Susanne Barth · Dan Milbourne *Editors*

Breeding Strategies for Sustainable Forage and Turf Grass Improvement

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Preface

From the 4–8th of September 2011, the Eucarpia Fodder Crops and Amenity Grasses Section held its 29th Meeting in the impressive surroundings of Dublin Castle in Ireland. Over one hundred and twenty scientists from 21 countries, all working in the area of the genetics and breeding of forage species, attended the meeting, which was themed '**Breeding strategies for sustainable forage and turf grass improvement**'. Why did we choose this theme?

Grasslands cover a significant proportion of the land mass of the world, and play a pivotal role in global food production. At the same time we are faced with several challenges that affect the way in which we think about this valuable set of resources. The population of the world is expected to exceed 9 billion by 2050, and increase of about one third relative to today's levels. This population increase will be focused in urban areas, and in what are currently viewed as "developing" countries, meaning that the buying power of this increased population will be greater—shifting the balance of demand from staple crops to high value items such as meat and dairy products. Overall this means that the world will have to approximately double agricultural output across all categories of food to meet the demands of this larger, urbanised population. This is occurring against a backdrop of equally large challenges in terms of global climate change. Agriculture is already a significant contributor to things such as greenhouse gas emissions, deforestation and soil erosion. The situation is made more complex by an increased emphasis on biofuels as a solution for our imminent oil shortage, resulting in increased competition between land utilised for food and fuel. In short, agriculture must continue to feed the world, whilst not contributing to damaging it further. It must be sustainable. Plant breeding plays a significant but frequently understated role in meeting the challenges presented by this complex and changing scenario. However, plant breeding and improvement is itself undergoing radical change, driven by technologies that, quite frankly, seem to have sprung from the pages of science fiction novels written decades ago.

Thus, it seemed to us, when given the opportunity to organise this meeting, that it was timely to explore how forage and turf breeding is changing and adapting to meet these challenges using the technological advances being experienced in plant breeding as a whole. Consequently, the meeting focused heavily on how next generation sequencing technologies are interacting with advanced phenotyping strategies for a variety of increasingly well defined traits. This type of analysis is powerful, potentially telling us a lot about the genetic control of these traits, but also has the potential to revolutionise plant breeding via approaches such as genomic selection (GS).

A wonderful characteristic of the membership profile of Eucarpia is that the membership is composed of a mixture of plant scientists from multiple disciplines and practical breeders. While some of us wax lyrical about the potential of approaches such as GS, it's always useful to have breeders present who can ask pointed questions about how much this is going to cost them, and how it's better (i.e. more cost effective per unit of genetic gain) than what they currently do. This can sometimes be an uncomfortable experience, but it is through such a frank exchange of ideas that real progress is made.

As well as the focus on advanced technology, the meeting featured the usual interesting array of topics that attract the broad audience that attends the section meetings. Several contribution focused on the use of germplasm of grasses and legumes to improve the vegetation in different environmental conditions, particularly under conditions to be expected by climate change—these addressed the theme in a way in which we hadn't considered when we discussed it originally (again showing the advantage in a broad section membership). There were also regular topics such as the results of the EUCARPIA multi-site rust evaluation, showing that over a period of 11 years there is no evidence that crown rust resistance in individual *Lolium* cultivars was overcome by the pathogen), and the Festulolium satellite workshop.

This book contains papers based on many of the oral and poster presentations presented at the Dublin meeting. With some minor changes to represent the diversity of material presented, the papers are organised in sections fairly similar to the session topics, and for the purpose of this volume, are grouped into the following sections: European grasslands in the future; Breeding strategies; Novel emerging tools for the breeding of forage and turf crops; Breeding towards breeding objectives; Genetic variation and adaptation; and Agronomy and performance of forage and turf crops. We hope they present a good snapshot of a very stimulating meeting, and will be a useful resource for participants and those who couldn't attend.

We would like to acknowledge the enormous efforts of the local organising committee members (Connie Conway, Dermot Forristal, Dermot Grogan, Eleanor Butler, Patrick Conaghan), with a special mention for Connie Conway and Eleanor Butler, without whom the meeting would not have run so smoothly and efficiently. Finally, the work of the scientific committee and referee board for this book (Beat Boller, Bohumir Cagas, Christian Huyghe, Daniele Rosellini, Danny Thorogood, Dejan Sokolovic, Dermot Grogan, Dirk Reheul, Jan Nedelnik, Joost Baert, Michael Abberton, Michael Camlin, Niels Roulund, Paolo Annichiarico, Petter Marum, Roland Kölliker, Trevor Gilliland, Trevor Hodkinson, Ulf Feuerstein and Ulrich Posselt) must also be acknowledged, especially in providing their time so graciously and uncomplainingly to review the papers for this volume, and ensuring a high quality of presentation in these proceedings.

Carlow, Ireland
Susanne Barth
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Part I

Introduction: European Grasslands in the Future

Chapter 1
What Global and/or European Agriculture Will Need from Grasslands and Grassland Breeding over the Next 10–15 Years for a Sustainable Agriculture

D. Reheul, B. de Cauwer, M. Cougnon and J. Aper

Abstract The paper analyses actual trends in (European) ruminant agriculture and grassland based production systems. Consequences of reduced and/or zero grazing for grass breeding and grassland management are discussed. The impacts on eco-efficiency, recycling of minerals and ecosystem services are highlighted as well as the role of ley-arable farming. Special emphasis is on the potential use of tall fescue as a component of mixtures or as an interspecific cross. In grazed grassland, the role of white clover, the disease resistance and the nitrogen use efficiency of the grasses and the significance of biodiversity are considered. Based on an article published by Parsons et al. (2011) some reflections on the way ahead in grass and forage breeding are presented.

1.1 Introduction

At the start of the second decade of the twenty-first century, agriculture is changing faster than ever in most (European) countries. Attempts to realize some radical changes in the way we live, confront us with the tremendous complexity of societies. This results in important gaps between what should happen and what really is occurring. In theory, sustainable development aims at compromises between socio-economic and ecological imperatives. The transition from today's reality to this new world is a most difficult process passing along several stepping stones (Meerburg et al. 2009). It is occurring mostly within existing paradigms improving the eco-efficiency or eco-productivity ("producing more with less") of processes and making them cleaner and more rewarding. Next to this major development new paths are explored.

Agriculture is changing in line with the major drivers in society. Mainly driven by European policy, farming has become a very regulated business. To cope with

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this, the most striking development during the past years is the very fast expansion of agricultural enterprises both in terms of means of production, technology application, management and alliances. While this evolution is going on, scientists and policy makers already think way ahead of actual evolutions. A striking example is the newest report of the Standing Committee of Agricultural Research (SCAR) (Freibauer et al. 2011). The report clearly proposes to move away from the existing paradigm of productivity and replace it by the paradigm of sufficiency where consumer-driven, technology-driven and organizational innovation-driven pathways are building blocks of the transition. The report states "Scientific advance has the potential to bring forward agro-ecosystems that are both productive, respectful for ecosystems and resource saving. Demand increases need to be mitigated through behavioural changes, the internalization of environmental externalities and appropriate governance structures". If one has to reflect on what European agriculture will need from grassland, one cannot deny this report.

Actual trends form the main frame of this presentation. Grafted upon this main frame are scientific developments, potential implications of climate change and personal reflections.

Apart from the mentioned SCAR report, a number of recent high quality publications inspired the authors, e.g. Towards sustainable grassland and livestock management (Kemp and Michalk 2007), Genetic improvement of forage species to reduce environmental impact of temperate livestock grazing systems (Abberton et al. 2008), Proceedings of the international conference on grasses for the future (O'Donovan and Hennessy 2010), *Handbook of Plant Breeding*, fodder crops and amenity grasses (Boller et al. 2010), Producing milk from grazing to reconcile economic and environmental performances (Peyraud et al. 2010) and Past lessons and future prospects: plant breeding for yield and persistence in cool-temperate pastures (Parsons et al. 2011). The reader can find a lot of *quantified* data in these publications.

1.1.1 Very Intensively Used Grassland in the Lowlands

In the (lowland) areas of Europe with an intensive dairy industry, the number of dairy farms continues to decrease while numbers of cows in surviving farms are increasing rapidly. Economic scale effects and robot milking (improving the farmer's comfort) are important drivers for this evolution. As these drivers most probably will persist, this evolution is expected to continue. Although grazing may be the cheapest way to produce milk (O'Donovan and Hennesy 2010), grazing becomes difficult with very large herds particularly if the land around the milking parlour is restricted. Initially, the decision to work with large herds often goes along with restricted grazing but eventually grazing may disappear totally. The higher the numbers of dairy cows on a farm, the higher the probability that they stay in the barn year-round. In some parts of the world (e.g. New Zealand, The Netherlands), removable milking parlours may sustain grazing even when herds become very large. The diet of cows held indoors is a combination of grass and other forages with conserved forages being far more important than fresh forage. Although grass remains an important component of the diet (mainly as a provider of nitrogen and of forage structure, the latter guaranteeing a good rumen fermentation), other forages (in many cases forage maize) become the main diet components very often supplemented with a source of concentrated protein. Hence, these large dairy farms need, next to the grassland area, a lot of arable land to produce their roughage and to recycle the nutrients in the slurry.

Zero grazing can comply well with a number of sustainability indicators.

1. Harvested dry matter is higher than under grazing. If silage losses are restricted the benefit remains. Uneven yearly distribution of grass yield becomes less important, since the animals are mainly fed with conserved forage.
2. A high nitrogen export going along with low (grass-clover) to very low (grass only) soil nitrate residues (Nevens and Reheul 2003a) makes zero grazing a good system for an optimal use of slurry. A high N-input combined with early cuttings (simulated grazing management) provides opportunities to restrict CH_4-emissions per produced milk quantum (Ellis et al. 2008, Bannink et al. 2010, van Zijderveld et al. 2011).
3. Nitrogen use efficiency (NUE) on the farm level can be substantially improved (a) by modern cowsheds and covered storage of slurry, (b) by uniform and emission-poor distribution of slurry reducing leaching and ammonia losses and (c) by the composition of animal diets balancing energy from non-grass feed and protein from the grass, improving the N utilization by the animal. The latter means that the chemical composition of the grass is less important than under grazing conditions, since excesses or shortages can be compensated by other forages.
4. Compared to continuous grazing, root depth of the grasses is on average deeper under a cutting regime offering opportunities for a better nutrient uptake efficiency and hence a better NUE by the grass plants (Crush et al. 2005; Abberton et al. 2008).
5. In large animal farms, most farmers live closer to their accountancy and their animals than to their crops. One can presume that grassland management will not (always) be the first priority of these industries. Mismanagement may deteriorate the grassland very quickly. On the other hand, farms may pay a lot of attention to good grassland management in order to cut feed costs.
6. According to the EU legislation on permanent grassland, farmers may avoid to keep all their grassland longer than 5 years in order not to lose degrees of freedom in their exploitation. Hence part of the grassland may be kept as temporary grassland. If managed under a high nitrogen input, it is difficult for legumes to maintain important abundances. On the other hand, farmers may cherish the legumes in order to save N-fertilizer costs.

What Are the Consequences of Reduced Grazing for Grassland Management, for Grassland Breeding and for the Ecosystem Services of Grassland? Given the intrinsic higher yield potential of early heading varieties, the attention for early varieties may increase in zero grazing systems, provided their persistence is high. According to Chaves et al. (2009) progress in the early varieties of *Lolium perenne* L. (perennial ryegrass) was lower than in the intermediate and late heading varieties offering opportunities for breeding, with a special emphasis on good quality. Good quality usually is very closely connected with leafiness. Hazard et al. (2006) showed that selection for longer leaves leads to earlier heading dates, indicating that selection for good quality may indirectly promote earliness (Barre et al. 2009). The trait "long leaves" has a high heritability (Cooper and Edwards 1961) and is mainly determined by leaf elongation rate, easily detectable as quick regrowth.

Since early varieties concentrate their production early in the season, the effect of summer droughts may be less detrimental than with intermediate or late varieties.

If zero grazing farms choose for temporary grassland, ley-arable farming offers a number of opportunities and threats (for a review see Vertès et al. 2007) but if well designed it may fit into a sustainable management.

In the short term, grassland sown into previous arable land significantly outyields grassland sown into ploughed down grassland (Reheul et al. 2007), particularly under dry conditions, most probably owing to the deeper rooting of the young grass plants. The establishment of white clover is better in grassland sown into former arable land and the clover tends to persist better (Reheul et al. 2007).

The rotation between grass and arable crops helps to manage weeds in the arable phase of the cropping system.

The opening crop in the arable phase can be grown without any nitrogen fertilizer (Nevens and Reheul 2002; Nevens and Reheul 2003b, Bommelé 2007; Reheul et al. 2007). Forage maize is an important component of ley-arable farming in large parts of Europe. In a sustainable system, forage maize is harvested early in the autumn offering the opportunity for a cover crop as *Lolium multiflorum* Lam. (Italian ryegrass) or *Secale cereale* L. (winter rye) to get established well before the winter. This way the cover crop prevents winter erosion, nutrient leaching and provides an early cut in the next spring. The Italian ryegrass may either be ploughed down, enhancing the soil organic matter or it may produce for the entire season, helping to overcome risks as the success of forage maize may be jeopardized by dry springs or very wet autumns. If the maize is harvested late, *Lolium multiflo*rum or even *Lolium perenne* may be undersown in the maize crop. Special machines are now available to sow or drill grasses into a forage maize crop. When this is done before the canopy is closing (maize height of approx. 40–50 cm), crop damage is minimal. Tetraploid varieties may offer advantages owing to their early vigour, good cold tolerance and presumed (has to be proven) deeper rooting.

Climate change is predicted to result in a higher frequency of extreme weather conditions as hot and dry summers and wetter winters in large parts of Europe. It is well known that ryegrasses and timothy may suffer from summer (or even spring) drought with low yields and low quality during the dry spells. Species with a better drought tolerance as *Dactylis glomerata* L. or *Festuca arundinacea* Schreb. (tall fescue) can overcome poor performances during dry periods. The work of Pontes et al. (2007) showed that both species can deliver as much as or even more digestible dry matter and digestible crude protein than perennial ryegrass. Although these parameters may not be very relevant under grazing (animals graze -or reject- fresh grass and not digestible matter) they may be less irrelevant for conserved forage as is the case when ruminants stay indoors.

Quite a lot of work is currently done on fescue breeding. Mixing *Lolium* with *Festuca* may combine the advantages of both species (excellent forage quality of *Lolium spp.* and e.g. good drought resistance of *Festuca sp.*). The mixing can be done genetically in the form of *Festulolium* (see Eucarpia workshop of the Festulolium working group) or mechanically by sowing mixtures of *Lolium perenne* and/or *multiflorum* and *Festuca arundinacea*. While the abundance of *Festulolium* in a pure *Festulolium* sward is not expected to change dramatically over seasons and years this may be well the case with mixtures. Preliminary results in Belgian trials (both under grazing and cutting) do not show important shifts in species composition although the proportion of tall fescue in the harvested material is higher in early spring and during dry summer periods. A mechanical mixture may result in a transgressive over yielding driven by pairwise inter-specific interactions as indicated by Kirwan et al. (2007) who compared during 3 years mixtures with four components (two grass species and both white and red clover) in different locations across Mid and Northern Europe. Swards were managed under a cutting regime and dressed with maximum 200 kg N/ha/year. Preliminary results of our own cutting trials with mixtures of perennial ryegrass, tall fescue and white clover (dressed with about 160 kg/ha N) do not indicate a transgressive over yielding, probably because both perennial ryegrass and tall fescue belong to the same group of functional types[1] (Kemp and Michalk 2007) meaning that—according to the redundancy hypothesis—their mutual replacement has no significant impact on productivity.

The transgressive over yielding may extend into the animal, since the half life of fescue protein in the rumen is substantially higher than that of ryegrass protein, enhancing the probability of a better utilization of the protein by the animal (Abberton et al. 2008).

Different breeding programmes are currently providing new varieties of tall fescue with long and soft leaves resulting in improved palatability (Rognli et al. 2010). Many ecotypes have a high lignin concentration in the leaves lowering the digestibility, but owing to the high genetic variability of the species further progress is expected (De Santis and Chiaravalle 2001). Selection for a high leaf/stem ratio is a proper way to improve digestibility and measuring ADF and NDF are the best parameters to quantify the progress (De Santis and Chiaravalle 2001). In the mean time, the results of Mosimann et al. (2010), comparing mixtures in which either perennial ryegrass or tall fescue were the dominant component, indicated a similar digestibility throughout the year. Since tall fescue leaves have a longer life span than leaves of perennial

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[1] Grime et al. (1988) described *Lolium perenne* as a CR/CSR type, while they categorized *Festuca arundinacea* as a CSR type (CSR: strategist, CR: ruderal competitor).

ryegrass (1.72 times longer, according to Lemaire et al. 2009), harvesting is quite flexible.

Tall fescue has a stronger and deeper rooting system than ryegrasses[2] (Abberton et al. 2008, Eickmeyer 2009; Bonos 2004). This results in a better water and nutrient use efficiency since tall fescue can retrieve water and nutrients from deeper soil layers. Its ability to protrude compacted soils makes it more resistant to mechanical soil compaction and allows a better water infiltration (Crush et al. 2005; Macleod et al. 2007). Simultaneously less nutrients are expected to be leached by heavy winter rains (Eickmeyer 2009). Compared to ryegrass, the deeper root system of fescue may stock a higher amount of organic carbon.

Although tall fescue and *Festulolium* may have promising traits, evidence is needed to show that these species perform well on the fragile sandy soils, where much of the intensive dairy is centralized. While tall fescue is growing in roadsides all over Europe, it is not abundant on sandy soils (were much of the animal production in the EU lowlands is concentrated) and on soils with a low pH. This may be an indication of poor performances/persistence on these soils. There is also a need to find out what the effects are of the lower digestibility of fescues when they are a component of a complex diet.

A warming up of the climate brings along new diseases and pests, advances their outbreaks and/or enhances their frequency (Kiritani 2007; FAO 2008; Ceccarelli et al. 2010). Therefore, breeding for disease (pest) resistance will become more important than ever, since in a sustainable agriculture the restriction of pesticide application is a prerequisite. This is particularly true for diseases striking the grass plants during seed production, since Mattner and Parbary (2007) showed a negative effect of a crown rust infection of a seed crop of *Lolium multiflorum* in (the non diseased) post-epidemic generation: the lower early vigour of the seedlings and poorer performances later on (registered in pot trials) were mainly due to the smaller seed size of the diseased seed crop.

A non-grazing management has consequences for the ecosystem quality and ecosystem services of grassland. According to Reidsma et al. (2006) the ecosystem quality of a region where grassland occupies a major part of the agricultural area, can be relatively high, even if the management is very intensive. They calculated a ecosystem quality of 20 % for intensive pastures as compared to 40 % for extensive pastures, while extensive crop production has 25 % and intensive crop produc-

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[2] Breeding for a changing pattern of root distribution in *Lolium perenne* is reported by Crush et al. (2007). They reported a wide variation in genotypes for patterns of root distribution in a full-sib mapping population. They found no relationship between N-interception and patterns of distribution of DM weight of roots. Genotypes reacted on moisture stress either by increased or by inhibited root growth. Since root growth in artificial circumstances is very variable, hampering a reliable selection, they expect much of indirect marker-assisted selection of root traits in ryegrasses. This hope seems justified because of successes in rice (Steele et al. 2006) and maize (Ribaut and Ragot 2007). A high root/shoot ratio does not automatically reflect a good drought tolerance. In the experiments of Crush et al. (2005) timothy had a root/shoot ratio of 0.86 versus 0.63 for perennial ryegrass. Yet timothy is known to have a low drought tolerance.

tion 10 %. Among grassland systems, the species richness is substantially lower in cut than in grazed grassland (Smith and Rushton 1994).

Although temporary grassland is a better carbon sink than arable land, it stores about 50 % less carbon than permanent grassland and cut grassland stores about 50 % less carbon than grazed grassland (Mestdagh et al. 2004; Conijn 2007; Vertès et al. 2007), since a proper cutting management allows less senescent material to return to the soil.

There seems to be a trade-off between different sustainability indicators (emissons, carbon balances, ecosystem qualities). As a result it seems impossible to optimize all productivities, efficiencies and eco-efficiencies as already stated by Jansén (2000).

1.1.2 Grazed Grassland

In important parts of Europe, mainly hilly, mountainous land or land with shallow soils, grazing still is the best agricultural option for use of the land. This is reflected in large areas of permanent grazed grassland, with a relatively low frequency of reseeding. In order to be sustainable, grazing in the EU must comply with environmental prescriptions as expressed in the Nitrate Directive (91/676/EEC) and the Water Framework Directive (2000/60/EC). Hence, pasture management is pushed in different directions: lower stocking density (where the land is cheap), less external N inputs, restricted grazing, a combination of grazing and cutting where appropriate and a strong reliance on biologically fixed nitrogen. Also in these areas the trend of larger farms is striking and the evolutions toward larger farms is occurring remarkably fast.

Low external N inputs allows legumes to persist in the grassland. The quantity of biologically fixed nitrogen (BNF) in the grass-clover herbage can be estimated by multiplying the white clover DM yield (expressed in ton/ha) in the herbage by 35 (BNF35) and corrected for applied mineral N (kg/ha). The total quantity of biologically fixed nitrogen *in the herbage*, $\mathrm{BNF} = \mathrm{BNF35} \ast 1 - (0.282 \ast \mathrm{N})/100$ (Humphreys et al. 2008). *Total white clover BNF* (including the non harvested clover DM (stubble, stolons, roots) is estimated by multiplying BNF by 1.27, which brings the total fixation at approx. 50 kg/ha per ton DM of white clover. The correction factor was calculated by Hansen (1995), based on the work and data of Nesheim et al. (1990). The latter applied no more than 80 kg/ha mineral N either as fertilizer N or as cattle slurry to Swiss swards dominated by perennial ryegrass, meadow fescue and white clover. Later publications (e.g. Humphreys et al. 2008) use the same correction factor for much higher mineral N dressings, asssuming that the linear relationship holds beyond the originally tested low mineral N applications. Anyway, the formula quantifies common knowledge: to take maximum advantage of the biological fixation, external mineral N-input should be low. There is ample scientific evidence that grass-clover pastures produce almost as much DM as pastures consisting of pure grasses dressed with 200–250 kg/ha mineral nitrogen (e.g. Peyreaud et al. 2010) provided soils are deep and water supply in summer is sufficient. Experience on organic farms, with no fertilizer N input, demonstrates that such grass-clover swards comply very well with the environmental regulations.

In these circumstances, grasses with high nutrient use efficiency (NUE) are requested. The trait NUE can be disentangled into a number of physiological more precise components: NUE can be expressed as the product of the uptake efficiency (NUptE) with the utilization efficiency (NUtE) (e.g. Gallais and Hirel 2004). NUpt refers to the efficiency with which roots absorb nitrogen (absorbed versus supplied nitrogen) while NUtE refers to the quantity of dry matter produced per unit N present in the dry matter. The latter depends on the retention time and the remobilization possibilities, again depending on the leaf longevity. Experimental breeding research in grasses has mainly focused on the NUtE at a given (mostly low) N supply (e.g. Baert et al. 1999, 2003). The strategy to focus on NUtE gets support from other species, since Gallais and Hirel (2004) and Schmidt (maize breeder at KWS in Germany; personal communication) indicated that under low N, NUtE was the driver for a better NUE in (grain) maize. Despite at lot of research (e.g. the past NIMGRASS EU-project, in which several EU grass breeders participated) and experimental breeding work, to our knowledge only few varieties are advertised strongly to have a better N use efficiency. However, grass breeders always have indirectly selected for a better NUE, since at a given N supply, the most productive varieties have the best nitrogen use efficiency. Eventually it is the (N)UE at farm level that is the most important driver for a production system with low emissions. Hence NUE in the grass plants should be integrated with NUE in the ruminants. If not, too many nutrients left unused by the animals, return to the soil or are lost in the atmosphere. In case the animals are fed with grass exclusively (or dominantly), the balance between N and WSC may improve the NUE in the animal and hence at farm level.

From a theoretical point of view genotypes or species with an extensive root system and a longer life span of leaves offer the best opportunities to improve NUE. However, genotypes with longer life spans may be more prone to leaf diseases, hence a good resistance is a prerequisite. The same applies to varieties with long leaves. Long leaves are advantageous in grazing since they guarantee a high supply of good quality herbage, the high supply being necessary for a high intake as demonstrated e.g. by the studies of Delagarde et al. (2001, 2006) and Delagarde and O'Donovan (2005). If long leaves are the result of a high leaf elongation rate, a quick regrowth after defoliation offers steady high herbage mass (Barre et al. 2009). As the rate of development of foliar diseases often is refrained by high N concentrations in the leaves, a low nitrogen use demands varieties with an excellent resistance to leaf diseases and this trait may become more important when the climate gets warmer. Although there is often a negative correlation between leaf length and number of tillers and a positive correlation between numbers of tillers and persistence, grass breeders have bred persistent varieties with long leaves.

Extensive root systems are able to restore soil structure in cases of trampling due to adverse weather conditions. Several studies demonstrate the deeper and stronger roots of fescues as already stated here-above and the positive effects of the association of grasses and clovers to guarantee a good soil porosity and water infiltration (e.g. Van Eekeren 2010).

Peyraud et al. (2010) give an overview of reasons why multi-species swards under mild fertilization are the way ahead for a sustainable animal production based on grazed grassland. The reader is referred to follow the MULTISWARD EU-project (http://www.multisward.eu/multisward_eng/) to get an idea of existing knowledge and ongoing research.

A recently highlighted function of (grazed) grassland is its value as a sink for soil organic carbon (SOC). Sonneveld and Van Den Akker (2011) report values of 9–21, 7 kg/m^2 in the upper 20 cm of sandy and peat soils respectively in the north of the Netherlands. When ploughed down, the rate with which the SOC is initially lost is approximately twice the rate of its accumulation as reported by Johnston (1986). Indirectly this is a plea for persistent grassland and for breeding of varieties with an excellent persistence.

There is currently a lot of work going on studying the carbon footprint of animal production systems. Although today there is no standardized methodology, it is clear that the carbon footprint heavily depends on the farming system. There seems to be a link with productivity: in many cases low input systems are also low output systems with a high carbon footprint expressed per kg produce. Eco-efficient production systems seem to comply best with low carbon footprints. Indeed, according to Edwards-Jones et al. (2009), emissions by on-farm activities were by far dominated by fertilizer-N and concentrates. Not surprisingly, these are also the most important drivers of N-surpluses. This is again a strong argument for a limited input of fertilizer-N and concentrates and for grassland systems heavily leaning on biologically fixed nitrogen.

The relation between carbon sequestration by (grazed) grassland and climate change is a much studied topic (for a review see e.g. Bartlett et al. 2008 and De Deyn et al. 2008). Provided there is no water shortage and no shortage of minerals, a rising temperature and a rising atmospheric CO_2 concentration are expected to stimulate the growth of the C_3 forbs and grasses, both above and under the ground. More roots, more dead material and more root exudations are expected to stimulate the microbial web in the soil. An enhanced heterotrophic respiration may be responsible for an initial carbon loss from the system. Enhanced mineralization of recent and old SOC may provide more nitrogen, stimulating again growth, strengthening the circle of accumulation and mineralization and carbon fluxes. Eventually the growing microbial biomass may immobilize N, refraining plant growth and carbon fluxes to the soil, except when legumes are providing extra N input. So it remains to be seen if the net result of climate change will increase or decrease the carbon sink in grassland. Whatever the outcome will be, the room to manipulate here is quite small, although Dijkstra et al. (2006) and De Deyn et al. (2011) showed that species richness (with an important role for legumes) continues to be the best guarantee for carbon sequestration.

Grazed grassland has a high potential for biodiversity both above and under the ground (Smith and Rushton 1994; Kemp and Michalk 2007; Van Eekeren et al. 2008, 2010 and Van Eekeren 2010). In a number of regions a reasonable yield and an acceptable biodiversity can go hand in hand, but in quite large parts of Europe, biodiverse grassland systems need to be financially supported, e.g. by agro-environmental schemes. In the absence of this support, these grasslands risk to be quickly abandoned, with the loss of a number of ecosystems and ecosystem services in the short term. It remains to be seen how the economic crisis in the world will influence the protection of these areas and their ecosystem functions.

To conclude: the semi-intensive grazed grassland of the future will have multifunctional roles (Reheul et al. 2010). The swards are multi-species swards, comprising persistent grasses and legumes with a dominant role for white clover in temperate regions: grasses have a long growing season, long leaves, a quick regrowth, good disease resistances, an extensive rooting system and a high NUE. The grassland and the animal production system is managed in a way to be as eco-efficient as possible, by applying best practices and common sense.

1.1.3 Reflections on the Paper of Parsons et al. (2011)

The paper of Parsons et al. (2011) should be compulsory reading for any (grass) breeder. Based on a thorough analysis of past breeding work, successes and failures, the paper partly questions if the (experimental) breeding—as it is actually conducted-is the right way to quickly move forward, given—according to the authors—the moderate (compared to other crops) breeding advances. The authors propose a more academic approach of the breeding work based on a quantified definition of breeding goals in clearly defined environments. They suggest focusing on specific traits, starting from—or referring to—physiological processes in the plant, unraveling how they are genetically regulated and interact with the environment and they propose to find out how traits eventually may be locked into varieties. They question the value of some experimental variety (field) trials—as they are actually designed and conducted—and would like to focus more on a tiered approach, with an important emphasis on the "proof of the concept", i.e. an early testing of trait performance rather than on variety performance. The latter is deduced from the finding that traits may be diluted (or eventually lost) during the development of synthetic varieties and that permanent grazed grassland can be such a complicated plant community with interactions above and under the ground, that genetic progress may be difficult to prove in experimental trials or in farm situations with different settings. Indirectly they ask for more fundamental research.

Essentially they rake up an old dilemma, very nicely defined as two models by Coors (2006). In model 1 "form follows function", while in model 2 "function follows form". Model 1 means that by selection of phenotypes the breeders' goal eventually is to change genotypes, while in model 2 one first changes genotypes in order to create new phenotypes. Model 1 is the model that breeders are applying for over a century now with proven success. Model 2 results from developments in molecular biology and genetics. The transition from model 1 to model 2 seems to be happening—as quoted by Coors (2006)—"by default, without any discussion and challenge". Put it in another way: it refers more or less to the confrontation between an academic view and the view of people working in the real world, between laboratory breeding and plant breeders who work "with mud and dirt and drought and wind" (quote of Prof. T. DeJong, tree crop physiologist, UC Davis). Or to conclude with Coors (2006), "at the end, it is the phenotype that matters".

Some reflections on the article

1. I have once read a scientific report (but unfortunately have lost it) stating that "there has not been a single (commercially viable) success booked in plant breeding programmes that were driven by deliberately creating genotypes with altered plant physiological characters". Parsons et al. (2011) show an example of such a failure (decreasing respiration), but they do try to explain the failure.
2. Tiered approaches are common in risk assessment (e.g. of genetically modified plants). Some scholars argue that standardized lab tests are necessary to "prove concepts", while others are urgently demanding "in planta" experiments. The reasons for the dispute are analogous to those given by Parsons: the farther away from standardized *ex situ* experiments and the closer to the real complex *in situ* world, the more difficult it becomes to prove anything. But in the end of the day, it is the reactions of organisms in the real world that matters.
3. Parsons et al. (2011) emphasize the importance of "fitness of traits", meaning that changed traits have to sustain during the process of variety building and in the complex communities of (grazed) grassland and management settings of animal farms. They show by smart analysis how varieties with a higher concentration of water soluble carbohydrates (WSC) do have a positive effect on NUE at low nitrogen inputs but that the effects fade away at high nitrogen input. Could (F1-) hybrids—e.g. based on CMS as proposed by Gaue and Baudis (2002)—bring more stability? At least no loss of traits is expected during the variety construction and we do know both from maize and cereal hybrids as well as from hybrids grown for their vegetative parts (sugar, forage beet, a series of vegetables) that they perform remarkably well in different environments, with in many cases, the best yield bonuses in rather poor environments. Moreover, the idea of fitness of traits, fits exactly in the "breeding model 1" as cited above.
4. Questioning if we really can increase the growth of perennial grasses, in particular by altering their growth strategy, Parsons et al. (2011) "speculate with credible evidence that our perennial grasses are holding back and not growing to the limits of their resource supply" since they have to combine good annual growth with the storage of reserves to guarantee persistence. Yet Chaves et al. (2009) demonstrated that progress over the last 40 years in dry matter yield and persistence (sic) in the short living *Lolium multiflorum* was very comparable to the perennial *Lolium perenne*. For crown rust resistance, progress was even better in *Lolium perenne* than in *Lolium mulitiflorum.*
5. As in many cases, the truth probably will lie in the middle. As Coors (2006) says: we do know that the model 1 is working as proven by more than a century of breeding; we do not know how successful model 2 will or can be, particularly for traits regulated by QTL's. It would be unwise to throw away a century of experience, as it would be unwise to neglect new developments. However, in line with the vision of Parsons et al. (2011) it is my opinion that there should be

> more clarity and continuity and perseverance into the focus of the application of new techniques or tools: this will enhance the probability to be successful or will quickly create clarity on the (non) feasibility and the (non) practicality. I have seen many projects focusing on molecular techniques passing by. All held bright initial promises that became less and less brilliant the closer the project came to an end. Once a project finishes, new projects are proposed with new and often completely divergent promises and new focuses. There is no clear link between the series of continuously emerging new techniques (or improvements of their performance) and achieved results in plant breeding.

1.1.4 Conclusions

Forage grasses are expected to excel in vegetative growth with good forage qualities during several harvests per year, to persist in these characteristics over many years and in many different settings and yet to have a good generative growth in order to produce enough seeds. Unlike a crop as e.g. forage maize, there is no possibility for compensation between generative and vegetative characteristics, and unlike some vegetables, grown for their vegetative parts, grasses can not yet take advantage of heterosis offered by hybrids. No surprise that genetic gain is slower than in many other crops.

There will always be funded or hyped arguments to select for extra traits. Plants breeders are well aware that the probability to create excellent all-round varieties is decreasing, the more traits are involved[3]. I do think that it is wise to focus on the core: producing good forage in an eco-efficient way with the application of best practices. Furthermore, I do think that there is no need to become nervous owing to induced hypes and/or alarming messages about dramatic evolutions in food production and climate change. The current breeding strategies and techniques have proven to create a steady progress and they should be continued. The introduction of new breeding tools into the existing programmes applying recurrent selection to create improved populations—as a base for variety development—may accelerate the selection response provided they are well focused. Hybridization may change the whole breeding progress, provided the created heterosis justifies higher seed costs.

As the era of plenty seems to have gone and in line with the recent SCAR-report (Freibauer et al. 2011), the transdisciplinarity between scientific disciplines as grass breeding, grassland management, forage use and animal sciences may be key for speeding up the transition to sustainable grassland based production systems. Reflecting on adjusted production systems followed by proper actions and applying best practices in every element of the production chain can make the whole process more sustainable. As, according to the presumed developments presented in the SCAR report, among other things, consumer behavior is expected to change (how

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[3] The number of genotypes in an F_2 population equals 3^n with n being the number of different loci. The greater n, the smaller the probability to find the ideal genotype.

difficult this will be?) and environmental externalities are expected (who knows when?) to be internalized in markets, the demand for animal products may (locally?) decrease[4] and/or their price may rise. It is unclear today how the effect of this evolution will affect grassland: will animal production with ruminants become even more concentrated in the very intensive areas and take advantage of both the economy and ecology of scale, or will we see the opposite?

If there is one particular worrying evolution, much more cumbersome than the conceptualized rather slow progress in grass breeding, it is the growing shortage of skilful agronomists, grassland scientists and plant breeders. We are losing a valuable expertise and a valuable professional genetic diversity which are all sources of vital creativity. Without these people it will be difficult to achieve any necessary transition and we will not be able to convince society that some actual hypes drain away a lot of energy and efforts that would be much more rewarding if they were focused on the core business instead of circling around it. Science can change the world, but science has to be honest. I think it is unwise to transform science into an advertising agency, concentrating on the regular emission of new promises. It is in a series of old values, methods and perceptions that lay many foundations of sustainability.

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[4] In university cities as Gent and Leuven in Belgium (and most probably in other major European cities), action groups promote one "veggie day" per week as a starter to decline meat consumption and the consumption of animal proteins. If a large part of the population goes along with this evolution a substantial decrease in the demand of animal products is expected, with inevitable consequences for animal production systems and their orientation.

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Part II
Breeding Strategies