual NY, also because of relatively fertile soils. The predicted NY derived from predicted DMY and CP% for 210 growing days for 2 rainy seasons combined is 162 kg N ha^{-1} $year^{-1}$ (respectively 206 and 128 kg N for the 5 and 16 week CI). The correction results in a yield reduction of about 41% without N application, and of 25% with N for N=210; see further below). This assumes that SNS on many practical farms is lower than indicated by the models for the experiments discussed, experiments being conducted in a situation with initially often relatively fertile soils (partly also after ploughing of grass) and mainly relatively short during experiments (see Chapter 2). It is also lower than for example indicated by N yields of Napier grass on zero-grazing farms monitored in Western and Central Kenya by Wouters (1987; if applied fertiliser N is accounted for at an ANR of 50-60%!), probably also due to residual effects of a pasture phase or regular manure application. In Exp 11 and 13 average SNS over a period of 5 year was about 100 kg N ha^{-1}. An SNS of 100 kg N ha^{-1} is still higher than often found on arable land on farms applying little or no fertiliser, exploiting largely existing soil fertility (see for example Rufino et al, 2006).

Table 16a Models for the relation of dry matter (DMY; Mg/kg ha^{-1}) and crude protein, ash and dOM content (%) with age (CI in days) and N rate (kg ha^{-1}) of Exp 1-4 and 6-7 (n=326. See further Table 3a and 7 and text, also for abbreviations.

Model	MSres	R^2	Intercept	CI	1/CI	N	CI*N	1/CI*N
DMY	**0.43**	**73**	-0.8929	0.07832		0.05799		-1.693
CP	**1.2**	**74**	5.432	-0.01917	240	-0.02068		2.538
ash	**1.41**	**43**	18.63	-0.0217	86.4		-0.000286	
dOM	**3.77**	**72**	75.72	-0.1266	198.5			

Scenarios are calculated for 1 ha farms for a total growing season of 210 days, combining 2 rainy seasons, and accounting for moisture retained in the rooting zone (Jaetzhold and Schmidt, 1983), leaving a total dry period without forage production of 155 days. A growing season of 210 days is possibly longer than in parts of Central Kenya, but shorter than in Kakamega and Kisii in western Kenya. However, results can be adapted to the length of the growing season (by multiplication). Live weight of dairy cows, representing breed, is set at 400 kg, the calving interval at 450 days, and the dry period at 100 days. It is assumed that there are 0.8 head of young stock (calves sand heifers) per mature cow. Forage required, milk yields and nutrient excretion are derived from a model calculating potential milk yield from DM intake and feed quality (Zemmelink et al, 2003; Snijders et al, 2009). Energy and crude protein requirements are derived from NRC (1989). Milk yield and other results are calculated for the most limiting nutrient, either crude protein or energy intake (energy requirements based on dOM). If degradation rates of forage components are also known, while using more sophisticated models, prediction of milk yield probably improves (Muia, 2000; Rufino, 2008). Therefore, results given are indicative, giving trends.

Scenarios explored
To explore specific effects of Napier management on dry matter yield, and on manure production, fertiliser requirements and milk production in particular, milking cows are supplied with Napier grass only in most scenarios (see further below). Scenarios 1-8 (Table 16b) explore variation in DMY for single cutting regimes only (CI of 5 to 16 weeks) and for 4 N rates (N rates of 0 (N=0), 35 (N=35) and 70 (N=70) kg N ha^{-1} cut^{-1} or 1 kg N per ha^{-1} growing day^{-1} resulting in 210 kg N ha^{-1} $year^{-1}$: N=210). For N=210, and for scenarios 1 (for N=35) and scenario 5 (for N=70; see below), also effects on manure production, fertiliser equivalent N requirements and effects on milk production are explored. To obtain annual N application, N rates per cut need to be multiplied by cut number, resulting for N=35 in declining annual N rates of respectively 210 to 66 kg N ha^{-1} for the 5 and 16 week cutting interval respectively (for 6 and 1.9 cuts during a growing season of 210 days!). For a CI of 5 and 10 weeks respectively, scenario 1 for N=35 and scenario 5 for N=70 equal the scenarios for N=210. Scenarios 9 to12 combine cutting regimes, respectively a CI of 7 weeks for grass to be supplied during the rainy season, and a CI of 14 weeks to reserve grass for the dry season of 155 days, in scenario 9 for pure Napier grass (7+14) and in scenario 10 (ND 7+14) for a Napier/Desmodium mixture. Yield and quality of Napier/Desmodium are based on well established mixtures, and are derived from Exp 11 (see Chapter 4). Scenario 11 (4C 7+14), explores the effect of additional concentrates for scenario 9 (4 concentrates $lactationday^{-1}$ to milking cows). To account for mixed farms in practical situations scenario 12 (4C Mixed) is included, also with 4 kg concentrates $lactationday^{-1}$. Scenario 12 combines feeding of Napier cut at 7 weeks during the rainy season (N=210), with, during the dry season, mainly maize stover, and in addition, limited amounts of Lucerne hay and fodder tree leaves and Napier cut at 14 weeks. In scenarios 5-10, for grass of 10 weeks and older, young stock, and for the oldest grass also dry cows, get a small amount of concentrates, in particular to cover lack of protein. In scenario 11 milk yield per ha is lower (see below), because about 30% of the area of 1 ha is used to cultivate maize, yielding 1771 kg DM as maize grain (the total annual biomass yield for 2 maize growing seasons is set to 15 t DM ha^{-1} of which 40% is grain). Biomass yield for Lucerne and fodder tree leaves is set to respectively 15 and 5 t ha^{-1}, using respectively about 7 and 17% of the area (no further details given). Quality of forages and supplements used other than grass is given in Table 16b.
The fertiliser N required, accounts for the use of all manure on Napier (except in scenarios 10 and 12). It is assumed that 40% of excreted urine N is lost during collection and 2 days storage in a concrete and covered pit, and 10% of dung N (storage as slurry, or separate storage of dung and urine; Snijders et al, 2009). Manure is incorporated with an ANR of 50%, assuming that the recovery of manure N increases in time with regular manure application, from an initially much lower ANR during the first years (Chapter 5). In reality, on mixed, less specialised, smallholder farms, a substantial part of manure may be applied to food and commercial crops (see below). This is also an option in legume scenario 10 (if nutrients required other than N are provided by fertiliser) and in the mixed scenario 12 (only 0.54 ha Napier grass and limited legumes). In reality, combinations of scenario characteristics may be preferred in practice.

Table 16b Composition of feeds used (in % of dry matter=DM; OM=organic matter; OMD=organic matter digestibility; CP=crude protein; TDN=Total Digestible Nutrients; P=phosphorus; K=potassium). Some of the sources used: Kariuki, 1998; Muia, 2000; Snijders et al. 1992c; Mwangi et al., 2004; Zemmelink et al., 2003. * Grass in the Napier/Desmodium mixture, contains 30% of total CP.

Forages	**DM**	**OM**	**OMD**	**CP**	**TDN**	**P**	**K**
Napier + 50% Desmodium 7 wks*	17	85	65	14	57	0.18	2.7
Napier + 50% Desmodium 14 wks*	20	87	59	10	53	0.15	2.5
Maize stover	33	90	55	5	50.8	0.10	1.25
Lucerne wilted (or hay)	30	86	65	18	57.2	0,3	3
Fodder tree leaves	25	88	75	22	67.3	0.30	2.50
Concentrates/supplements							
Dairy meal	90	93	88	16	80	0.60	0.60
Cotton seed cake	93	90	80	38	78	1.25	1.35

Scenario results
If from scenario 1 to 8 (Table 16c), cutting age increases, annual DMY of Napier for 2 growing seasons combined (210 days) first increases (from about 15 to 21 Mg ha^{-1} for N=70), but subsequently stabilises (except for N regime N=210). However, it should be noted that the total N rate for the 5 week cutting regime (over a growing period of 210 days) is 210 kg N ha^{-1}, but only 131 kg N ha^{-1} for the 16 week cutting regime, the N rate per growing day being much higher for the short cutting regime

(constant for N=210). Moisture probably also becoming more limiting at higher yields with N. It is probably recommendable to adapt N rates to target yields per cut (and/or harvest age), for example for older cuts to be reserved for dry periods, provided that the optimum for yield and quality, and drought risk are taken into account (the ANR in drought affected Exp 10 was only 30%, although part of the residual N may be recovered at a later stage; see Chapter 7.1). Stocking rate and production of manure N increase with cutting age (for N=210), because of the lower intake of older grass, while N (nutrient) content of manure decreases (results not given). Without concentrate supplementation, annual milk yield ha^{-1} at N=210 is highest for the 6 week CI, decreasing to only 1266 kg at the 16 week CI due to the combined effects of lower feed intake and quality if grass ages, while N input from concentrates increases to supply sufficient protein to young stock in particular (see before; N in concentrates derived from CP divided by 6.25). At a CI of 5 and 10 weeks for respectively N=35 and N=70, predicted milk yield is equal to the 5 and 10 week CI for N=210 (see also Figure 14).

Table 16c Annual dry matter yield (DMY) per scenario (1-12), stocking rate (SR in cows ha^{-1}), and available manure N (MN), N import from concentrates (CN) and fertiliser N (FN; all in kg N ha^{-1}), annual milk yield (M in kg ha^{-1} and increase in milk yield kg^{-1} applied N (in brackets for N=105), from forage only and with concentrates (scenario 11-12). See further text, also for scenarios and abbreviations.

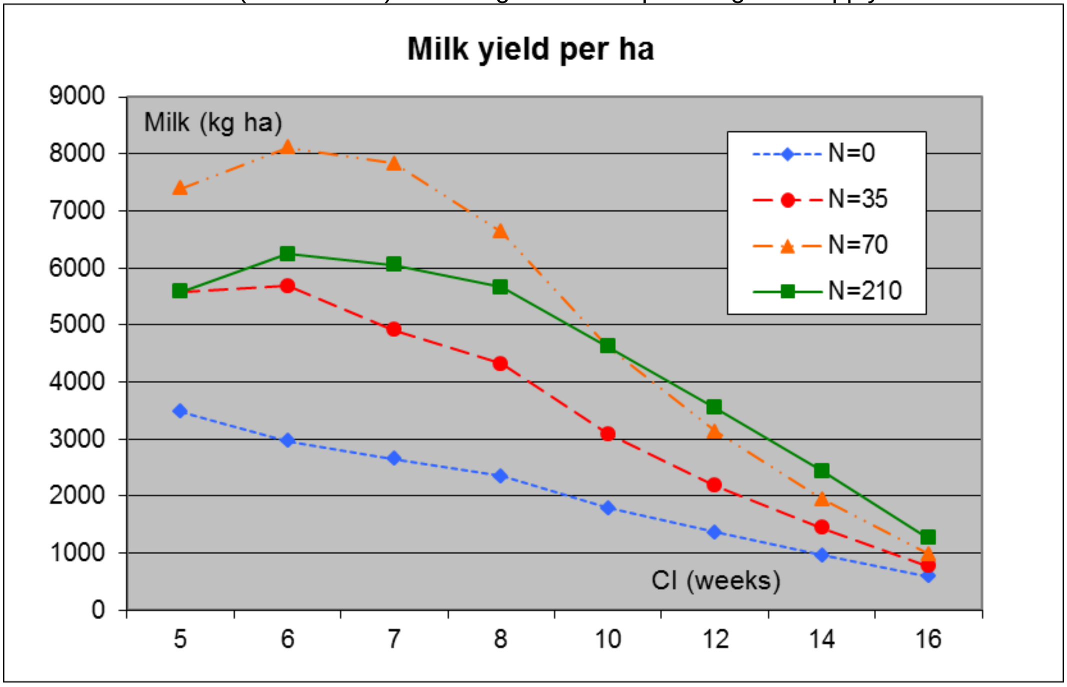
Scenario	N=0	N=35	N=70	N=210	SR	CN	MN	FN	M	Milk kg^{-1} N
1 (5)	11.09	13.11	15.13	13.11	1.81	0	121	149	5586	10 (10.9)
2 (6)	11.98	15.08	18.17	15.7	2.29	0	138	141	6238	13.1 (15.2)
3 (7)	12.62	16.14	19.65	17.54	2.63	0	148	136	6055	12.3 (14.5)
4 (8)	13.1	16.74	20.39	18.93	2.94	5	156	132	5659	10.4 (14.4)
5 (10)	13.77	17.32	20.87	20.87	3.55	26	170	125	4619	5.4 (12.1)
6 (12)	14.21	17.53	20.84	22.16	3.93	43	173	124	3542	0.3 (9.5)
7 (14)	14.53	17.59	20.64	23.08	4.36	65	177	122	2434	-5 (6.5)
8 (16)	14.77	17.59	20.4	23.78	4.76	83	176	122	1266	-10.6 (3.5)
9 (7+14)				19.6	4.29	25	214	103	6708	
10 (ND 7+14)	17				3.72	21	295	0	6016	
11 (4C 7+14)				19.6	4.62	192	296	62	17137	
12 (4C Mixed)				12.8	2.96	99	195		11058	

For combinations of cutting regimes (7 weeks for 2 rainy seasons and 14 weeks to reserve grass for 2 dry periods; scenarios 9-12), expected annual milk yield per ha is slightly higher in scenario 9 compared to scenario 10 (Napier/Desmodium), because of the lower DMY and dOM of Napier/Desmodium. With supplementation of 4 kg concentrates lactation day^{-1}, annual milk yield strongly increases, from 6708 kg in scenario 9 to 17137 kg milk ha^{-1} in scenario 11, because of a much higher milk production per cow and a slightly higher SR. Concentrate use increases to 31.7 kg concentrates per 100 kg milk produced (28.7 kg concentrate DM kg^{-1} milk). Annual N input from concentrates also strongly increases from 25 to 192 kg ha^{-1} (of which 32% derived from cottonseed cake). Total N import from fertiliser and concentrates combined is much higher in scenario 11 (210+192=402 kg N ha^{-1}) than in scenario 9 (210+25=235) kg N ha^{-1}; results not given in Table 16c). In scenario 10, annual N "import" through symbiotic N fixation by Desmodium is 169 kg N ha^{-1}, assuming that 75% of Desmodium N (being 70% of total forage N) is derived from symbiotic N fixation. In mixed scenario 12, stocking rate and milk yield are substantially lower than in scenario 11, because of the land used for production of maize grain and lower DMY from maize stover and fodder tree leaves in particular (see before).
When the N rate is decreased from 1 to 0.5 kg N ha^{-1} day^{-1} (N=105) predicted milk yield for the 6 week cutting regime is reduced from 6238 to 5083 kg ha^{-1} $year^{-1}$. Milk yield per ha for the 6 week cutting regime and N=210 decreases to 4585 kg ha^{-1} $year^{-1}$ if for poor soils the average SNS is reduced to 50 kg N ha^{-1} $year^{-1}$, and increases to 7891 kg ha^{-1} $year^{-1}$ for and SNS of 150 kg N^{-1} ha^{-1} year (assuming that Napier quality remains the same). For large cows with a LW of 600 kg, potential annual milk yield ha^{-1} decreases for the same supplementation rate per lactation day, but increases for similar supplementation rates per kg milk, also because higher supplementation decreases (relative) forage intake (results not given). When, for similar supplementation rates per kg milk, target annual milk yield ha^{-1} remains at the same level as for scenario 11, the ratio between young stock and mature cows can

be reduced. However, it should be noted that potential grass and milk yields and growth rates of young stock may be lower than predicted from experiments and feed tables, depending on environmental conditions and management (see also discussion).

Indicative effect of fertiliser N on milk yield
Without use of manure in scenario 1-8, and for N=210 (1 kg N growing day^{-1}), increase in milk yield per kg fertiliser N varies from 13.1 kg milk kg^{-1} N at the 6 week cutting interval to -10.6 kg at the 16 week cutting regime (Table 16c). However, at half the N rate (105 kg or 0.5 kg N growing day^{-1}), the effect of N improves substantially (3.5 to 15.2 kg milk kg^{-1} fertiliser N; no further details given). There is an optimum around cutting ages of 6 to 8 weeks. If manure N is included without costs, milk production per kg N increases (see lower fertiliser N requirements with manure in Table 16c). But in reality, also the use of manure N goes at a cost, even if it is not paid for, because use on grass prevents use and yield increases on other crops. Alternatives for fertiliser and manure N are the use of forage (scenario 10 in Table 16c) and grain legumes. Assuming prices of 0.35 and 2.10 $ kg^{-1} milk and fertiliser N respectively, an increase of at least 6 kg milk kg^{-1} fertiliser N would be required to cover the costs of fertiliser N only. In reality also other costs have to be made, including costs for other nutrients and for labour.

Figure 14 Potential annual milk yield (kg ha^{-1}) from Napier grass only for N rates (0, 35, 70 kg N ha^{-1} cut^{-1} and 210 kg N ha^{-1} = 1 kg N ha^{-1} growing day^{-1}) and cutting intervals of 5 to 16 weeks (CI in weeks). Stocking rate is adapted to grass supply. See further text.

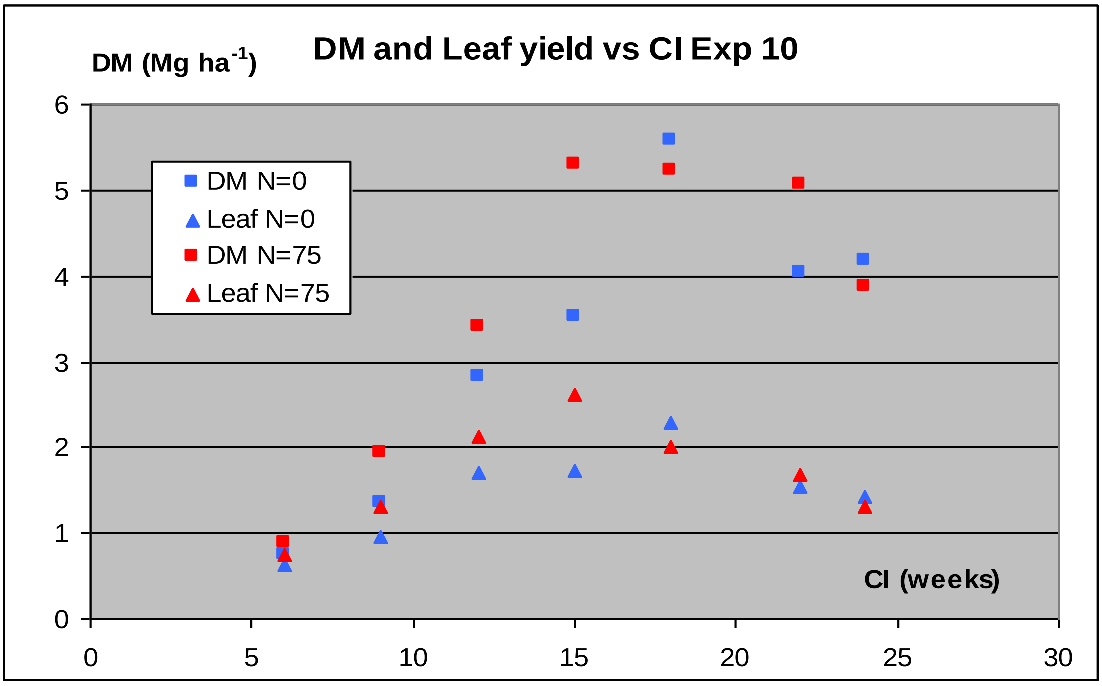


7 Discussion

7.1 Yields, morphological characteristics and nitrogen utilisation

Results of Exp 11-12 and Exp 13-15 are partly discussed in Chapter 7.1 (nitrogen utilisation), and further in respectively Chapters 7.3 and 7.4. Dry matter yield increased with age and N rate. But the variation between experiments is large, due to differences in soil N supply (see Table 4a, 15 and below). But also differences in moisture supply and temperature probably play a role. In Exp 4, DMY was much higher than in Exp 3 (beyond a CI of 6 weeks), despite a similar design, probably mainly due to the fertile soil after ploughing of pasture (Annex 1; Schreuder et al, 1993). Season is significant if included in Eq 1.1 in Table 3a (P<0.016), predicted DMY being about 1 Mg ha^{-1} higher during the dry season S2, but higher temperatures and variation in precipitation and residual soil moisture (not well known), also because of overlap between seasons, complicate the use of the parameter season (Chapter 2). When comparing cutting regimes over the same overall harvest period, predicted LY and NY tend to peak at a cutting age of approximately 6-7 weeks, subsequently decreasing, while DMY continues to increase, also depending on N availability. With similar N rates per growing day for all cutting regimes, predicted DMY continues to increase slightly to a CI of 18 weeks (Table 16c, N=210). Both, nutrient and moisture deficits, probably play a role in stabilising yield, moisture utilisation (when based on harvested forage) improving if N is less limiting (for N=210). Experiment 10 (1 cut only) was conducted under severe drought. Nitrogen utilisation was poor and varied much. DMY and LY increased at a relatively low rate, peaking at about 15 weeks, and decreasing subsequently (Figure 15; see also ANR below).

Figure 15 Dry matter and leaf yield (in Mg DM ha^{-1}) of Exp 10 plotted against cutting age for N rates of 0 and 75 kg N ha^{-1}. The design of Exp 10 was similar to Exp 1, but results are not reported in Chapter 3 because extreme drought resulted in loss of plants (yields of 1 cut!).



In Exp 8 several cutting regimes were compared during 3 years, including dry seasons. The results indicate that the cumulative NY was always higher for the shortest cutting regime A (average CI of 10.4 weeks), while the DMY yield was highest for regime D (starting with a long CI after a clearing cut at the start of the rainy season (Table 2b; Figure 3a, b). The yield decline in the third year was relatively lower for regime D, possibly due to deeper rooting and a reduced drought risk, but also use of residual, earlier immobilized, N may contribute (see later).

Dry matter yields in the present experiments are in the same range as results reviewed by Boonman (1993) for East Africa and Primavesi et al (2004) in Brazil, but lower than measured by Vicente

Chandler et al (1974) in Puerto Rico under more favourable growing conditions. Variation in soil fertility and moisture supply are large in Kenya (and East Africa) and can result in large variation in Napier yield and quality (Wouters, 1987; Boonman, 1993; Kariuki 1998). In farmer and researcher guided experiments on farms in 5 districts of Kenya (Wouters, 1987), average annual yields (average over 3 years for farms per district), varied from 11.4-25.4 Mg DM and 108-306 kg N ha^{-1} on farmer guided plots (A plots) and from 13.5-21.8 Mg DM and 160-281 kg N ha^{-1} on researcher guided plots (B plots, B plots only with fertiliser N at 75, 100 and 100 kg ha^{-1} $year^{-1}$). On A plots yields were significantly higher than on the B plots in Kakamega (precipitation of about 1750 mm), also due to heavy manure application, but significantly lower in Kilifi (precipitation about 800 mm and sandy soils). The average cutting interval varied from about 70 days (respectively 68 and 71 days for A and B plots) in Kakamega, to about 90 days on A plots in Meru and Kilifi. Variation was much larger for individual farms and years. Assuming that 50% of applied N on B plots is recovered (see Table 5 and below), average annual soil N supply (SNS) would vary from 114 to 235 kg N ha^{-1} $year^{-1}$. These relatively high values are probably also due to residual soil fertility from previous pasture and/or manure application (yields tended to decrease; see below).

Dirven (1977) estimates that it takes about 20 days after harvest of tropical grasses to reach a closed leaf surface. Also results of Exp 6 and 7 and the models for DMY in Table 3 (and changes in tiller numbers) indicate that initial growth rates after cutting are low until about 2-3 weeks (and longer for Eq 1.2, including also long dry periods) . This suggests that for practical purposes harvest ages below 4-5 weeks may be to**o** short under the conditions of these experiments. The effect of heavy preceding cuts and drought is not clear. Regrowth may be depressed initially (first week?), also depending on the amount of green leaf left after cutting, but additional reserves (root/stubble) and deeper rooting may have a positive compensating effect subsequently, also depending on moisture supply.

Content of dead leaf is minimal until an age of about 6 weeks, the subsequent increase varies, surpassing 30% during the dry season at very long CI in for example Exp 8. Loss of dead leaf is not determined, but variable quantities of dead leaf were seen on the soil below grass, and this has possibly contributed to increase variation in measured content of dead leaf. Leaf loss (and loss of plants) is possibly also the cause of the decrease in DM yield in Exp 10, but there was also some new leaf regrowth with arrival of rains (results not given). This probably indicates the relative sensitivity of green and dead leaf% as indicators for quality characteristics (compared to grass height; see further Chapter 7.2).

In Exp 4, tiller numbers per plant increased with N at the 6 week CI (from 128 for N=0 to 187 for N=100), but not anymore at 9 weeks and older. Tiller number strongly decreased with cutting age (181, 93 and 44 tillers at ages of resp 6, 12 and 18 weeks; results derived from Van der Kamp, 1986). The increase in tiller number with N is also found by for example Nyambati et al (2010). In Exp 6, the tiller number of the re-growth, one week after the last cut, was much lower for the 12 week than for the 6 week cutting regime (Annex 6), without a clear N effect at this stage. These effects on tiller number probably implicate that at younger age N stimulates new tillers and leaf development. At older age some young tillers (with a relatively high leaf%) may get lost, while the positive effect of N on stem yield becomes relatively more important, also because of leaf death, and concordant with the peak in LY (and decreasing NY).

Tables 5 and 15 and Figure 6a and b indicate more or less linear N effects at modest N rates, also for separate cutting intervals. Yields were higher in Exp 4 than in Exp 3, but trends were similar (but variable, probably due to variable soil fertility; Annex 3a). The deviating DMY and NY for the 15+3 week CI of Exp 3-4 (Figure 6a), are possibly due to variation in soil fertility (despite blocking) and/or errors (see further Annex 3). When cutting regimes are compared over the same growing period, NY tends to decreases with cutting age, but only after peaking first at a CI of 5-6 weeks in case of N application (Figure 6c and discussion later), in concordance with changes in LY.

Models for yields, CP and ash content, including models for all experiments.
Models in Table 3 predict DMY, and in particular LY, rather well. The models do not account for residual effects of fertiliser N and cutting age (Chapter 2). It implies that models may underestimate or overestimate effects of N on yields, depending on cutting management and N rate (see residual effects below).
The prediction of DMY derived from grass height only is rather good for Exp 1-7 (Eq 1.5 in Table 3), and improves if N application is included. But the prediction is less good if growing conditions vary

substantially (Eq 1.6). It should be also noted that plant(ing) density was similar for experiments concerned. In practice plant density may vary due to variable planting arrangements or plant loss due to for example drought and (soil) nitrogen supply. So when using the models to estimate DMY, for example using a measuring stick (see later), it is necessary to validate relations for deviating conditions.

When, to account for variation in soil N supply, the NY without N application (=NYN0; per cut and replicate) is included in models as a co-variant, the prediction of DMY, LY and NY (MSres and R^2) improves substantially. Models for the prediction of DMY and NY with the parameter NYN0 for dataset A1 (n=326) are given below:

DMY= -0.3512+0.0163*CI +0.09061*N -2.281*N/CI +0.009343*NYN0 -0.0004784*N*NYN0 +0.0008094*CI*NYN0 (MSres=0.31; R^2=91; P<0.001; **Eq 1.1.1**)
NY= 7.191 -302.7/CI +0.5982*N +0.9056*NYN0 -0.002513*N*NYN0
(MSres=37.2; R^2=91; P<0.025; **Eq 1.7.1**)

The resulting high value for R^2 masks that the variation without N is excluded. However, the strong improvement compared to Eq 1.1 and 1.7 in Table 3 for MSres indicates that there are probably important differences in soil N supply between experiments and plots not accounted for by blocking and REML as used in models (see also Table 5 and Annex 3a). But the use of the NY without N application supposes that the NY without N can be estimated sufficiently accurate. The estimation of NYN0 also becomes more complicated if there is a large variation in soil fertility within and between fields (Zingore et al, 2007).

Table 17 gives prediction models for results of samples available from all experiments (Exp 1-15), including treatments with manure application (compare to Table 3). Sample number is highest for DMY (n=1802), but lower for LY, NY and ash content. The contribution of surface applied manure (NMs) is only included if significant (P<0.05 for Nms in Eq 1.2.1). Models for CP are not included because of a low variation explained (despite a fair MSres and prediction of CP%), probably because (substantial) residual effects of manure N (Chapter 2 and 5) are included. CP% is very sensitive for N supply at young age in particular (see before).

Table 17 Relationship between DMY and LY (Mg ha^{-1}), NY (kg ha^{-1}) and ash (%) with age (CI in days) and N rate (kg ha^{-1}) from fertiliser and/or manure (NMinc=incorporated; NMs=surface applied; in kg ha^{-1}). Experiments, MSres, R^2, P and n (datasets A4 and A5) are also indicated. See further text, also for abbreviations, and Chapter 2.

Eq	**DMY**	**LY**	**NY**	**NY**	**NY**	**Ash**
	Eq 1.2.1	**Eq 1.4.1**	**Eq 1.8.1**	**Eq 1.8.2**	**Eq 1.8.3**	**Eq 3.2.1**
Exp	1-15	1-15	1-15	1-9/13/15	1-15	1-15
Constant	6.138	4.03	80.63			20.11
CI	0.008727	-0.007615	-0.1492	10.77	13.48	-0.03258
1/CI	-155.5	-93.13	-1616			113.8
N	0.05831	0.01251	0.4974			-0.02852
CI.N			-0.00145			
N/CI	-1.941					
NMinc	0.01331	0.006357	0.1237			-0.01549
N*NMinc	-0.0008525	-0.0003067	-0.0102			
NMs	0.007093	0.004135				-0.02263
LY				19.86	18.36	
MSres	1.54	0.2	91.5	59.7	54.7	1.99
R^2	81	87	89	92	94	76
P<	0.001/0.05	0.001		0.001	0.001	0.001
n	1802	1539	1368	573	1143	1309

Beyond a cutting interval of about 10 weeks, predicted DMY derived from the model in Eq 1.2.1 without manure application (Table 17; and Eq 1.2 in Table 3; harvest period of 18 weeks) is increasingly lower than from short during experiments with fertiliser given in Eq 1.1 (Table 3; DMY of

respectively 11.4 and 14.6 Mg ha^{-1} for the 18 week CI at a N rate of 1 kg day^{-1}). With an application of 0.75 kg incorporated manure N ha^{-1} growing day^{-1} (compare to Chapter 5) predicted DMY increases by app. 1.2 Mg ha at the 18 week cutting regime for Eq 1.2.1. The predicted contribution of surface applied manure N is approximately 50% of incorporated manure N (Eq 1.2.1). The predicted NY from Eq 1.8.1 (NMs is not significant) is lower for all cutting regimes than from Eq 1.7 (Table 3; on average respectively 96 and 78 kg ha^{-1}), despite the relatively high NY without N application in Exp 15 (Table 15). Lower predicted yields from Eq 1.2 and 1.2.1 are probably due to (average) lower N rates and long dry periods (resulting in long cutting intervals) if annual experiments are included (Exp 8, 11, 13 and 14 in particular) and also due to in time declining soil fertility (lower SNS in Exp 11 and 13). The NY over a growing period of 18 weeks peaks at a CI of 5 to 7 weeks, and subsequently gradually declines (by about 50% without N application and less with N; see also Figures 6a-c). At the short 4 week CI yield is also lower if annual experiments are included, possibly due to slower regrowth and model deficiencies (Eq 1.1 represents relatively more cuts with N application and on average shorter CI).
Predicted DMY and NY for long duration Exp 13-15 only (results not given) are lower compared to Exp 1-15, probably for the same reasons. But these models are not given, because residual effects disturb the comparison of fertiliser and manure N (models derived from single cut; see Chapter 2). The results given in Table 15 give a more reliable presentation of these effects.
Season is not included in models in Table 17 (and Table 3), but is sometimes significant, especially for DMY. For short cutting intervals predicted DMY tends to be higher during season 2 (warm dry season), possibly because of higher temperatures (moisture is not yet limiting), while for long cutting intervals predicted DMY is higher for season 1, possibly because of better moisture supply.
If included as a covariant, NYN0 is also significant for models in Table 17, improving MSres sometimes substantially (results not given).

Leaf content is important for quality characteristics, also in prediction models for CP and ash content (see further Chapter 7.2). A model with leaf yield only also predicts NY very well (Table 17). However, the use of LY in practice to predict NY is not very feasible.

Apparent N efficiency and recovery
The apparent nitrogen efficiency (ANE) increased with cutting age (Table 5). But ANE varied much, in Exp 1-7 from 21 to 40.1 kg DM kg^{-1} N if averaged over cutting ages up to 12 weeks, and more in Exp 12-15. ANE tended to decrease slightly at the highest N rate, in particular in Exp 14 and 15. Vicente Chandler et al. (1974) measured higher average ANE values, up to about 70 kg DM kg^{-1} N at the 90 day CI, probably due to more favourable growing conditions. In Exp 6 in Kakamega ANE reached about 60 kg DM kg^{-1} N at the 12 week CI, also under relatively good growing conditions.

The average apparent N recovery ANR of fertiliser N in Exp 1-4 and 6-7 (averaged over N rates and cutting ages), was approximately 53%, varying from 39% to 64% (Table 5), without a clear effect of N rate, and excluding residual N effects (see below and Annex 4). The variation was much larger for single cutting intervals (see below). In Exp 13, with fertiliser and manure application, ANR of fertiliser N was on average respectively 54% and 53% at the low and high N rate respectively (averaged over a period of 5 years; Table 15). In Exp 13 the ANR of fertiliser N tended to decrease marginally during the last 2 years (Chapter 7.4), probably partly due to periods with extreme drought, resulting in older cutting ages (see discussion before and below). However, at the same time ANR of manure N increased, in particular for surface applied N, probably due to increasing residual effects of organic N. For the lowest N rate of Exp 14 and 15, ANR of fertiliser N was in the same range (respectively 51% and 45%; lower on the fertile Kakamega site). In Exp 12, ANR of fertiliser N was 52%. But ANR of fertiliser N was only 33%, in a 2 year during cutting experiment with manure incorporation and fertiliser N application (results not reported; average CI of 102 days), and only 28% in drought affected Exp 10. Long cutting intervals and/or extreme drought have probably affected ANR in these experiments (results not given). A long CI may increase N immobilisation (see discussion below).

For separate cutting ages of Exp 1-4 and 6-7 ANR varies from 9-84%. The ANR was highest for the 4 week CI of Exp 6 in Kakamega (84% and 73% at respectively N=84 and N=168) and lowest for the 3 week CI in Exp 1 (13%). This may be due to lower leaf yields at very young and at older age (Figure 1) and to lower N contents at older age. In Exp 4 and Exp 6-7, nitrogen content of green leaf decreased by about 0.5% and 1% per week respectively (see also Table 4a; results not given). These results exclude a negative ANR and an ANR above 100% for the 15+3 week CI of respectively Exp 4 and Exp

3 (at N=50; results not given). These exceptional values are probably due to variation between plots (despite blocking) and/or other sources of variation, possibly including errors (Annex 3a).

In particular in Exp 8, 11 and 13 and 14 grass was sometimes cut at a very old stage during long dry periods in particular (in regime D of Exp 8 also during the rainy season; CI up to half a year), possibly depressing ANR, also depending on the rate mineralisation of earlier immobilised N from crop residues.

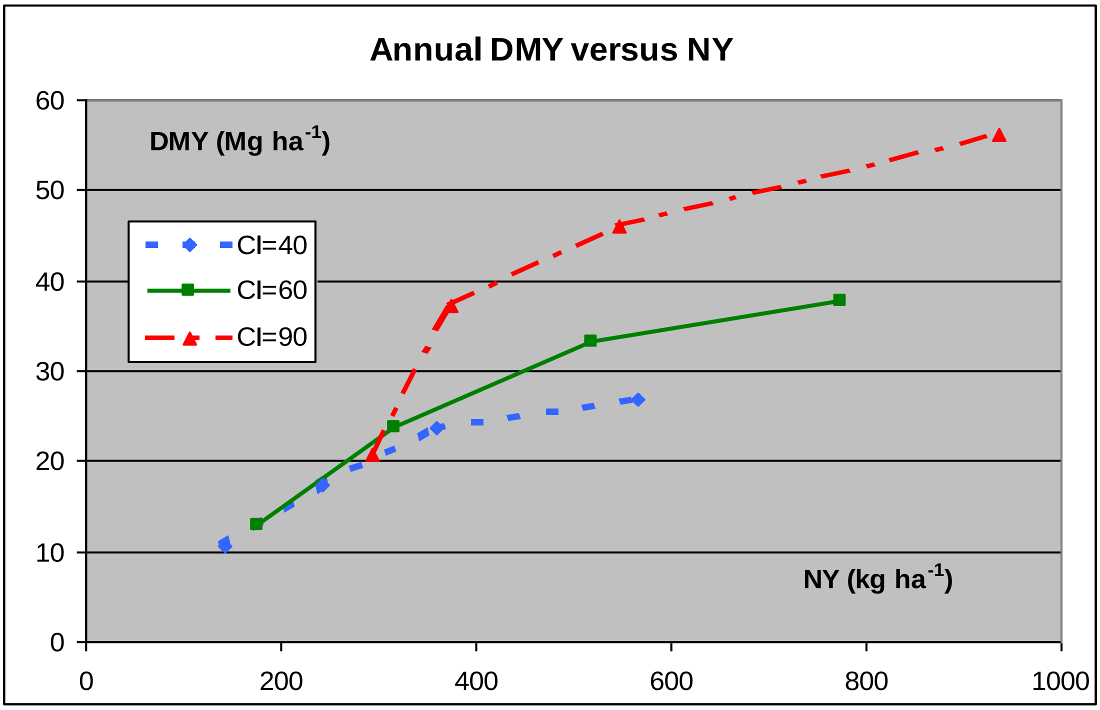
Model derived ANE and ANR. The predicted ANE for fertiliser N derived from the model in Eq 1.2.1 increases from 29 kg DM kg N^{-1} for similar N rates and CI to 48 kg DM kg^{-1} N if the CI is twice as long as the N rate (for example 50 kg N and a CI of 100 days). The predicted ANE for incorporated manure without fertiliser application is 13.3 kg DM kg^{-1} manure N, approximately twice as high as for surface applied manure N, and approximately 45% of fertiliser N at similar N rates and CI, but less for relatively longer CI. Also in other models without the interaction of fertiliser and manure N, the predicted ANE of surface applied manure is about 50% of incorporated manure (in models with the square root of NMinc NMs and in models for Exp 13-15 only). However, manure experiments do not include the interaction of surface applied manure N and fertiliser N. Also residual effects of manure N are not included, but are relatively important, in particular for surface applied manure (Chapter 5 and below). because manure and fertiliser N were only applied for a few cuts per year in Exp 13-15. This contributes to the marginal significance of NMs in models (at P<0.05; just significant for DMY and not significant in models for ANR discussed below).
The models for NY in Eq 1.7 (only linear N effect), Eq 1.8 and Eq 1.8.1, suggests an ANR of respectively 51, 50 and 39% if CI and N rate are both set at 50 (Table 3 and 17). Predicted ANR derived from Eq 1.8 (and Eq 1.8.1; interaction of CI and N included) decreases substantially, in particular beyond a CI of 10-12 weeks, possibly because of N immobilisation (by crop residues, see below) and drought. The decline is in line with changes in LY (Annex 5). Although fertiliser N in annual Exp 8-9 and 11-15 was applied during the rainy season (on a few cuts), moisture limited growth probably also plays a role (Annex 2 and 3). The predicted ANR of manure N is 25-30% if CI and N are both set at 50. The lower predicted ANR for fertiliser N derived from Eq 1.8.1 in particular is probably also because the model insufficiently accounts for variation due to residual effects of manure N (and fertiliser N; large number of unfertilised cuts in annual experiments, no fertiliser N in Exp 11) and because of serious drought in Exp 10 (see before). It should be noted that the interaction with Cut_No in the random model of REML (Chapter 2) may partly account for residual effects.

Residual recovery of fertiliser N
The residual N recovery in Exp 3 and 4, after the first fertilised cut, varied from 17% to -3% (Annex 4). Residual N recovery was highest for the 6 week CI, but low for the long CI (and sometimes negative at the low N rate). In Exp 6 and 7 residual N recovery varied from - 8.3% to +7.8%, tended to increase with N rate and to decrease with CI. It was always positive for the high N rate in Exp 6 and negative in Exp 7. In Exp 6, part of the residual N may have been derived from decomposing crop residues (dead leaf and roots). At the 12 week CI of Exp 7, N content of dead leaf was low at only about 0.5% (derived from Table 4a). This results in a high C/N rate and probably N immobilisation (probably also because of a higher moisture deficit; Exp 6 was cut after 4 weeks after the last regular cut and Exp 7 after 10 weeks, during the dry season). Also Vicente Chandler et al (1974) measured a higher residual N recovery at higher N rates, probably also because of high N rates in those experiments (and higher precipitation). The positive effect of higher N rates and shorter CI are probably due to faster N recycling of higher quality residues (Palm et al, 2001 and discussion below). Residual N recovery may still increase in time, in particular when in crop rotations immobilised organic N is released after ploughing of grass.

Changes in SNS derived from literature
The decline in NY from the peak in NY (at a CI of 5-7 weeks) to a CI of 18 weeks is about 3% per week increase in CI (Figure 6 and Table 3; stronger decline without applied N if derived from Eq 1.7 and Eq 1.8). The trend for a lower NY over the same harvest period if cutting frequency decreases (Figure 6 a, b; Exp 8, 11 and 13, see before) is in agreement with a trend suggested by results of Mwaka (1972), Ferraris (1980), Zewdu et al (2002), Van Man and Wiktorsson (2003), Prine and Woodward (1991) and results derived from a review by Muia (2000). But it contrasts with results shown in Figure 16, derived from results of Vicente Chandler et al. (1959, 1961; as summarized by De Geus, 1977), and results from Bryan and Sharpe (1965). This may be due to higher precipitation and temperatures, and higher N rates and growth rates in these last experiments, probably resulting in

higher residual N recovery due to shallower roots and more degradable crop residues, resulting in faster N recycling (Humphries, 1991; Rezende et al, 1999; Trujillo et al, 2006; Fisher et al, 2007). Vellinga and André (1999) found no effect of cutting frequency on SNS for temperate grass, but refer to contrasting effects in literature reviewed. ANR tended to increase with cutting frequency. However, also very short CI may reduce NY of Napier cut at a stubble height of 5 cm, because re-growth takes time. In Exp 1, ANR was only 28% at a cutting age of 3 weeks (results not given). But only long term comparative experiments covering the same period, allow correction of SNS for previously sequestered residual N for both, tropical and temperate grasses.
The decline in NY at older CI is probably (mainly) due to immobilisation of N from crop residues (dead tillers and leaf, stubble, and roots; Annex 6). But growth limited by drought or other nutrients, errors and model deficiencies may also play a role. If N immobilisation would be the only cause, the quantity of organic matter added to the soil might be calculated from the decline in NY for a given average N content of crop residues.

Figure 16 Relationship between average annual dry matter yield (DMY) and NY for 3 cutting intervals (CI of 40, 60 and 90 days) for results derived from Vicente Chandler (1959 and 1961, reviewed by de Geus, 1977), averaged over Napier, Guinea and Pangola grass. Annual N fertilisation varied from 200 to 900 kg N ha^{-1}; see increasing NY). See further text**.**



ANR values for fertiliser N derived from the literature
Crowder and Cheda (1982), reviewing literature, indicate ANR values ranging from about 20 to 90% for tropical grasses, with a common range of about 30-65%. Vicente Chandler et al. (1974) measured for Napier grass an ANR of respectively 52, 56 and 53% for annual N rates of 225, 450 and 900 kg N ha^{-1}, with an average ANR of 51, 54 and 47% if all 6 investigated grass species are considered. A further 2.5-5.6% residual N was recovered in a third harvest year without N application for a few species (residual recovery increasing with N rate). Ferraris (1980) measured recoveries up to 79% at the shortest 3 month cutting interval. Whiteman et al. (1985) found an ANR of 40-45% for Setaria at annual N rates between 150 and 600 kg N ha^{-1} but only 23% at a low rate of 75 kg N ha^{-1}. Results reviewed by Boonman (1993) for Napier grass suggest an ANR of about 50%. Results from Shilin et al (2007), working with different, frequently harvested, elephant grass varieties, suggest a marginal ANR varying from 36 and 85% (between 200 and 400 kg N ha^{-1}), the highest ANR being for types yielding most leaf. Primavesi et al (2004) and Silveira et al (2007) measured an ANR of about 70-80% for Cynodon dactylon cut about once per month (at N rates of 125-250 kg N ha^{-1} in the form of calcium ammonium nitrate; lower for urea). At high N rates, ANR decreased to 40-50%. Osborne (1999) working in the USA with Cynodon dactylon (cut 4 times), measured an ANR up to about 90% at the lowest N rates. Henzell (1971) working with Rhodes grass gives a marginal ANR of 56% averaged

over 7 years (N from ammonium nitrate; lower for urea). Beyaert and Roy (2005) working in Canada with sorghum-sudan grass (cut 3 times), give an ANR up to 93% at the lowest N rate for incorporated and banded N given at the 6th leaf stage, applying N at this stage possibly improving recovery.

Feasible ANR values
Zingore et al (2007) indicated that soil fertility gradients, also within farms, have an effect on nutrient use efficiencies of maize, resulting in low efficiencies on poor outfields. Vanlauwe et al. (2010) introduce a concept for Integrated Soil Fertility Management with a focus on agronomic efficiency of nutrient sources, depending on availability of germplasm and responsiveness of soils to fertiliser. They distinguish responsive and minimal or non-responsive poor soils. A third class of fertile less responsive soils is distinguished, often near to the homestead, because of regular high organic matter application in the past, or newly opened (grass)land, requiring only maintenance applications. Also in Exp 4 after pasture, average ANR was lower than in Exp 3 after maize (Table 5). Also the lower MSres for models including NYN0 (see before), indicate important effects of variation in soil fertility. But differences in experimental design, variation in growing conditions, insufficient soil sampling and possible inaccuracies do not allow firm conclusions.

An ANR of about 50 to 55% by Napier grass is probably a fair indication of what might be expected for moderate N rates under the conditions of present experiments, with possibly lower and higher values on respectively soils with a very high and low SNS (provided that other nutrients are not limiting). If residual N is included, ANR may surpass 60% for a CI below 8 weeks, and 70% under favourable conditions (see discussion on 4 and 6 week CI of Exp 6 before and literature). But for very long CI (negative residual effects and negative interaction in Eq 1.8) or too short cutting intervals (3 week CI of Exp 1), or growing conditions where growth is limited by other factors than N (drought or other nutrients), ANR may decrease below 30% (average of 28% for Exp 10), with an increasing variation, also depending on for example the variation in soil sensitivity for drought. The use of ANR is probably less suited for Napier grass harvested at old age, because of the probably relatively large contribution of crop residues to N immobilisation increase and increase in soil organic matter contents. However, deeper rooting may increase DMY under stress (possibly indicated by results of cutting regime D in Exp 8), due to a higher buffer capacity for nutrients and moisture, and a higher recovery of N and other nutrients over a longer time horizon (or for example after ploughing in a situation with crop rotations). These effects are not accounted for if ANR is determined in short term experiments. A more systematic exploration is probably required to assess required nutrient use in heterogeneous agro ecological and socio-economic environments, combining different approaches (Giller et al, 2011), while accounting for variation in Napier management (Chapter 6 and 7.5), in particular at higher N rates.

Feasible yields and N requirements
Models in Table 3a may contribute to estimate yields at farm level, provided that the variation in soil fertility and moisture supply (indicated by the length of growing season, see Chapter 6) are sufficiently accounted for. The average annual NY without N application (averaged over cutting regimes if applicable) was 95, 118, 125 and 171 kg N ha^{-1} in respectively Exp 11, 13, 14 and 15, and, when adopting an ANR of 50 % for fertiliser N, 102 kg N ha^{-1} in Exp 8 (see further below).
Although estimated NY without N application from on farm experiments was comparable, the SNS derived from the present experiments may be too high compared to soils of many farmers applying only small amounts of fertiliser or manure, exploiting mainly existing soil fertility, also indicated by low maize yields (see also Rufino et al, 2006). An annual biomass yield of maize of 4-5 Mg ha^{-1} is more comparable to an annual soil N supply of about 50 kg N. In the present experiments residual soil fertility from an earlier pasture phase (Naivasha), and earlier manure or fertiliser application (sites in Kakamega and Kisii) may still be important.

Table 18 gives results of a simplified approach to estimate potential DMY derived from variation in harvest stage of Napier grass, reflected in N contents of respectively 2 and 1% (for cutting at 5-6 weeks and 13-14 weeks, respectively 12.5 or 6.25% CP; derived from to Eq 2.1), variation in annual soil N supply (SNS of respectively 50 and 100 kg N ha^{-1} year^{-1}; compare to Exp 8, 11 and 13) and a measured ANR of respectively 60 and 50% (higher for younger cutting at 5-6 weeks; see before) and without and with an N application of 100 kg ha^{-1} year^{-1}. An ANR of 60 and 50 % results in a yield increase of respectively 30 and 50 kg DM per kg applied N for young and old grass. The results of this exploration (Table 18) indicate the large variation in potential DMY (from 2.5 to 15 Mg ha^{-1} year^{-1}), due to variation in N supply (from SNS and/or applied N) and harvest stage. However, it should be noted that SNS tends to decline with cutting age (see before) and that the increase in potential milk production per kg N is low if grass is cut old (Table 16). But some older grass may be required to bridge longer dry periods, also depending on the availability of other dry season roughages such as maize stover.

Table 18 Estimated DMY of Napier grass (Mg ha^{-1} year^{-1}) without and with 100 kg fertiliser N ha^{-1} year^{-1} (N=0 and N=100) for 2 harvest stages (%N=2 and %N=1), levels of soil N supply (SNS in kg^{-1} ha^{-1} year^{-1}) and apparent N recoveries (ANR in%). See further text.

N content	SNS	ANR	DMY	DMY
			N=0	N=100
2 % N	50	60	2.5	5.5
(CI=5-6 weeks)	100	60	5	8
1 % N	50	50	5	10
(CI=13-14 weeks)	100	50	10	15

If manure produced in such a situation is stored and applied as slurry, assuming good manure management (see Chapter 6), additional N required decreases. When it is assumed that under good management 20 % of ingested N is excreted in milk and live weight (LW) gain, and 20% of excreted N is lost during collection and storage (from a zero-grazing unit with a concrete floor and 2 days storage in a concrete pit (derived from Hiddink, 1987; see further Chapter 6.4) and for an ANR of incorporated manure N of 50% for sustained manure application (Chapter 6), the amount of 100 kg additional N indicated in Table 18, may be reduced to 68 kg N ha^{-1} year^{-1} (100-100*0.8*0.8*0.5). But during the first application year, without residual effects, ANR may be only 25% (Chapter 5), resulting in an additional N requirement of 84 kg (100-100*0.8*0.8*0.25). Under poor manure management N losses from collection and storage (for example a heap) can be substantially higher, also depending on the storage period (Hiddink, 1987; Rufino, 2006, 2007; Tittonell et al., 2010). When N losses from collection and storage increase to 50%, only 10 kg manure N would be available during the first year (100-100*0.8*0.5*0.25), and less in case of higher losses (see also Rufino et al, 2007). But if under good management 75% of manure N would be released and recycled on the long run, the contribution of manure N in the first situation could increase to 48 kg N ha year^{-1} after many years of sustained manure application (100-100*0.8*0.8*0.75). But this also indicates that still 52 kg of additional fertiliser or legume N would be required to compensate for losses during collection, storage and application, and for N used for milk and LW gain of cattle. However, it should be noted that manure also contains many other nutrients than N, being less easy to supplement because of increasing costs, availability and/or problems including proper application techniques, in particular also for minor elements. Manure also improves soil pH and buffering capacity through added organic matter, resulting in improved moisture and nutrient availability.

Considerations for optimal N utilisation
To increase milk production in farming situations where the supply of grass is less limiting, and for faster growth during the rainy season, added N may be used more efficiently if Napier is harvested at a relatively young stage, in particular if supplements are expensive. But when forage quantity is most limiting, in combination with cheap supplements, or to reserve grass for dry periods, N application may be relatively efficient if Napier is harvested at older age, probably also contributing relatively more to soil organic matter content (see below and Chapter 6). This requires advance planning to avail optimal forage quality throughout the year (Picture 1), adapting N rate while accounting for expected weather, (and, in as far as feasible to weather forecasts).
Forages are not yet included in the approach of Valauwe et al (2010). But also on Napier grass, fertiliser N is probably best used on medium fertility soils. However, because of the relatively high N uptake if grass is harvested at young age, relatively more fertile soils may be considered responsive (compared to maize for maize), provided that moisture supply is not limiting. This also because under zero-grazing conditions labour for transport is important if fertile soils are situated nearer to the homestead. Because N fixation of forage legumes is related to yield and environmental conditions, The danger for N loss from well established cut forage legumes is probably low, in particular for mixtures such as Napier/Desmodium grass. Such a mixture may be suited for medium and, with sufficient attention to other limiting nutrients (i.e. P, possibly from rock phosphate), and moisture supply, also on less fertile soils (see Chapter 7.3). Also older Napier grass reserved to bridge the dry period may be grown on less fertile soils (possibly feeding only tops, mulching of stems to improve soils?). Long Napier grass probably requires less labour for transport! Manure nitrogen is probably

best used if manure is applied in a few applications relatively early in the growing season, because N released from late applications in the may be less well used, also depending on rates applied. Farmers sometimes try to expand fertile soil on their farm incremental, probably also because of labour requirements. This concept is sometimes applied in the form of tumbekiza for Napier grass, applying and mixing once a larger amount of manure with top soil on small spots of land to obtain high yields (Orodho, 2005). Well established fast growing crops require less from management and save on labour, i.e. for planting and weeding.

Picture 1 Napier grass cut at different stages to improve forage intake of high productive cows

Mineral contents of Napier grass
Contents of crude ash of Napier in these experiments are relatively high compared to other tropical grasses, in particular in Naivasha experiments. This may be due to a relatively high potassium (Vicente Chandler et al, 1974, Kariuki, 1998) and/or silica content (Minson, 1990; Samson et al, 2005), contamination with soil, and differences in growth rate (and K supply). In models to predict ash content, effect of DM content on ash content was positive at younger cutting ages, but DM% was not significant in models if DMY was also included (results not given). Contents of Ca, P and K tended to decrease with CI. At the 12 week CI in Exp 6-7 P content also tended to decrease slightly with N rate (Table 4b). The decline in contents of calcium, phosphorus and potassium with CI and to a lesser extent with N**,** is in line with results from Vicente Chandler et al (1974) and Kariuki (1998). The high potassium contents, also found in Kenya by Kariuki (1998), indicate liberal potassium supply. The rather low P content at the 12 week CI in Exp 6 (compared to Crowder and Cheda, 1982), and the increasing N/P ratio from 6-7 without N to about 8-9 with N, possibly indicates less than optimal P supply in a few cases. In Exp 6 green leaf and stem of Napier cut at an age of 12 weeks contained respectively 0.41 and 0.10% Ca, 0.09 and 0.09% P and 2.7 and 5.7% K, contents of Ca and K being respectively higher and lower in leaf than in stem (results not given in Table 4). Dead leaf contained much less P and K, possibly due to redistribution to living plant parts (and/or leaching). The high ash content of dead leaf is probably also due to contamination with soil and higher silica contents. At the 12 week CI of Exp 6, silica content of green leaf was much higher compared to stem (respectively 9.0 and 3.3% insoluble ash and 3.1 and 3.7% lignin in leaf and stem). This is also mentioned by Samson et al (2005) and may be partly due to more hair on leaf and soil characteristics (silica content not measured, but possibly higher silica content in Naivasha).

7.2 Napier quality

At the same age, differences in growth rate and contents of CP, dOM and other quality characteristics between experiments are sometimes large, probably mainly due to differences in moisture supply (and temperature) and available N (Table 2; Chapter 7.1). The relatively high average CP content at a CI of 6 weeks for Exp 3 and 4 compared to Exp 6 (Table 1) is mainly due to the high CP content of Exp 4 at this age, probably due to the fertile soil after ploughing of pasture (Annex 1). However, at a cutting age of 12 weeks and older, CP contents of Exp 4 tended to be lower than for Exp 3, because of a much higher yield (for separate results see Schreuder et al., 1993). Decreases in contents of leaf, and leaf/stem (LSR) ratio, and in CP and dOM, and increases in OM content and cell wall constituents with cutting age (Tables 2 and 6 and Figures 2 and 8), are in line with reviews, for example by Crowder and Cheda (1982), Minson (1990), and results of Muia (2000), Zewdu et al (2002) and Tessema et al (2010). At the same age, leaf/stem ratio is lower with N (Table 2), but higher than given by Tessema et al (2010), probably because of lower growth rates (see also below). In Puerto Rico, under more favourable growing conditions, Vicente Chandler et al (1974) measured a much stronger decrease in CP% in experiments with high N rates and higher GR.
Content of OM ranges from about 74% at young age to about 85% at old age (except for a few exceptional low values at young age between 70 and 74%, possibly due to attached sand; results not given). Contents are in the same range as given by Muia (2000), but lower than sometimes given in the literature, possibly also due to higher sand, potassium and Si contents (also due to soil characteristics; see before).

Cell wall (NDF) content in Exp 1-9 ranges from 41 to 72% (results not given). Contents of NDF, ADF and lignin (Table 4, Figure 9) are in the same range as reviewed by Kariuki (1998) and results of Muia (2000) and Tessema et al (2010). At higher growth rates, contents of NDF, ADF and ADL tended to increase faster, similar to results from Muia (2000) in an experiment with variable moisture supply (higher GR with more irrigation). Vicente Chandler et al (1974) measured higher lignin contents in Puerto Rico, possibly also due to higher GR and probably differences in development stage (Groot et al, 2003). Table 6b shows no important effects of N on contents of NDF, ADF and ADL, except for the12 week cutting interval of Exp 6-7, probably due to the high DMY. At the same NDF content (in OM), dOM tended to be lower at higher N rates (Figure 11b). This is probably due to longer plants with less green leaf (see before) and lower NDF digestibility (Poppi et al, 1980; Laredo and Minson, 1975). Fat content is similar to results given by for example Vicente Chandler et al (1974) and Islam et al. (2003).

In Exp 6 and 7, nitrogen application increased contents of CP and OM significantly and decreased dOM (significantly only at the highest N rate; Table 6b and Snijders et al, 1992b). In other experiments trends are similar (results for 1 replicate only!), probably also because of much higher GR with N (Table 2 and 6a). The effect of N rate on dOM is small or absent at the same CI, in agreements with results given by for example Zewdu et al (2002) and Minson (1990). But when accounting for differences in DMY, dOM is higher with N (Tables 6a-b and Figures 8d-f). Target DMY of for example 6, 8 and 10 ton DM ha^{-1} are reached at a much earlier age with fertilizer N (Figure 4a). At the same yield, quality is substantially improved with N. At the same growth rate, the rate of decline for dOM was less with N and during the cold season (Table 6a), possibly due to lower ADF and lignin contents at the same age. This indicates that N supply can have a positive effect on both yield and quality if growing conditions allow. Contents of dOM are relatively higher than given by Nogueira Filho et al (2000) and Tessema et al (2010), possibly because of higher temperatures in Brasil (lower altitude) and/or lower GR in the present experiments.
The rate of decline in CP and dOM decreases with age, even more so if expressed in DM (due to the decreasing ash content). But the decrease is relatively higher for CP than for dOM at young age, also depending on N supply (Eq 2 in Table 3). This is important if protein content of rations becomes limiting (Muia, 2000). In Exp 6-7 for example, the ratio between dOM and CP increases from 7.7 to 10.7 from the 6 to 12 week CI. From a review of Minson (1990) a decrease in dOM content (in DM=DOM) of about 1.5% per week can be derived for Pennisetum hybrids. This is much higher than what can be derived from the present experiments (Table 6a). This slower decrease is possibly also due to differences in GR and LSR and development stage (Groot et al, 2003), and relatively lower temperatures in the Kenyan highlands, also depending on variety/hybrid.

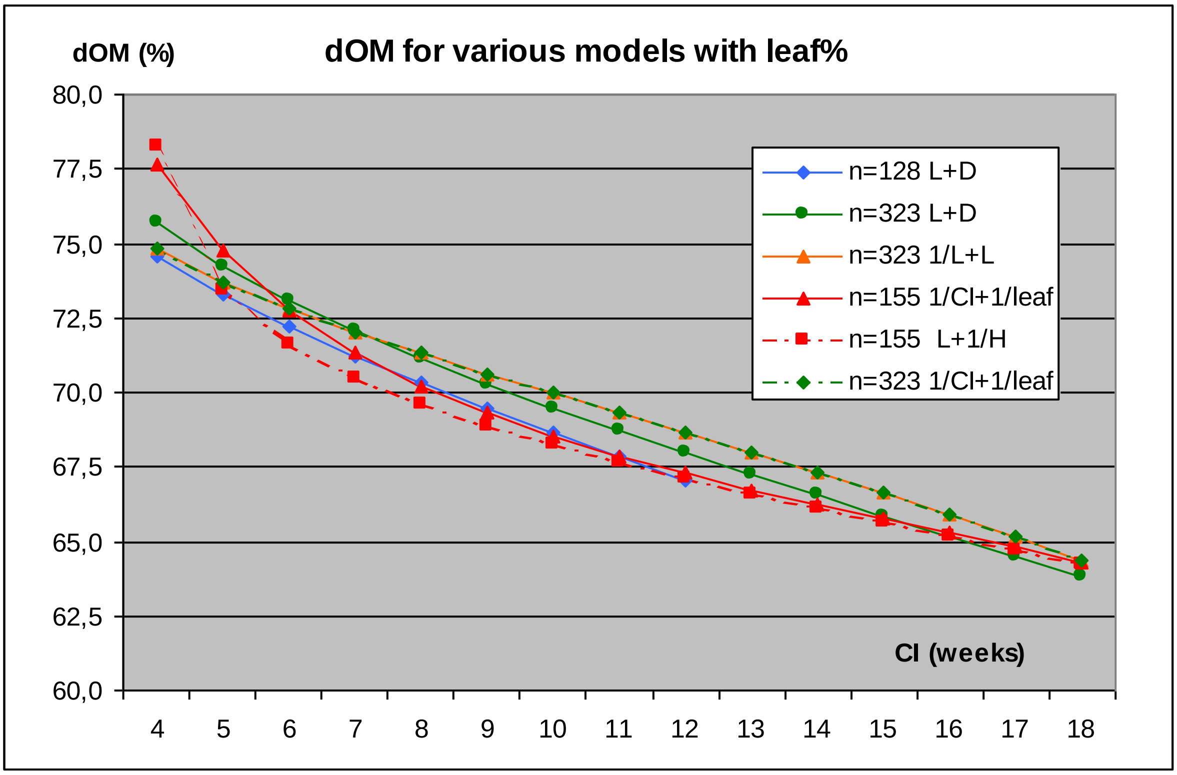
Nogueira et al (2000) suggested that Napier grass is better suited to reserve grass during the dry season than 3 other grasses investigated, probably because of a less advanced maturity stage (Viera et al, 1997). Also in Kenya Napier, in particular the variety Bana, is valued as a dry season forage, staying long “green” (Boonman, 1993), provided that the dry season is not too severe. In Exp 3 and 4, changes in NDF and dOM between cutting ages of 12 and 18 weeks (dry period) were relatively small. Differences between Bana and FC possibly also suggest a lower rate of aging for Bana, the thinner stem of FC possibly also playing a role.

Models to predict dOM

Models with leaf contents and the reverse of grass height (L+1/H and 1/L+D+1/H are the best “morphology” models (Table 7 and 7.1). The prediction of dOM is only slightly less accurate than for models including the reverse of age and leaf content or grass height (1/CI+1/L or 1/CI+CI*H), the model with leaf being best. The reverse of age (CI), and leaf content or height indicates a smaller and decreasing effect on dOM at higher values. Adding leaf, and sometimes H (not in combination with leaf) to models for dOM with age probably accounts to some extent for differences in growing conditions and development stage between experiments (Groot et al, 2003; see discussion below).

Figure 17 shows only small differences in predicted dOM between models. Grass H and contents of green and dead leaf used in these models are derived from Eq 1.9 to 1.11 in Chapter 3.1.2 (without N application), but cannot be shown separately in Figure 17. The models for n=155 (CI 4-18 weeks) predict a slightly higher dOM at an age of 4 weeks, the decline in dOM being also slightly higher, probably partly due to higher growth rates (relatively higher N rates; and model deficiencies at this age?). The models for n=323 (all cutting ages; Annex 8b) probably account better for the slower decline of dOM at older age (and during the dry season). But differences are smaller with N, while cutting ages of 4 weeks are not very common for Napier.

Figure 17 dOM for various models with combinations of green (L) and dead (D) leaf, grass height (H) and age (1/CI) plotted against cutting age for datasets A and C1 (n=155/323; n=128 is dataset A limited to ages of 4-12 weeks) 1/CI and 1/L are the reverse of age/leaf. See further text, also for abbreviations.



Also models with age (1/CI) and dead leaf predicted dOM rather well in some datasets (D is not significant with L for n=155), but the variation explained is lower, probably also due to more variation when measuring dead leaf content (see before). In experiments of Chia Sheng Chen et al (2006), in vitro true digestibility of Napier grass was best predicted by the combination of age and grass height, leaf content was not determined.

Season and T are not significant in the best models with age and leaf or H for cutting ages up to 18 weeks (Table 7). The role of season and temperature vary between models and datasets. Including temperature in models, if significant at all, tends to improve the variation explained, while season tends to improve MSres. For all cutting ages, adding age and/or leaf, season or temperature to models with 1/CI+1/L sometimes improves the prediction of dOM slightly, but the improvement is often marginal (Annex 8a, b). If temperature and season are both added to a model with 1/CI+1/L for dataset C1 (Eq 5b in Annex 8b), season is significant, but T not (also not for Eq 6b). But if both are added to the model with L+D in Eq 7b.1 Annex 8b), season is not significant (results not given). In a model with 1/CI+D for dataset C1, temperature and season are not significant. Adding DMY sometimes still improves the prediction slightly. If added to the model with age, H and season, both DMY and T are not significant anymore (Eq 6b1 in Annex 8b). Also in the model with age, dead leaf and DMY for dataset C1 in Eq 5b.5 below, temperature, but also content of green leaf (!) are not significant. However, use of DMY to predict dOM is probably not feasible in practice.

dOM=69.65-0.001859*CI+204.7/CI-0.1519*dead+0.1069*DMY-0.0061398CI*DMY (MSres=3.65; P<0.001; **Eq 5b.5**)

Minson (1990) and Wilson et al (1991) indicate a (strong) negative relationship between digestibility and temperature. The decrease in dOM in the present experiments is also lower during the cold season, if accounting for differences in growth rate (Table 6a). But temperature effects may be (partly) due to differences in development stage if GR increases with temperature (Groot et al, 2003). This can also be derived from the models for dOM (see above). Higher temperatures increase GR (if other growing conditions allow) and rate of leaf appearance (Groot et al, 2003; Lemaire et al, 2009), also resulting in faster stem development and ultimately leaf death (Wilson and ‘t Mannetje, 1978a). This probably also appears as a positive effect of temperature on lignin content (Wilson et al, 1991; Figure 9e). Including dead leaf apparently caters largely for these effects, but without DMY models with dead leaf predict dOM less well than models with green leaf (larger variation for dead leaf content, see above). Apparently the combination of green leaf and age or leaf and H cater to a large extent for temperature and seasonal differences (accepting that the use of DMY is not feasible). Nitrogen availability has an effect on leaf content (see Eq 1.9 in Chapter 3.1), contributing to differences in development stage. In models of age with leaf content, differences in N availability and DMY are probably less important, but differences in season still contribute to predict dOM if long cutting ages are included.
The effect of H on dOM, in addition to leaf content is small (Figure 10d). The difference is similar for dataset A and B, also if CI is limited to 12 weeks for dataset A. Very large differences in leaf contents at the same age are probably not very likely, unless growing conditions differ extremely.

Models with chemical parameters
For dataset D, a model with CP and NDF (in OM!) predicts dOM slightly better than morphology parameters with or without age (Eq 19 in Table 8a). With more extensive chemical analysis, including ADF (Eq 28 in Table 8b), the prediction is best for the model with CP and ADF if based on MSres. However, derived from the variation explained, also age and leaf predict dOM well (Table 8a, b). Models with NDF or NDF and ADF combined predict dOM less well. Adding crude fibre to Eq 28 improves results only marginally, while CF is often not significant in other models.
For models including ADL, the parameter 1/ADL only and the combination of ADF and ADL predict dOM best, MSres being substantially lower than for the model with age and leaf (Table 8c). But these models account only for the 15 samples with known ADL of Exp 4.

Adding 1/L, CF and season improves Eq 19 slightly (MSres=2.31; R2=91), but if DMY is also included, CF and 1/L (and T) are not significant (results not given). The reverse of leaf is still significant if added to a model with CP and ADF (Eq 28 in Table 8b). If season is also included, T is not significant (MSres=1.86; R2=91). In a model for dataset F (n=57; Annex 8c) grass H is significant if added to ADF, but 1/CP, NDF and T are not (results not given). This probably indicates that variation in lignification needs to be included in models to predict dOM (but this cannot be verified sufficiently). Leaf content (1/L) may partly compensate for ADL if results for ADL are not available. Including ADF probably more or less accounts for effects of variation in temperature, or possibly more important, differences in (morphological) development, but not sufficiently to always exempt variation in leaf content (see before). Validation of chemical models based on the RPE criterion is difficult (if not impossible) because a suitable dataset of sufficient size is missing.

It should be noted that presently Near Infra Red Analysis (NIRS) probably provides more opportunities to predict quality characteristics. However, its use for practical purposes on smallholder farms is still questionable. But it may help to easier validate the prediction of quality characterics discussed before. And it may be worthwhile to try and use NIRS as a tool to estimate and validate leaf and stem contents and leaf colour to improve estimate quality characteristics (see below)

Model for CP and ash content

Comparable to models for dOM, models with leaf% and grass height also predict CP and ash content rather well, in particular if age and (for ash) N rate are also included (Table 19). Grass H is not significant if added to Eq 2.2.4, but the reverse of H is if added to Eq 2.2.3 (CP=3.367 +0.05938*L - 0.06435*D +116.1/H; n=504; MSres=1.39; R^2=44; P<0.005). In models for CP for Exp 1-15 (with manure) MSres is good, but variation explained is low.

In line with positive effects on DMY, predicted ash content is lower for shorter CI during season 2 (if included, results not given), but higher at long CI (see above). If DMY is included as a parameter, prediction of quality characteristics improves (results not given). The ash content of the variety FC is lower than of Bana, also if variation in DMY is included (Chapter 3.1 and 3.3.4). The lower crude ash content in Kakamega and Kisii, also if corrected for variation in DMY, cannot be explained properly, but soil characteristics (higher silica content in Naivasha), and K supply (there are limited results on K contents available; Table 4b) and soil contamination may play a role. Morphology apparently accounts for a large part variation in CP and ash content.

The content of NDF is sometimes used as a predictor for forage intake. The model in Eq NDF (n=153) with 1/leaf and 1/H only also predicts NDF content rather well (better than 1/CI+1/leaf: NDF=63.38-429.3/CI+214.7/leaf; MSres=3.64; R^2=44; P<0.001).

Table 19 Relationship between CP, ash and NDF content (%) with contents of green and dead leaf (%) or grass height (H in cm) and age (CI in days) and fertiliser N (kg ha^{-1}). Experiments, R^2, P and n (datasets A4, A5) are also indicated. See further text, also for abbreviations and Chapter 2.

Eq	**CP**	**CP**	**CP**	**CP**	**NDF**	**Ash**	**Ash**	**Ash**
	Eq 2.2.1	**Eq 2.2.2**	**Eq 2.2.3**	**Eq 2.2.4**	**Eq NDF**	**Eq 3.2.1**	**Eq 3.2.2**	**Eq 3.2.3**
Exp	1-9/13-15	1-9/13-15	1-9/13-15	1-9/13-15	1-11	1-9/13-15	1-15	1-15
Const	3.367	1.719	1.97	1.571	61.65	18.43	20.11	1.86
CI							-0.03258	-0.03099
1/CI		250.4		146.3			113.8	62.89
N							-0.02852	-0.02271
CI.N								
N/CI								
Leaf	0.05938	0.3785	0.216	0.0526				0.0602
1/Leaf					288	-158.5		
Dead%	-0.06435		-0.05103					0.02966
H								
1/H	116.6				-404.2	191.4		
MSres	1.37	1.11	1.72	1.2	4.615	2.301	1.99	1,89
R2	44	70	42	60	53	46	76	78
P<	0.005	0.001	.0.001	0.001	0.001	0.001	0.001	0.001
n	504	504	573	573	153	476	1309	1094

Variety

Leaf and stem content differ significantly between FC and Bana in various models with age and DMY (respectively lower and higher for FC; see chapter 3.3.4). The trend for a faster decrease in dOM for FC than for Bana in a model for dOM at the same NDF content may be due to faster stem development (Groot et al, 2003) and resulting higher lignin content. But if 1/CP or 1/leaf are also included in the model, NDF is not significant anymore. Variety is just significant (P< 0.02) if included in a model with CI+1/CI+1/L+season for dataset C1 (dOM being 1.9% higher for FC), but just not if DMY is also included (P<0.08 for variety). Variety is also just significant in a model for content of dOM in DM (DOM; P<0.04), probably also due to the lower ash content of FC (Figure 12d). Apparently the combination of age and leaf content can also cater for differences in dOM between varieties (see before), but not in all models. However, no firm conclusions are possible about differences in dOM between Bana and FC from the present dataset, although there are differences in leaf, stem and ash content, and a possible tendency for faster aging of FC (see 3.3.4). Nyambati et al (2010) did not find clear differences in morphological characteristics between FC and Bana, although tillers of FC were marginally taller. But leaves of Bana were larger and tended to have more hair. This may contribute to higher silica content (Samson et al, 2005), which together with higher leaf content may contribute to relatively higher ash contents (see also trend for higher ash content in leaf in Table 4a).

Leaf colour
Leaf colour is sometimes used to characterise Napier (Tessema et al, 2010). If leaf colour could substitute for CP%, it might improve the use of morphological models, provided that a reliable method for estimation of the leaf colour is developed (see below and Picture 2). Adding 1/CP to age and leaf improves MSres slightly (Eq 13.1 in Table 8a), and marginally for Dataset C1 (Eq 5b in Annex 8b; MSres=3.7; R2=64). The model in Eq 13.1 implies that predicted dOM is reduced by about 3% and 6% at a CP content of respectively 14% and 7% CP (expressing CP in DM; results not given). Adding 1/CP to a model with leaf% (Eq 7b1 in Annex 8b), clearly improves MSres (MSres=4.24; R2=60). A model with 1/H+1/CP also substantially improves a model with H only (Eq 9 in Table 7), but age and H (Eq 6) still predict dOM slightly better.

Picture 2 Coloured stick to measure Napier colour and estimate CP content (higher to dark green). Leaf colour ranges from light green to dark green; red indicates cutting too long, black too short.

Use of models in practical conditions
It is a question which of the morphological models offer the best perspectives for use under practical conditions. Based on the results of the present analysis, the relatively simple models with 1/CI+1/L, and L+1/H (with or without dead leaf) are the most promising morphological models (Eq 5, 10 and 11 in Table 7), approaching results of chemical analysis. But based on the RPE (Table 7.1), also age and H predict dOM rather well (Eq 6 in Table 7). The models with age are possibly easier to use in situations where growing conditions do not vary much (H is easier to measure than leaf%). But the

model with L+1/H may be better adapted to a wider range of growing conditions with variable GR. Including dead leaf probably can better cater for longer cutting ages, in particular if the dry season is also included. However, the variation in dOM is larger and relatively more important at younger age. Measurements of leaf content are probably too time consuming in practical situations, estimates being more convenient. Estimating both green and dead leaf may result in more reliable estimates. But estimating leaf contents requires learning through experience, comparing estimates with measurements. Grass height only is not a reliable predictor of dOM, probably due to variation in growing conditions (such as nutrient supply), resulting in variation in yield, stem development and aging. But although leaf only is a better predictor than H, requiring only one determination, a combined estimate of leaf and height may be best if feasible.
Substituting leaf colour for CP content may improve estimates from morphology for dOM, in particular also for a model with H alone. The use of leaf colour is possibly more practical than season or temperature. The coloured measuring stick in Picture 2 is for example successfully used by a farmer in Western Kenya to judge quality and related price of purchased Napier grass. Season and temperature interact with GR (lower GR during the dry season S2 and higher GR with increasing T, if other growing conditions allow). This makes the use of season and temperature situation dependent. Besides, the dry season used during analysis (harvest dates from January to the beginning of April) sometimes includes the beginning of the rainy season, while the temperature used was sometimes based on monthly long term averages (Chapter 2).

Leaf and stem quality
In Exp 2, 6 and 7 dOM was sometimes substantially higher in stem than leaf, despite higher fibre, cell wall and lignin contents in stem(Table 6c), but not always in Exp 4 with the variety FC (also analysed in another laboratory). But silica content (acid insoluble ash), was much higher in leaf (possibly partly due to more hair on leaves; attached sand may also contribute). Contents of ash were relatively high, particularly in Naivasha, possibly also due to relatively high soil silica contents (not measured). But ash content tended to be lower for FC than for Bana (Chapter 3.3). Vicente Chandler et al (1974) measured higher silica contents for Napier grass compared to other species, and found higher contents on soils with high silica content. However, they found much higher differences in CF content between stem than leaf, but only small differences in silica content (results not given). In a review, Van Soest (2004) indicates that each unit increase in silica, decreases organic matter digestibility by about one unit, but he also indicates the need to standardize determination of silica content. Also a relatively high digestibility of the leaf sheath (Wilman and Moghaddam, 1998), included in stem content for these experiments may have contributed to the measured higher stem dOM.

A higher stem digestibility is unexpected, but has been found before (Minson, 1990; Poppi et al, 1980), but in particular at young age. Several factors may contribute to these results. An important aspect is possibly the milling of stem and leaf to a particle size of < 1mm before determination of dOM, being relatively more advantageous for stem dOM (Wilman and Moghaddam, 1998; Laredo and Minson, 1973). Also the standards used for determination of dOM may not have sufficiently reflected the digestibility of Napier samples (see Chapter 2). Wilson and Hatfield (1997) discuss the importance of particle size for stem digestibility (< 1mm highly digestible). Bruckner et al. (1990) indicated larger effects of particle size on stem digestibility compared to leaf.
The results in Table 6c show only small differences in leaf and stem digestibility for FC. A relatively higher NDF digestibility of the Bana stem, because of lower silica content and a relatively larger fleshy pith with less vascular bundles and lignin, similar to maize, may contribute to explain the difference with FC (Wilman and Moghaddam, 1998; Boonman 1993). But also slower aging (see before) and/or to a higher soluble carbohydrate content of Bana may contribute (see below).
At high temperatures stem digestibility of tropical grasses decreases faster than leaf digestibility (Wilson et al, 1991), but this difference may be relatively less important at higher altitudes and lower temperatures in Naivasha (and Kakamega) in the Kenyan highlands. Lower GR (during the dry season for example) may also stimulate soluble carbohydrate content of stem (Chapter 3.2), comparable to high sugar content sometimes found in the maize stem if the cob is absent or small due to drought.

7.3 Napier/Desmodium

Role of Desmodium N
Yields were much higher for Napier with Desmodium in Exp 11. Compared to the first 3 years of Exp 11 (1985-1988), DMY and NY of pure Napier grass declined by respectively 42 and 44% during the

last 2 years (1988-1990; averaged over cutting heights), but by only 30 and 28% for Napier/Desmodium mixtures (results not given in Table 11). This may be because during moderate drought, Desmodium provides more N than fertiliser N (lower N uptake and ANR during drought, see for example Exp 10). This effect is sometimes also experienced with for example clover. In Exp 12, DMY is comparable to an annual N application of about 200 kg N ha^{-1}, derived from the difference method, and much higher if based on NY. In Exp 11 respectively 93 and 87% of the annual NY of 201 and 164 kg Desmodium N ha^{-1} was apparently derived from symbiotic N fixation for cutting at younger and older age. This is high compared to an N fixation of 75% for legume N sometimes used. The estimated N fixation from Desmodium of 238 kg N $ha^{-1}year^{-1}$ in Exp 12 is in the upper range mentioned for tropical legumes and Desmodium by Mannetje (1997) and Giller (2001). But the estimate possibly includes N derived from recycled, previously soil stored N (from crop residues) during Exp 11. Nitrogen from residues from pure Napier have probably a higher C/N ratio, releasing less N (see also Annex 1 and Cantarutti et al, 2002; Herridge et al, 2008; Peoples et al, 2001). Keya (1974) working in Kenya, mentions that Desmodium species in a mixture with Nandi Setaria may increase DM yield by an equivalent of 100-200 kg N $ha^{-1}year^{-1}$. Whiteman et al (1985) measured a nitrogen yield in a mixture of Setaria anceps and Desmodium intortum equivalent to more than 300 kg N ha^{-1}. Skerman (1988) refers to N fixation from Desmodium intortum up to 375 kg. Boonman (1993) indicates that 30-40 % Desmodium in a mixture may contribute the equivalent of 100 kg N per ha and can maintain itself if Napier is not cut very frequently or infrequent (optimum length about 1.25-1.5 m).

Other aspects

The cutting intervals were longer than anticipated, also because of drought and problems with irrigation , probably affecting quality, despite lower decline in quality at older age (see before). Once properly established, the mixture of Napier with Desmodium was able to control weeds well. The Desmodium content was only slightly lower at the long harvest height and CI, and varied between cuts from 38-67%. During serious drought in 1988/1989, Desmodium content was lower, at around 40%, with a slightly larger difference between cutting regimes (5% lower Desmodium content for the older long cut mixture during the last 2 years of Exp 11), but it recovered again gradually afterwards. Average Desmodium content was still 57% after 6 years at the end of Exp 12. This indicates good Desmodium persistence under the cutting conditions of this experiment and a rather good balance with grass. Even lower Desmodium contents may suffice from nutritional point of view (Kariuki, 1998), if grass is not harvested too old (see also discussion on CP% below). Persistence was probably favoured by good soil fertility, including liberal P and K supply. Cutting method (not too short; preferably with some green leaf left), probably favoured Desmodium content compared to grazing conditions (Jones, 1989, Boonman, 1993). Under grazing conditions Desmodium may disappear faster, resulting in lower milk yields per ha.

The content of CP and dOM in Napier in the mixture with Desmodium was on average about 1% higher than for Napier without Desmodium. Crude protein content of Desmodium was about 10% higher than of Napier, but dOM was about 15% lower. Long cutting intervals resulted in relatively low protein contents. Crude protein content in Desmodium varied from 10.8%-18.3%, in Napier from 2.4 to 8.6%, and it was nearly always slightly lower in pure Napier (results not given). In Exp 12, crude protein content in green leaf, stem and dead leaf of Desmodium was determined in one cut harvested at a CI of 12 weeks. Contents of green leaf, stem and dead leaf were respectively 42, 55 and 3%, with a CP% of respectively 20.4, 5.4 and 7.9%. Desmodium contained about 65% of the total protein yield, of which 70-75% in green leaf, indicating the importance to retain Desmodium leaf, similar to Lucerne. Both, ash content and dOM were lower for the Napier/Desmodium mixture than for pure Napier. Mwangi et al (2004) reported similar DMY for a Napier/Desmodium mixture in Central Kenya, but Desmodium contents were lower, possibly also due to a more fertile soil. They also measured higher Desmodium contents for a shorter CI (8 versus 16 weeks). But if CI becomes too short the reverse may happen (Olsen, 1973). Tessema and Baars (2006) found that in mixtures of Desmodium uncinatum with grass, Desmodium established slower than grass, but mixtures produced more than pure grass (Chloris gayana or Panicum maximum) fertilised with 50 kg N $ha^{-1}year^{-1}$.

The adoption of forage legumes such as Desmodium on smallholder farms is less common than might be expected, probably due to problems such as poor soil fertility and fertilisation (lack of P in particular), availability of planting material and slow establishment, cutting and grazing management, competition for land, and, also very important, market access and other socio-economic constraints (Shelton et al, 2004; Gebremedhin et al, 2003; Jones, 1989; Mwangi et al, 2003; Mannetje, 1997). Participatory development and the use of bulking plots and vegetative propagation, similar to propagation of Napier grass, contributed to the use of Desmodium in a farmers group in central Kenya (Mwangi and Wambugu, 2003). Establishment under maize (Hassen et al, 2006), in combination with

Napier strips around maize can reduce pest incidence of maize (Khan et al, 2008) and demand for land and labour, also due to less weeding. In a small experiment in Naivasha stem cuttings of Desmodium established in an existing stand of Napier at a row distance of 90 cm, germination was on average 37% after 10 weeks if Napier was cut at a height of 1-2 feet and 57 % for cutting at 2-3 feet of Napier (Desmodium not cut; Snijders et al 1992c). Initially increase in ground cover was slow from stem cuttings (only about 50% ground cover compared to establishment from seed after half a year), but later development went faster. The Desmodium field still performed well more than 10 years after first establishment.
The rather high productivity of the Napier/Desmodium mixture in these and some other experiments reviewed, indicate its potential under favourable conditions if integrated well into moderately intensive farming systems, including its potential to contribute to pest and weed control in “push and pull” strategies (Cook et al, 2007), soil improvement (organic matter content, erosion), cattle nutrition (Tolera and Sundstol, 2000; Kariuki, 1998) and, if compared to “intensive” use of fertiliser N, to limit N loss. Nitrogen loss is probably also restricted because of the probably relatively slow degradation of tannin containing Desmodium and decreasing N fixation if surplus soil N can be used. It should be noted that the soil pH tended to decrease more if Napier was mixed with Desmodium compared to unfertilised Napier.

7.4 Cattle manure

Role of manure N
In Exp 13, DMY without N decreased from 13.6 Mg ha^{-1} during the first 3 years to 9.3 Mg ha^{-1} during the last 2 years, and, if averaged over the 2 rates of fertiliser N, from 19.6 to 15.3 Mg ha^{-1} (results not given in Table 15). The soil N supply decreased by nearly 50%, from 147 kg N ha^{-1} year^{-1} during the first 3 years, to 75 kg N during the last 2 years. Averaged over 5 years, ANR of manure N was 27 and 33% for respectively surface applied and incorporated manure, being equivalent to 50 and 61% of fertiliser N. Manures also release organic N after the season/year of application (gradually decreasing residual effects), also depending on manure quality, including C/N ratio and lignin content (Mutiro and Murwira, 2004; Lekasi et al, 2001; Nhamo et al, 2004; Kimani et al, 2004; Rufino et al, 2006; Schröder et al, 2007) and soil characteristics (faster if aerated, i.e. after ploughing). The ANR of surface applied and incorporated manure N increased from an average of respectively 22 and 31% during the first 3 years to 35 and 36% during the last 2 years (derived from Table 15), probably because of such residual effects, this despite drought and a resulting increase in cutting age (from an average of 66 to 100 days). At the same time ANR of fertiliser N decreased from 57 to 49%, possibly because of drought and the resulting increase in cutting age and (extreme) drought (see Chapter 2) and increasing N immobilisation (higher C/N ratio of crop residues; see Chapter 6.4). The relatively larger increase in ANR for surface application is partly due to the initially lower ANR (higher N losses after application compared to incorporation) and relatively larger contribution of organic N.

In Exp 15, and for high application rates in Exp 14, ANR values of fertiliser and manure N were substantially lower. This may be partly due to lower residual effects because of the shorter duration of these experiments and higher application rates (in particular in Exp 15). But also higher N losses after incorporation in slits (leaching and de-nitrification due to wet/warm conditions; Van der Meer, 2008b), higher soil carbon (and probably N) content and more frequent application (more damage from making slits) may have contributed to the relatively lower ANR value. In Exp 15, also disturbance by grazing cows may have played a role (see before). In Exp 13, weeding before manure application may have contributed to reduce N losses of surface applied manure (from ammonia volatilisation). It could be observed that surface applied manure spread over a relatively smaller soil area (more porous soil after weeding and faster urine infiltration?) compared to Exp 14 and 15 in which weeding was done at a later stage. In Exp 13 and 14 irrigation after manure application may have contributed to N losses from de-nitrification.

From results of Zewdu et al (2002) with one application of 1 and 2 Mg ha^{-1} incorporated cattle manure before planting of Napier grass, a high ANR of respectively 64 and 70% can be derived (2 year experiment), possibly also because improved soil-manure contact (manure was ground; see also Lekasi et al (2001). Van der Noll and Janssen (1983) measured a FE of 45-62% for incorporated slurry manure on sandy soil at a low manure rate at the Kenyan Coast (based on ANR; above 100% for a high rate), but ANR of fertiliser N was rather low and the variation was rather large. Sunusi et al (1997) measured an ANR of 23% by Napier grass. But results from experiments with use of manure on Napier are still limited. A positive effect of slurry incorporation on N utilisation of grass is also often

found elsewhere (Rotz, 2004; Wulf et al, 2002; Van der Meer et al, 1987).
In Exp 13, the fertiliser equivalent (FE) of manure N (based on ANR), was about 50 and 60% for respectively surface applied manure and incorporated manure. The opposing trends for the ANR of fertiliser and manure N during the last 2 years (see before) result in an increasing FE value of manure N (results not given separately). In Exp 14 and 15, FE of surface applied manure was much lower, possibly also due the shorter duration of experiments (see ANR), and reasons discussed before.

The indication for a higher DMY with manure at the same N uptake (Figure 13), indicates an additive effect of manure, for example through the supply of nutrients other than N (see P contents before) and/or an improved moisture supply (Zingore et al, 2008, 2011; Franke et al, 2008; Nyamangara et al, 2003; Van der Meer et al, 1987). In another experiment in Naivasha (during almost 2 years, results not given), the effect of distribution of incorporated manure was explored, applying similar manure rates between either all Napier rows, or between every second row (the last among others to save on labour). The resulting ANR value was (much) higher if manure was applied between every second row of Napier grass, compared to the control with application between all rows (an ANR of respectively 15 and 26%; Snijders et al, 1992a). This may be due to damage to grass (roots) when making furrows for incorporation. But this effect requires further confirmation (see also Van der Meer et al, 1987), also because the average old cutting ages (102 days), probably contributed to a low ANR of 33% for fertiliser N. On average old cutting ages in all experiments with manure application due to occasionally serious drought (Annex 2, 3) may have affected ANR (see before).

The measured values for ANR of incorporated manure N are lower than often found in temperate countries (Rotz, 2004; Wulf et al, 2002; Van der Meer et al 1987). This is partly due to the much lower ammonia N content of the slurry manures discussed in this report (26% ammonia N of total manure N in Exp 13). But also N immobilisation because of Napier residues (dead tillers and leaf, stubble, roots) with probably much lower N contents may play a role (also for dung N), in particular when grass is harvested at older ages as was the case in these experiments (Table 15; Chapter 7.1). The N content of approximately 1% N of harvested grass in these experiments would result in a C/N ratio of about 50 and probably much lower in crop residues (stubble and roots; see also below).

It should further be noted that N losses between excretion of faeces and urine and manure application can be substantial. From results of 2 mineral balance trials of Hiddink (1987) in a zero-grazing unit with dairy cattle in Naivasha with only cubicles covered by a roof, losses between excretion and application, after 2 days storage as slurry in a “closed” pit (slurry collected twice daily from a concrete floor), can be derived. Losses were respectively 19.6% and 20.7%, for rations with 9.4 and 14.7% CP (average of 3 replicates per experiment) . The losses given combine collection and storage losses (from short during slurry storage if slurry is applied 2-3 times per week as was recommended by NDDP). Losses are probably mainly due to losses before collection. Losses between excretion and storage are often not measured. Losses before application are often much higher, depending on collection and storage systems (see below). If losses before application are high, losses afterwards are expected to be lower.

In a scenario analysis, N utilisation from manure may be explored (in preparation; Snijders et al, 2009). If N losses for field application from mineral and organic manure N (respectively 25 and 75% of manure N; see Chapter 4) are set at respectively 60% and 20% at a high loss level, and 20% and 10% at a low loss level, grass available N can be calculated. Assuming further that in the first year after application 15% of organic manure N is recovered in harvested grass and 2% of remaining organic N in the subsequent 4 years, the expected ANR after 5 years would become 23% at the high loss level and 35% at the low loss level (compare to ANR in Table 15). The results are very sensitive for the % of urine N excreted. When we assume a low N loss of 20% between excretion and application of slurry N (see before; Hiddink, 1987), approximately 45% of excreted N would consist of mineral N (25% ammonia N in slurry + 20% lost before application), a % urine N not uncommon for rations more or less balanced for energy and protein. In such a situation, improved use of urine N has to be realised mainly by improved application techniques. When the high and low loss levels are supposed to represent respectively surface applied and incorporated manure in Exp 13, the scenario ANR is slightly lower for surface applied manure and slightly higher for incorporated manure after 5 years than measured values (27 and 33% in Table 15). But the ANR for surface applied in Exp 13 is relatively high compared to Exp 14 and 15, possibly also because surface applied manure in Exp 13 was applied after weeding, allowing easier penetration of in particular urine N into the soil. In Exp 15 in Kakamega (regularly rain later in the afternoon), a slightly sloping experimental site may also have contributed to N loss from erosion, also resulting in a lower ANR. These factors probably contribute to the large variation in ANR for surface applied manure N if applied as slurry. For incorporated manure the N loss from de-nitrification is uncertain.

Other aspects
The annual application rate of 55 Mg wet slurry ha^{-1} $year^{-1}$ in Exp 13, more or less reflects manure production on a moderately intensive specialised zero-grazing farm. The total N content of applied slurries was low compared to slurries from intensive dairy farms in the Netherlands, the content of easy available ammonia N being about 50% lower (Table 13). But contents were higher than given for solid manures in Africa (Lekasi et al, 2001; Onduru et al, 2008). Differences in N contents are probably mainly due to differences in ration composition, and probably also to higher N losses before collection and/or during storage, also because of less favourable storage conditions, including higher storage temperature (Rufino, 2006; Lekasi et l, 2001; Gichangi et al, 2007; Snijders et al, 2009). Slurries used were stored in a covered concrete pit. Lignin content was not determined, but manure may contain rather high lignin contents with possible negative effects on N utilisation (Lekasi et al, 2001; Sorensen, 2003).
To improve manure utilisation not only the application technique, but also improved collection and storage require attention (Mutiro and Murwira, 2004; Rufino et al, 2006; Vander Meer 2008a), using for example simple plastic covers (Rufino et al, 2007). In 2 experiments in Naivasha on slurry storage (Hiddink, 1987), N losses were much lower when slurry was stored for 3 weeks in an (uncovered) soil pit compared to uncovered heaps with a larger surface, in particular for slurries with higher N content derived from rations with higher protein contents (average of respectively 18 and 45%). Also Lekasi (2001), Rufino et al (2006, 2007) and Tittonell et al (2010) measured variable and sometimes high N losses from storage of (solid) manure, depending on storage systems .
To reduce collection and/or storage losses liquid manure (slurry or urine) may be diluted with water. Or the other way around, if available, organic material may be added for aerobic composting of solid manure. Pits and (compact) manure heaps may be covered with a simple (plastic) cover (Lekasi et al, 2001; Gichangi et al, 2007; Rufino et al, 2007). Depending on the situation, separate collection of and solids and liquids may be opted for, or separation after collection as slurry liquids (for example slurry from biogas production through a strong fine mesh PE sheet or “big bags” hanging in a pit?). This may increase flexibility and improve nutrient utilisation, for example through top dressing of diluted urine liquids. Solid manure may be stored less costly and for longer periods and may be applied as a basal dressing in relatively large quantities because of low risks for N losses (Nyamagara et al, 2003; van der Meer, 2008 a, b), in particular if the soil is kept “green” to minimize N leaching. An application rate of 40 Mg ha^{-1} solid manure with 2% total N and 0.1% mineral N contains only 40 kg mineral N ha^{-1} and can probably be applied in planting holes for fruits/shrubs or a so-called tumbukiza arrangement for Napier (Orodho, 2005; Onduru, et al, 2006). This may help to reduce storage capacity and labour use, in particular if planting is arranged over a longer period.

Changes in soil carbon content in Exp 11 and 13
Changes in soil C content are important for soil productivity and are also considered relevant in relation to climate change (Ogle et al, 2004; Lal, 2006). Trends are discussed for Exp 11 and 13 combined, both experiments being conducted over a period of 5 years. However, it should be noted that the single soil sample taken at the time of ploughing in 1982 a few years before the start of Exp 11 and 13 does not allow conclusions about the rate of decline. The results measured for differences between treatments have a more solid basis, but the number of samples is still too limited (Annex 1). In Exp 13, soil carbon content decreased without, and increased with fertiliser N, and in particular with manure. It decreased by about 3-4% per year without N in Exp 13 (from 1982), probably due to an initially fast decline after ploughing of pasture (see also discussion by Ridder et al, 2004) and subsequent low Napier productivity (poor germination and open sward due to drought). Compared to the unfertilised control, carbon content increased by approximately 2% per year from 1985 to1990, the increase being higher with manure. The fast increase is probably also stimulated by relatively long cutting intervals (see before), resulting in lower N contents of crop residues and less degradable residues (Table 4; Trujillo et al, 2006). In Exp 11, soil carbon content decreased less, while it was higher for the longer cutting interval (Table 10). Carbon contents in Exp 11 were lower than in Exp 13, possibly because the cut Napier/Desmodium mixture produced lower quantities of crop residues than fertilised Napier in Exp 13. The relatively high silica content of Napier may also have contributed to reduce degradation rate and increase soil C contents (Humphries, 1991; Parr and Sullivan 2005; Samson et al, 2005).

Annual C accumulation in Exp 13 was about 0.5 Mg C ha^{-1} higher with manure application than with fertiliser N (derived from Annex 1). Based on an annual application of 55 Mg wet slurry, about 1.8 Mg manure C is applied (based on 55% C in OM). This implies that about 25-30% of applied manure C is stored in the top 20 cm of soil. This is within the range reviewed by Soussana et al (2004). Lee et al (2007) recorded annual C accumulation rates of 2.4 and 4 ton per ha with application of respectively fertiliser N and manure, while about 39% of added manure C was retained in the top 30 cm after 4 years. Manure application tended to increase soil P, as may be expected from additional P supplied with manure.
The estimated carbon stock in the soil layer 0-20 cm varies from 29-72 ton per ha (Annex 1). Fisher et al (2007) and ’t Mannetje (2007) give (much) higher values for some (grazed) tropical grasslands if deeper soil layers are included. For treatments without N input, there are probably similarities with declining C stocks of degrading pastures, also being strongly depending on management (Fisher et al, 2007; Soussana et al, 2004). Under cutting conditions decline is probably faster, and increase slower (lower quantities of grass residues and less faeces, depending on manure management). But long CI of Exp 11 and 13 may have increased accumulation. Noble et al (2008) indicated much lower C sequestration for Gamba grass under cutting conditions, even if deeper soil layers are included. Tarré et al (2001) and ‘t Mannetje (2007) indicated higher C accumulation for grass/legume mixtures under grazing conditions.

7.5 Scenarios for use of nitrogen from fertiliser, manure and Desmodium at farm level

If cutting age increases in the scenarios, N content of manure decreases, while the C/N ratio of manure (and crop residues) increases (results not given in Table 16c). This will probably result in an increasing contribution to soil C content. However, the short term contribution of residual manure and fertiliser N to Napier productivity will probably be higher if grass is cut younger (Chapter 7.1).
The digestibility of Napier derived from the models is relatively high (thus increasing intake and potential milk production!), probably also because of the lower temperatures and growth rates in the highlands (Wilson et al, 1991 and discussion before). The scenarios indicate trends for potential milk production, in reality milk production may be lower than calculated, depending on the situation (see below).

Wouters (1985), comparing younger and older Napier grass in Naivasha, measured DM intakes of 154 and 118 g kg^{-1} $LW^{\wedge 0.75}$ (10.8 and 13.7 kg DM cow^{-1} day^{-1}; live weight of cows about 400 kg). Intakes of organic matter are relatively lower, because of the high ash contents of Napier. Contents of green leaf of young and old grass supplied were respectively 57 and 40% (dead leaf 7.5 and 9.8%), ash% 20 and 16.3%, CP% 9.5 and 5.9% and % dOM 67.7 and 63%. This would allow a potential (calculated) milk production of respectively 13.1 and 7.5 kg cow^{-1} day^{-1} for young and old grass respectively based on energy intake, and of 10.7 and 2.9 kg d^{-1} based on CP intake, CP being limiting. In reality daily milk production was respectively 5.6 and 4.1 kg day^{-1} (during the pre-period 6.2 and 6 kg), probably mainly because animals were not able to produce more.

In a survey on zero-grazing farms, Napier grass being an important forage, average milk production lactation day^{-1} in Kiambu in Central Kenya was 7.8 kg with 2.2 kg concentrates cow^{-1} d^{-1} (9.8 kg milk for the 25% best farms; Valk, 1990). Only 30% of the farms used compound fertiliser on Napier grass (average of 125 kg ha^{-1}). A review and experiments from Muia (2000), also indicate that the milk yields presented in Table 16c may be over-estimated. In his experiments, Napier grass of 10 weeks old with 9% CP constituted 78 and 62% of the ration, resulting in a milk yield of 10.9 and 13.1 kg cow^{-1} d^{-1}. The effect of nitrogen on sward composition and animal production was not measured in these experiments. Cowan et al (1995) measured in Queensland in Australia an N effect of 8 kg milk per kg N for cows grazing on Rhodes grass, and 4.5 kg milk at higher N rates (from 150 to 600 kg N ha^{-1} $year^{-1}$), but also refers to lower and larger effects in his discussion, depending on the situation. He also indicates that swards degenerated in botanical composition and yield without N .

Table 16c indicates a potential annual milk yield of about 17 Mg ha^{-1} Napier with an annual application of 210 kg N ha^{-1} (for 2 growing seasons combined), and for an average supplementation of 4 kg concentrates lactation day^{-1}. Specialised dairy farmers are able to realize this potential. This was demonstrated by for example an intensive specialised dairy farmer in Kisii district with 3 dairy cows (and 1 young stock) in a zero-grazing unit with excellent manure management. He daily applied and incorporated slurry manure produced on about 0.4 ha Napier grass (with little or no use of fertiliser).

The farm nutrient balance mainly depends on contents in exported milk and imported concentrates (at a low cattle replacement level). With a supplementation of approximately 1 kg concentrates 5 kg^{-1} (exported) milk, and respectively 0.5 and 2.5% N and 0.09 and 0.45% P in milk and concentrates, NPK input and output are more or less in balance. An question is to what extent optimal management, including frequent manure collection and incorporation (as soon as feasible) can minimize nutrient losses and external nutrient requirements.
In this respect it might be interesting to compare 2 systems of Napier management during a longer period: cutting at relatively younger and older age to investigate the role of N cycling (lower NY if grass is cut older in the present “short” during experiments; see before), while recycling all manure to Napier, complemented with model approaches.

Picture 3 Maize inter-cropped with the legume lablab (Lablab purpureus), also an option for silage making

Other questions are how forage legumes and grass/legume mixtures (probably minimal N losses if cut only), feed reservation/conservation and crop rotation best fit into such a system. Relatively small proportions of additional reserved/conserved forage may suffice to maintain animal productivity during periods of Napier shortage, provided that dry periods and stocking rates are no too long/high (Farina et al., 2011), possibly also including maize (stover) silage (made co-operatively by a group of farmers?; Picture 3). The quality of maize stover may improve through intercropping with for example a protein rich legume such as lablab (Picture 3). Both can be ensiled together (according to an experiment in Naivasha; results not given).
Under conditions of (mainly) zero-grazing the danger of N losses from leaching from relatively deeper rooting Napier grass is probably much lower than from systems based on grazing as described by Farina et al (2011). Cutting management of Napier grass may also depends on risks for drought. If cut older, deeper rooting Napier (if the soil allows) probably reduces drought sensitivity, while leafy tops of Napier grass may be fed, using stemmy parts for mulching (on for example less responsive plots; see before). The present experiments cannot answer these questions. It probably requires on farm monitoring of the nutrient cycle from excretion to harvest for a longer period under variable conditions, supported by on station research. Separate urine collection or slurry passing through a biogas unit (frequent collection and incorporation) may also be options to consider to minimize N losses. Where feasible, crops may also be also rotated in together with neighbouring or local farms to maintain potential positive effects of specialisation (local mixed farming; Steinfield et al., 1996).

Picture 4 Feeding of dairy cows in a zero-grazing unit

Provisional guidelines to improve Napier management
In optimizing fertiliser and Napier use some of the guidelines below may help

- Nitrogen application can be profitable if it helps to supply additional forage in periods of shortages, depending on the milk price, but not in times of surplus. Nitrogen rates need to be adapted to target yields (less for lighter cuts), sward characteristics (less if plant distance increases; use residual green leaf as an indicator of rate of re-growth), and expected variation in moisture availability (not if (longer) dry periods are expected, for example using region specific weather forecasts).
- Variation in N application and cutting management can help to balance forage supply and demand in time (see also Picture 1). The NDDP recommended to apply and incorporate slurry manure produced twice weekly on Napier grass, with additional application of compound fertiliser N during the middle of the long rains and at the start of the short rains.
- In using fertiliser N as topdressing, in addition to manure, practical tools such as leaf colour and/or fertilizer windows with higher application rates may also play a role in correcting application rates (see later).
- Incorporation of manure and fertiliser N, also depending on type, limits N losses from ammonia volatilisation, erosion, and leaching from low spots
- To optimize N distribution spot application or banding close to plants is required, in particular if plant distance increases. Adaptation to soil characteristcs such as organic matter content (and SNS, provided that a fair estimate is feasible; see before), soil texture (also of the topsoil; Snyman, 2005), and expected N release of nutrient sources may help. Optimal timing and distribution may not only reduce N losses, but may also contribute to weed control, thereby also improving ANR of Napier.
- In periods with surplus forage, young grass with high leaf content may be prewilted and ensiled, while older grass may be reserved as standing forage for dry periods. Alternatively, tops of old grass may be fed, while lower stem parts may be used for mulching.

In reality it is still more complicated to optimize grass supply throughout the year than explored in the scenarios given. To maintain a more or less constant grass quality, different development stages are required (see Picture 1 in Chapter 7.1). During the start of the rainy season it will be necessary to combine feeding of older reserved grass with new young grass, increasing the amount of young grass if availability increases. It may also be an option to fertilise cuts differently, according to forage requirements (see before). Alternatives are silage or hay making to bridge the dry period, but alternatives such as silage from maize (stover) and hay from for example Rhodes grass (drying faster than Napier) or Lucerne may be more feasible. But if labour availability allows, wilted silage from young leafy Napier grass (or hay from mainly leaves of young chopped Napier grass dried on black plastic?) may be alternatives to reservation of older grass if dry periods become too long.

Preliminary tool to estimate forage and roughage quality
To support the discussion on methods to help farmers to improve forage management and animal nutrition, tools may be developed to estimate forage quality as an alternative to laboratory results (see 7.2). Scheme 1 explores this approach through the devise of a preliminary tool to estimate forage quality (including some crop residues) from morphology (leaf content and grass height) for Napier grass, colour and forage stiffness. It consists of 8 forage classes indicating differences of in particular CP and dOM. It is also inspired by maturity classes for Napier given by Muia (2000), and classes developed for use of green manure (Palm et al, 2001). Picture 2 shows a stick, as possible tool to estimate Napier colour and height. Such a tool (or another) may be further developed in successive cycles of learning and improvement together with farmers. The ranges in dOM are rather wide, and additional parameters including age and DMY may be required. Nitrogen supply (external and soil N) is not included, but N supply is important for CP content at young ages (Chapter 3.1, 7.1 and 7.2).

Scheme 1 Preliminary scheme to estimate ranges in contents of CP and dOM from indicative grass height (H in feet) and leaf content (for Napier only), and colour and stiffness.

Forage class	**H (ft)**	**Leaf%**	**CP (%)**	**OMD (%)**	**Forages/roughages**
1. Hard yellow brown			3-7	40-55	Poor grain stover
2. Softer yellow green	>4	20-35	3-7	55-65	Poor old tropical grass
3. Harder light green			7-11	40-55	Legume stover
4. Soft hard light green	3-5	30-50	7-11	60-70	Medium old grass
5. Soft light green	2-3.5	45-70	10-14	65-75	Medium young grass
6. Harder green			10-17	55-70	Grass/legume mixtures
7. Soft green	1.5-3	55-80	13-17	70-80	High quality tropical grass
8. Soft dark green			17-30	65-80	High quality legumes

8 Conclusions

1. In Exp 1 to 7, DMY increased with cutting age and N rate. The leaf content and leaf/stem ratio and contents of CP and ash decreased with CI, while content of dead leaf increased
2. If cutting regimes are harvested over the same period, leaf and nitrogen yields tend to peak at a cutting age of about 5-7 weeks, starting to decline subsequently.
3. In Exp 11, DMY and NY of mixtures of Napier grass with Greenleaf Desmodium were higher than of unfertilised Napier grass, respectively 44 and 196% at the short cutting height of Napier. Under the cutting conditions of these experiments, Desmodium content was still 57% after 6 years at the end of Exp 12.
4. In Exp 13-15, incorporation of cattle manure improved yields more than surface applied manure.
5. The apparent nitrogen efficiency ANE increased with CI and was more or less linear for the rather modest N rates used, with an average of 29.7 kg DM kg^{-1} N for the 4-12 week CI of Exp 1-7 and 35 kg DM kg N for the 6-18 week CI. In Exp 14 and 15, ANE was lower at the high application rate. In Exp 6, ANE reached a maximum of about 60 kg DM kg^{-1} N for the 12 week CI.
6. The apparent nitrogen efficiency ANE of surface applied and incorporated manure was respectively 24 and 27 kg DM kg^{-1} manure N in Exp 13, and on average for Exp 14 and 15 respectively 6 and 28 kg DM kg^{-1} manure N at the low application rates.
7. In Exp 1-7, average ANR was on average 53.3 and 53.7% at the low and high N rates. In Exp 13, averaged over 5 years, ANR of applied fertiliser N was respectively 54 and 53% at annual applications of respectively 110 and 153 kg N ha^{-1}. The apparent nitrogen recovery ANR of surface applied and incorporated manure N in Exp 13 were respectively 27 and 33% after 5 years of bi-annual applications. During the last 2 years, ANR of manure N increased, while ANR of fertiliser N decreased. In Exp 14 and 15, ANR of both fertiliser and manure N was lower at the high N rate.
8. In Exp 6 and 7, residual effects of fertiliser N tended to be larger if grass was cut younger and for higher N rates.
9. In Exp 12, DMY with Desmodium was approximately equivalent to an annual N application of 200 kg N ha^{-1}. Annual biological N fixation of Desmodium is estimated at 238 kg N $ha^{-1}year^{-1}$. In Exp 11, an estimated 93 and 87% of the annual yield of respectively 201 and 164 kg Desmodium N ha^{-1} in Exp 11 was derived from symbiotic N fixation if cut shorter and longer.
10. In vitro organic matter digestibility of Napier in Exp 1-9 increased with contents of green leaf, leaf/stem ratio and CP%, and strongly decreased with age and contents of dead leaf, CF, NDF, ADF and ADL.
11. The decline in dOM decreases with increase in growth rate. At the same age, effect of N on dOM is marginal, but at the same DMY, dOM is (substantially) higher with N. Corrected for differences in DMY, decrease in dOM is lower with N and during the cold season. Nitrogen can have a positive effect on both Napier yield and digestibility if other growing conditions allow.
12. A model leaf content and the reverse of grass height (L+1/H) is the best morphology model to predict dOM. A model including dead leaf is almost as good (1/L+D+1/H). These models predict dOM better than age only, and almost as well as models with age and leaf content (1/CI+1/L). Only models with the reverse of ADL and the combination of ADF with ADL predict dOM better.
13. The simple model L+1/H is probably most feasible for use in practice, in particular if leaf colour could be included. But for older grass including dead leaf may improve estimates.
14. Also CP and ash content are predicted rather well by morphology characteristics, in particular when combined with age.
15. The leaf and ash content of FC tend to be lower than for the variety Bana. Although there is a tendency for faster aging of FC, no consistent differences in dOM between both varieties can be established if corrected for differences in growth rate. Ash content also tended to be lower in Kakamega and Kisii experiments than in Naivasha.
16. Contents of CP and dOM of Napier in a mixture with Desmodium was about 1% higher than without Desmodium. Crude protein content of Desmodium was about 10% higher than of Napier, but dOM was about 15% lower.
17. In scenarios exploring effects of N on milk yield at a rate of 210 kg N ha^{-1} $year^{-1}$ (1 kg N ha^{-1} day^{-1}) during the growing season), the increase in milk yield per kg fertiliser N varies

from 13.1 kg milk per kg N at the 6 week cutting interval to -10.6 kg at the 16 week cutting regime. However, for half the N rate, the effect of N improves substantially, from 15.2 to 3.5 kg milk per kg fertiliser (equivalent) N. There was an optimum for N use around cutting ages of 6 to 8 weeks.

18. The results of Exp 11 and 13 indicate that, if compared to unfertilised pure Napier grass, use of organic manure in particular, but also fertilizer N and Napier/Desmodium tended to improve soil carbon content, also under the (cutting) conditions of these experiments. This effect tended to be higher for older cutting in Exp 11.

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Annexes

Annex 1 Results of soil analysis.

Soil contents 0-20cm of carbon (C), nitrogen (=N), C/N ratio, pH, phosphorus (P), and calcium (Ca) before the start and at the end of some experiments. Estimated quantities of soil C and N (respectively Mg and kg ha-1) and annual soil nitrogen supply (SNS in kg ha-1) are also given. See further text and abbreviations.

Experiment/ period	**C** (%)	**N** (%)	**C/N** ratio	**pH**	**P** ppm	**Ca** meq %	**Soil C**	**Soil N**	**SNS**
Before start									
Exp 6 (1989)	2.9				15				
Exp 7 (1989)	1.65				12				
Exp. 11/13 (1982)	1.7	0.17	10	8.1	26	16	42.5	4250	
Exp. 15 (1990)	2.9				15		72.5		171
At the end									
Exp. 11 (1990)									
Na-s	1.33	0.19	7.0	7.5	44	15	33.3	4750	96
Na-l	1.43	0.16	8.9	7.4	40	18	35.8	4000	94
NaDes-s	1.41	0.17	8.3	7.1	40	19	35.3	4250	
NaDes-l	1.52	0.21	7.2	7.2	28	20	38.0	5250	
Exp. 13 (1990)									
N=0	1.17	0.15	7.8	7.2	32	23	29.3	3750	118
N=158	1.84	0.18	10.2	7.5	32	20	46.0	4500	
Ms	1.93	0.23	8.4	7.5	44	25	48.3	5750	
Mc	1.95	0.23	8.5	7.6	40	24	48.8	5750	

Samples are composite samples to a depth of 20 cm from 20 spots per field or treatment. In Naivasha (Exp 11 and 13), a single composite soil sample was taken from a larger field (including the experimental sites) after ploughing of pasture in 1982. At the end of experiments in 1990 single composite samples were taken per treatment. But at the actual start of the experiments, carbon and N contents were probably already (substantially) lower, because Napier established after ploughing in 1982 (?) developed irregular due to drought and a failing irrigation system, and was established again in 1983. This was followed by several unfertilised clearing cuts before the start in 1985 (cuts with still a fair/reasonable yield, probably due to nutrient release from decomposing organic matter). Soils of Exp 6 and 15 in Kakamega and Exp 7 in Kisii were sampled at the start of experiments. Soil C and N contents are based on an estimated 2500 Mg dry soil ha^{-1}.
The results of soil analysis in 1982 give probably an indication of soil fertility for other experiments in Naivasha because all experiments were executed on the same larger former pasture field. But history was not always the same. Exp 3 for example, was established after an intermediate maize crop, while Exp 4 was established after pasture.

Annex 2a. Precipitation and temperature in Naivasha

Precipitation (P in mm) from 1985 to 1991 and temperature (T in ^{0}C) in Naivasha. Normal precipitation for Kiambu in Central Kenya is also shown. Based on Jeatzhold and Schmidt (1982).

	1985	1986	1987	1988	1989	1990	1991	Normal		*Kiambu*
	P	P	P	P	P	P	P	P	T	*P*
January	0	10	23	60	55	27	17	24	17.6	*44*
February	89	11	6	0	34	96	0	39	17.6	*48*
March	0	12	57	81	47	133	115	59	18.3	*113*
April	278?	104	37	231	107	165	58	113	18.0	*246*
May	89?	105	107	76	129	88	61	84	17.2	*177*
June	51?	23	150	50	22	18	80	41	16.0	*48*
July	21	0	53	26	48	47	4	34	15.5	*26*
August	14	35	40	81	109	48	19	44	15.8	*31*
September	69	24	4	25	53	18	40	44	16.2	*31*
October	36	44	16	33	100	71		47	17.2	*72*
November	49	43	46	37	43	54		59	16.8	*148*
December	*25*	*40*	*15*	*35*	*128*	*33*		*39*	*17.0*	*84*

Annex 2b Precipitation and temperature in Kakamega and Kisii.

Precipitation (mm) and average temperature (^{o}C) for Kakamega and Kisii during the experiment and long term averages (Normal).

	Kakamega				Kisii			
	P	T	P	T	P	T	P	T
	1989	Normal	1989	Normal	1990	Normal	1990	Normal
January	20	55	20.3	21.1	136	72	21.0	19.4
February	81	111	21.2	21.6	217	103	20.9	20.2
March	187	178	21.3	21.4	334	194	20.1	19.8
April	243	240	19.7	21.1	425	290	20.3	19.4
May	240	239	17.4	20.5	304	238	20.3	19.6
June	167	150	18.3	20.1	91	155	19.9	18.9
July	111	133	19.3	19.3	110	104	19.6	18.4
August	273	224	19.4	19.8	143	169	19.6	18.8
Sept	176	172	19.7	20.4	126	193	20.5	19.1
October	219	169	20.4	20.4	134	148	20.7	19.5
November	125	152	20.9	20.6	125	165	20.3	18.7
December	148	98	20.3	20.8	105	122	20.4	19.1
Total/Ave	1990	1918	19.9	20.6	2250	1952	20.3	19.2

Average precipitation in Naivasha, Kakamega and Kisii is about 600, 1900 and 1950 mm. In Naivasha precipitation was supplemented to about 1000 mm year^{-1} through irrigation, to simulate the long and short rainy seasons in Kiambu district in central Kenya (no irrigation from January to March). Supplementary sprinkler irrigation, if functioning, was mainly applied during night time (range from about 20-60 mm per irrigation?) but water distribution from sprinklers was far from optimal. Irrigation was also irregular at times, due to failure of the irrigation system, in particular during Exp 1 and part of Exp 10 and 13. The precipitation during Exp 3, 4, 6 and 7 was respectively 217, 107(including irrigation 278 mm for Exp 4), and about 1000 and 700 mm (Kakamega and Kisii). Intensity of rain varied. During the dry season of Exp 3 there was a shower of 76 mm in the beginning of February (after the harvest of the 12 week CI).

Annex 3a Experimental variation

Experimental sites were sometimes irregular due to lack of suitable land. Despite blocking and randomisation variation in for example soil fertility between treatments was too high in several experiments. Also poor water distribution from irrigation (and failing irrigation during part of 1984 and 1988) and salty spots in Naivasha increased variation during serious drought. For that reason a dry season experiment (Exp 10) with a design similar to rainy season Exp 1 is only partially discussed. In Exp 3 and 6 some treatment combinations were sited more frequently on productive edges. Heavy rainfall and/or irrigation (in Naivasha; sloping site in Kisii) may have increased N losses in some experiments. Although fertiliser N was concentrated on and around the stubble, some N might have been eroded and leached after a heavy shower soon after application. In Exp 13 there was serious damage from mole rats in a cut after a very long dry period. Also determination of CP% in single samples and some mistakes probably play a role (see below).
In Exp 3 in Naivasha the yield for the 15+3 week CI at the 50 kg N rate was much higher, possibly due to poor water distribution and probably salty spots or another unknown reason, including mistakes. Also in a few other cases errors were suspected (in particular exchange of results between plots), but errors could not be confirmed, therefore no changes have been made. The experimental plot of Exp 7 was sloping and less homogeneous and because of lack of suitable land the 4 and 8 week cutting interval were omitted. In Exp 6 there was a fertile edge on some blocks. The data for DM contents of the second cut of the 6 week CI of Exp 6 were not available and assumed to be 15%. In Exp 13 only 2 of the 3 replicates were used for further analysis because of poor water distribution from irrigation. In Exp 15 the third cut was incidentally grazed by cattle and excluded from analysis, including the first re-growth (total of 9 weeks). Dung pats were removed. Slurry composition was also missing for 1 (of 6 cuts) and assumed to be average.
Collection and content of dead leaf was relatively more prone for mistakes, because of relatively small quantities and higher contamination with sand. Some fallen dead leaf was sometimes included unintentionally during sampling. The high % dead leaf at the 12 week CI for N=84 (21.4%). Results for this treatment are derived from this cut (the second) only. The reason is unknown. Contents of green and dead leaf and grass height were sometimes not determined to save on labour (mostly for later cuts). Although statistical analysis was performed for the same dataset when comparing for example morphological and chemical parameters, this may have contributed to variation between prediction models. The relatively high ash content of Napier grass may have contributed to variation for results expressed in organic matter.

Annex 3b Chemical analysis

The chemical analysis was carried out by the laboratory of the Research Institute for Livestock Feeding and Nutrition (IVVO-DLO) in Lelystad (The Netherlands), the department of Animal Nutrition of Wageningen University (Exp 4) and the University of Nairobi (Exp 5), possibly contributing to variation. The contents of ash, crude protein (CP) and crude fibre (CF) were determined according to the Weender Analysis. The content of NDF, and where appropriate, ADF and ADL were determined according to the Van Soest methodology (Steg et al., 1990), the in vitro organic matter digestibility, according to the two stage in vitro technique described by Tilley and Terry (1963). The data were corrected to a predicted in-vivo digestibility by including in-vivo tested samples in each in vitro run. The in vivo digestibility's of these standards was: 81.4 (grass), 45.7 (wheat straw), 67.1 (grass), 84.9 (grass), 16.0 (reed), 30.0 (willow twigs), 81.2 (grass), 64.4 (grass), 75.3 (grass), 76.3 (grass), 81.3 (grass), 79.5 (grass), 77.2 (perennial ryegrass). Standards with known in vivo digestibility of Napier grass were not available in Lelystad. Therefore wheat straw, willow twigs and reed were included to represent the older, less digestible Napier samples. More details are given in the (grey) reports of respective experiments.

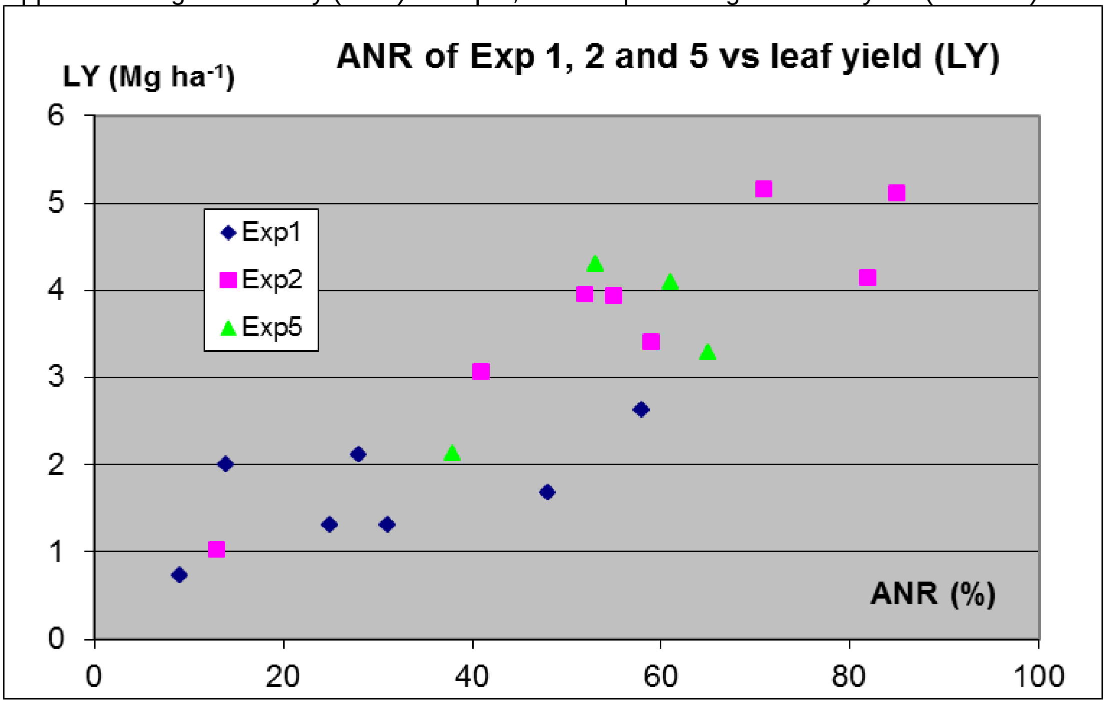
Annex 4 Residual nitrogen recovery in Exp 6 and 7

Residual nitrogen recovery (%) in Exp 3 and 4 (after the first cut), and in Exp 6 and 7 (determined at respectively 4 and 10 weeks after the last cut)

	CI in weeks	**N=1**	**N2**
Exp 3	3*6	16	17
	2*9	-1	11
	12+6	7	3
	15+3	4	0
Exp 4	3*6	17	3
	2*9	-3	3
	12+6	2	4
	15+3	4	3
Exp 6	4	7.8	6.2
	6	5.7	6.3
	8	-4.4	2.8
	12	-5.0	3.1
Exp 7	6	-8.3	-0.2
	12	-6.4	-6.5

Annex 5 Nitrogen recovery and leaf yield

Apparent nitrogen recovery (ANR) of Exp 1, 2 and 5 plotted against leaf yield (R^2=0.87)



Annex 6 Tiller density, cutting age and N application

Tiller number of the re-growth per CI and N rate one week after the harvest of the last cut of Experiment 6. The least square difference (LSD for P<0.05) is also given

CI	N=0	N=84	N=168	Average
CI=6 weeks	94	68	93	85
CI= 12 weeks	29	19	26	25
Average	62	43	59	LSD=14/12

Annex 7 Correlation matrix for dataset A (n=155)

dOM	1														
leaf	0.627	1													
dead	-0.624	-0.817	1												
stem	-0.525	-0.942	0.577	1											
leaf2	0.636	0.995	-0.808	-0.941	1										
1/leaf	-0.586	-0.974	0.794	0.919	-0.949	1									
H	-0.588	-0.744	0.606	0.703	-0.736	0.741	1								
1/H	0.638	0.709	-0.573	-0.672	0.722	-0.659	-0.892	1							
DMY	-0.651	-0.773	0.654	0.716	-0.764	0.766	0.917	-0.835	1						
CI	-0.752	-0.803	0.804	0.671	-0.807	0.757	0.769	-0.758	0.773	1					
1/CI	0.760	0.762	-0.704	-0.670	0.775	-0.701	-0.747	0.820	-0.744	-0.946	1				
T	-0.034	0.409	-0.335	-0.385	0.395	-0.417	-0.104	0.165	-0.188	-0.298	0.292	1			
ash	0.132	0.266	-0.186	-0.269	0.261	-0.271	-0.591	0.562	-0.504	-0.378	0.409	-0.018	1		
CP	0.766	0.745	-0.685	-0.658	0.759	-0.691	-0.624	0.661	-0.594	-0.837	0.860	0.169	0.159	1	
CPOM	0.760	0.755	-0.689	-0.670	0.768	-0.701	-0.666	0.706	-0.630	-0.858	0.887	0.172	0.264	0.994	1
	dOM	leaf	dead	stem	leaf2	1/leaf	H	1/H	DMY	CI	1/CI	T	ash	CP	CPOM

Annex 8a Models for dOM for dataset B

Models for the relationship between dOM and age (CI in days), % green or dead leaf, grass height (in cm) and DMY (Mg ha^{-1}) for all cutting ages of Exp 1-11 (n=255). The standard errors of the regression coefficients, MSres and R^2 are also given. See text for abbreviations.

MSres	R^2	Cst	CI	CI_1	leaf	leaf_1	dead	H	H_1	CI.H	T	S	Eq
4.37	**35**	69.75	-0.057	253.1									4a
P<0.001		±1.38	±0.008	±32.5									
3.94	**44**	70.58		306.1		-329.7							5a
P<0.001		±1.24		±24.8		±35							
3.82	**44**	70.72		299.4		-319.7						-1.09	5a1
P<0.004		1.24		25		34						0.38	
3.86	**45**	71.87	-0.0237	257.7		-258.6							5a2
P<0.009		±1.32	±0.009	±31		±44							
3.82	**52**	83.76	-0.02448	241.9		-269.4					-0.66		5a3
P<0.007		±4.198	±0.0089	31		±43					±0.22		
4,01	**43**	67.94		265.1						-0.00041			6a
P<0.001		±1.09		±28.7						±0.00005			
5.14	**32**	78.17				-446.7	-0.1054						7a
P<0.004		±1.17				±53	±0.037						
5.2	**37**	56.97			0.221		-0.106						7a1
P<0.002		±1.6			±0.02		±0.034						
5.28	**38**	60.81			0.1982	-171							8a
P<0.02		±3.38			±0.034	±76							
7.42	**4**	71.1						-0.058	151.1				9a
P<0.007		±2.17						±0.014	±55.5				
5.38	**40**	54.36			0.224				107.6				10a
P<0.004		±1.18			±0.02		21-1		±32.6				
4.82	**44**	71.77				-271.2	-0.1492		211.6				11a
P<0.001		±1.35				±53	±0.035		±27				
4.79	**48**	84.08				-308.6	-0.1233		201.1		-0.67		11a.1
P<0.008		±4.69				±54	±0.035		±27		±0.25		
4.54	**45**	71.92				-272.4	-0.1273		214.3			-1.45	11a.2
P<0.001		±1.33				±52	±0.034		±26			±0.42	

Annex 8b Models for dOM for datasets C, C1 and C2

Models for the relationship between dOM and age (CI in days), % green or dead leaf, grass height (in cm) and DMY (ton ha-1) for other datasets C (n=386), C1 (n=323) and C2 (n=304). The standard errors and MSres and R^2 are also given. See further text, also for abbreviations and Chapter 2.

MSres	R^2	Cst	CI	CI_1	leaf	leaf_1	dead	H	H_1	CI.H	CI.DMY	T	S	n	Eq
5.46	**52**	72.99	-0.08725	183.1			T+ ns							323	4b
P<0.001		±1.23	±0.0073	±23											
5.45	**59**	72.49	-0.089	202.3										386	4b.1
P<0.001		±1.11	±0.007	±27											
3.39	**78**	74.39	-0.1073	221.1									-3.773	199	4b.2
P<0.001		1.75	0.014	43									0.81		
4.37	**64**	73.35		256.4		-414.7								323	5b
P<0.001		0.97		21		25									
4.35	**68**	83.15		249.8		-420.5						-0.56		323	5b.1
P<0.009		3.84		21		25						0.21			
4.25	**65**	73.54		250.2		-407.6							-1.14	323	5b2
P<0.002		0.96		21		25							0.36		
4,18	**70**	84.97	-0.03329	189.2		-334.8						-0.56		323	5b3
P<0.008		3.78	±0.0083	25		33						0.21			
4.13	**66**	75.09	-0.02875	199.7		-335.9							-0.85	323	5b.4
P<0.02		1.06	0.009	25		33							0.37		
4.08	**52**	67.75		285.3						-0.00044				304	6b
P<0.001		±0.97		±26						±0.00004					
3.94	**53**	68.06		276.2						0.000435			-1.24	304	6b.1
P<0.001		0.96		26						0,00004			0.38		
4.08	**52**	66.57		315.4							-0.0054			304	6b.2
P<0.001		0.91		24							±0.0005				
5.79	**58**	79.55				-499	-0.1023							323	7b
P<0.001		±0.82				±37	±0.32								
5.93	**53**	56.43			0.2377		-0.1067							323	7b1
P<0.001		±1.41			±0.018		±0.033								
5.57	**57**	67.38			0.1427	-327.4								323	8b
P<0.001		±2.48			±0,025	±53									
7.42	**22**	72.21						-0.0687	133.3					304	9b
P<0.004		1.77						0.011	46						

Annex 8c Models for dOM with age, grass height and NDF and/or ADF for dataset F

Models for the relationship between dOM and age (CI in days), grass height (H in cm) and NDF and/or, ADF for Exp 1-4 and 6-7 (n=57; dataset F). The standard errors of the regression coefficients, and MSres and R^2 are also given. See further text, also for abbreviations and Chapter 2.

MSres	R^2	Cst	CI_1	H	CI.H	CI.DMY	CP	CP_1	CF	NDF	ADF	T	Eq
2.87	**61**	73.16	167.6		-0.00079								6c
P<0.02		2.98	69.3		0.00013								
3.11	**66**	69,8	266,2			-0.00908							6c1
		2,56	61			0.0016							
3.25	**45**	80.23		-0.1093									9c
P<0.001		3.06		0.007									
3.17	**88**	132.4		-0.0979								-2.875	9c1
P<0.007		9.66		0.007								0.49	
3.53	**77**	147					-0.6164	-73.22	-0.8155	-0.4229			29
P<0.05		13					0.248	26	0.28	0.21			
2.29	**71**	124.7									-1.299		30
P<0.001		3.7									0.73		
2.4	**88**	147.5									-123.4	-1.38	31
P<0.009		9									0.08	0.49	

Abbreviations and definitions

ADF = acid detergent fiber
ADL = acid detergent lignin
AIA = acid insoluble ash (silica)
ANR = apparent nitrogen recovery (see below)
ANE = apparent nitrogen efficiency (see below)
CI = cutting interval is the age (growth period) of grass (in days or weeks) at the cutting date or the interval between 2 cuts; 1/CI is 1 divided by age
CP = crude protein
CF = crude fiber
DM = dry matter content
DMY = dry matter yield
dOM = in vitro organic matter digestibility
DOM = dOM in DM
GR = daily growth rate in kg DM ha^{-1}
H = grass height in cm (1/H = 1 divided by grass height)
L and D = contents of green and dead leaf ; 1/L=1/leaf
LSR = leaf stem ratio
LSD = Least square difference ($P<0.05$)
MSres = the residual mean square.
N = nitrogen
NDF = neutral detergent fiber
NY = nitrogen yield
OM = organic matter
Pennisetum purpureum (= Pp): elephant or Napier grass
R^2 = correlation coefficient
se = standard error
SNS = soil N or, if applicable nutrient supply (yield) without fertilisation.
T = average daily temperature in C^o.
TDN = Total Digestible Nutrients = DOMD +1.25 (based on 1.25% fat!)

Definitions:

ANR (apparent N recovery in %) and **ANE** (apparent N efficiency in kg DM kg^{-1} N) are based on the increase in respectively harvested N and harvested DM with applied N compared to a control without N.
The square root of **MSres** is equal to the standard error (se)
SNS equals the NY (harvested N) without N application, excluding N in stubble and roots!
The **T-sum** equals the sum of **T** based on monthly long term daily temperature averages for Naivasha and for temperatures measured on site in Kakamega and Kisii (Exp 6 and 7). In regression equations the T-sum is divided by 100!
Leaf content is content of green leaf, 1/leaf is one divided by green leaf content.

Acknowledgements

The authors are indebted to all who contributed to the execution of the original experiments and to this resulting overall report. We thank especially the Kenya Agricultural Research Institute (KARI), the National Dairy Development Project (NDDP), the director of the National Animal Husbandry Research Centre (KARI-NAHRC) in Naivasha, staff of the zero-grazing unit and laboratory of KARI-NAHRC, directors and staff of the KARI regional research centers in Kakamega and Kisii. We thank especially Mr Francis Wekesa (who passed away), and Mr William Ayako (both formerly KARI-NAHRC), because they contributed throughout the period that experiments were conducted.
For their suggestions to improve experiments and for their comments to improve the initial manuscript we thank especially Mr. S. Schukking, Mr. V. Hindle and Mr Arne Steg (present or former collaborators of Wageningen UR Livestock Research) and Mr Hugo van der Meer (Wageningen UR, Plant Research international). For support during statistical analysis of data we thank especially Mr Johan van Riel, Gert Jan Holshof and Ronald Zom (all Wageningen UR Livestock Research). But the authors remain responsible for the content of the manuscript.



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