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Socio-economic Analysis of the diversity of

Impacts of Public Research for Agriculture

Breeding for feed value and seed production in the forage legume alfalfa (*Medicago sativa*)

23.6.2015

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With methodological support from ASIRPA team

The forage energy value and seed production of alfalfa are key components in the use of this forage legume and the competitiveness of seed companies. INRA has carried out scientific studies to evaluate the potential for the genetic improvement of these two traits, proposed criteria to assess them in breeding programmes and illustrated the findings by the creation of two varieties that were registered in 2013. Energy value has been evaluated by the CTPS during the registration procedure for alfalfa varieties since 2003.

Context

(The programmes were conceived and started during the period 1990-2000)

Technical and economic:

Alfalfa is a forage legume that is recognized for its ability to produce the highest protein yield per hectare of all temperate legumes. It is a perennial, high yielding species that also has major zootechnical (buffering effect, fibre content, mineral content), agronomic (enrichment of soil nitrogen for the next crop, soil structure) and environmental (biodiversity protection, GG emissions) qualities. Its forage is known to have a relatively low energy content, so it has an unbalanced protein/energy ratio. Part of alfalfa forage is used on-farm to feed ruminants, mainly dairy cattle. Increasing the energy content of alfalfa contributes to creating a more balanced protein/energy forage, limiting the use of energy concentrate and/or to increasing milk or meat production by the ruminants. The choice of growing alfalfa depends on agricultural situation of the farm (high soil pH, drought), technical choices (moving) and strategy (protein independence). Farmers of this type are not well organized enough to express their requirements to seed producers or breeders. Generally speaking, technical advisory services for forage crops in France are quite limited, even though temporary grasslands represent 3.5 million ha (300,000 ha of pure alfalfa, at least 300,000 ha of alfalfa-grass mixtures[5], with an average yield of 12 t/ha). A reason for this situation is the apparently small economic importance of this crop: forage is usually not sold but used on-farm, and these crops require few inputs (seeds once every 3-5 years, little fertilization, no pesticides, etc.). Alfalfa forage is also sold in pellet form following dehydration. Dehydrators need to meet the needs of farmers (in France and abroad) who buy alfalfa pellets in order to obtain high-protein, high fibre, high mineral forage. The energy value is also a positive aspect to be taken into account. Dehydration plants establish contracts with farmers for alfalfa forage production, and these farmers are paid as a function of their forage production tonnage. Depending on the outcomes achieved by other crops, the farmers will accept or not to grow alfalfa. In past years (2000-2013), alfalfa acreage grown for dehydration has declined markedly because of high wheat prices. This sector is well organized and its requirements are determined by Coop de France-Déshydratation.

In addition to economic and environmental aspects, independence in protein production is also a means of securing protein sources and avoiding health threats as previously encountered with BSE (Bovine Spongiform Encephalopathy). Nowadays, alfalfa production in Europe is 100% GMO free, a criterion that is compulsory for organic farming and is in line with European social concerns. In contrast, it is almost impossible to guarantee GMO-free soybean meal because soybean is produced in countries (Brazil, USA) where GMO varieties are commonly grown.

Seed production is not a trait of interest for farmers who grow alfalfa forage, but it is an important trait for seed producers. Indeed, farmers who are paid as a function of the seed tonnes they produce may refuse to grow alfalfa varieties that are known to have low seed yields or will ask for a compensation payment. Moreover, seed production drives seed prices and the margins of seed companies (which are also breeders in most cases). Because of studies and trials by the FNAMS (National Federation of Seed Producing Farmers, or *Fédération Nationale des Agriculteurs Multiplicateurs de Semences*), much progress has been achieved regarding management practices for alfalfa seed production: identification of favourable pedoclimatic zones, establishment practices (such as row spacing, seeding rate, cover crop), clipping dates, pollination, weed and pest management, harvesting methods. All these efforts have contributed to the fact that France is a major exporter of alfalfa seed[6]. The genetic lever to improve seed production had been little studied, mostly because the evaluation of seed production within an alfalfa breeding scheme is time and cost intensive. For both energy value and seed production, this situation requires the involvement of public research to evaluate the potential for genetic gain and to propose new breeding methods.

At present in France there are four alfalfa breeding companies (Barenbrug, Desprez, Jouffray-Drillaud/GIE Grass and R2N), Barenbrug is a large multinational company with headquarters in the Netherlands. The three other companies have headquarters in France but, both Desprez and R2N have subsidiaries outside France. In 1994, there were two other companies whose alfalfa breeding activities have since stopped and another which has since been taken over. The four companies that exist now are indeed a significant force throughout northern Europe. Most of the alfalfa varieties grown in France were developed by French breeders.

Between 1960 and 2000, the land sown to alfalfa grown for forage declined steadily in France and other European countries. This trend was linked to several aspects, mainly (1) the import of low price soya cake that simplified the work of farmers, (2) the low cost of chemical nitrogen fertilizers, so that legume cultivation was no more an agronomic need. One way to limit this decrease was to increase genetic progress and develop better adapted varieties. Today, the economic and agronomic context has changed considerably; nitrogen and protein prices are high because of strong global demand and the ecosystem services associated with perennial legume forage crops are better established and taken into account.

Scientific:

The quality or feed value of forage determines animal production (meat or milk). The main components of forage quality are its protein and energy contents. At a scientific level, the evolution of energy value (measured by digestibility or ADF – acid detergent fibre) with forage growth was extensively described, particularly by INRA in Lusignan (G. Lemaire et al., Fourrages, 1993). The usefulness of highly digestible alfalfa varieties to milk production was also proved, the gain being on average 1.4 kg of milk/day (Emile et al., Agronomie, 1997). However, the measurement of digestibility using wet chemistry was time consuming and this method was hardly applicable to a breeding programme in which hundreds or thousands of samples had to be measured yearly by a breeding company. At the time when the project was initiated, NIRS techniques (Near InfraRed Spectroscopy) were emerging worldwide and showing promise. For seed production, a group in Poland (Prof. Stasewski) had just created a high seed yielding variety. All this scientific context and knowledge were favourable to the initiation of genetic studies, even if the chance of determining a breeding progress (i.e. a genetic gain) without reducing forage production was not established, either for energy value or seed production.

Regulatory:

CTPS, the French body responsible for the evaluation and registration of new varieties, had established a list of traits of major interest for alfalfa varieties. Until 2000, a single quality trait, protein content, was measured and included in the score of each variety compared to control varieties by means of a weighing coefficient of 1. Seed yield was also evaluated but not used to make decisions on variety registration. However, the CTPS needs to fit and adjust traits to user requirements. It may therefore consider adding new traits to describe the agronomic value of different varieties.

Inputs and productive configuration

Energy value trait: the start of studies by INRA's Plant Biology and Breeding Division (BAP) in 1994; previous studies by INRA's Environment and Agronomy Division (EA) (agronomy, crop physiology, 1980-1995) and Animal Physiology and Livestock Systems Division (PHASE) (ruminant nutrition, 1995-2000); use of experimental facilities at INRA in Lusignan (greenhouses, fields, chemistry laboratories, statistical analyses); use of genetic resources maintained by INRA in Lusignan (now the Centre for Biological Resources). The evaluation of a large number of genotypes for energy value, as required for any genetic study or breeding programme, was hampered by the cost of wet chemical analyses. NIRS technology emerged in the 1990s as a cost-effective method that was sufficiently accurate to detect small variations (between a set of genotypes). In Lusignan, pioneering studies on genetic variation for the energy value of forage maize contributed to establishing this fact. As a consequence, similar developments were possible with respect to other forage crops such as alfalfa.

1994-2003: Initiation of an INRA programme on **forage digestibility**

- Evolution of digestibility with forage growth for a set of varieties during a multi-site trial
- Genetic variability between varieties and populations regarding digestibility
- Genetic variability within varieties for digestibility
- Development of NIRS equations and testing of their accuracy to predict the digestibility and protein content of dried forage in experimental studies designed to describe genetic variations.

Seed production trait: studies by INRA's BAP Division in 1998-2003; use of experimental facilities at INRA in Lusignan (greenhouses, fields, seed threshing and testing equipment, statistical analyses);

1998-2003: Initiation of an INRA programme on **seed production**

- Genetic variation for seed production
- Interaction between variety and the environment (location and management) for seed production Resources involved

included field experiments, statistics, chemistry laboratories, and NIRS facilities.

For both traits, the main risk was that any genetic progress in energy or seed production was related to a correlative reduction in forage production.

Demonstrative breeding programme 2000-2005:

The scientific knowledge collected on within- and between-variety genetic diversity, the heritability of the traits, the identification of selection criteria for both feed value and seed production was favourable to illustrating these findings. A very small plant nursery was established in 2000 with recent disease resistant varieties by INRA, and private companies were invited to do the same for their own plant materials. Selection was focused on feed value and seed production at the individual level. At INRA, three polycrosses with various numbers of parents were made and tested in 2003-2005. Two of them produced valuable agronomic results. They were proposed for registration in 2009 by Agri-Obtentions (Lukal and Ludelis).

ACVF: the "Luzerne" section of the Association of Forage Variety Breeders (*Association des Créateurs de Variétés Fourragères)* which involves all private alfalfa breeding companies - six companies in 1994, four today). An ongoing collaboration with INRA since 1970 on various topics (forage yield, disease resistance, insect resistance, genetic resources, etc.). These collaborations have received support from the Ministry of Agriculture (continuous support 1994-2002 through branch contracts, now CASDAR semences). Under these conditions, collaborations have offered private companies opportunities to investigate new topics with limited risks.

Field experiments: a comprehensive network of field trials capable of covering most pedoclimatic conditions. While performing these field experiments, the ACVF contributed financial support for INRA programmes.

Contribution from the start to INRA studies on energy value.

Coop de France Déshydratation, cooperative:

Field experiments (through the chamber of Agriculture for the Marne region): this experimental site complemented those of the ACVF and INRA and enabled access to conditions in a major drought area.

Financial support 1997-1999

FNAMS: staff working on alfalfa seed production were hosted by INRA in Lusignan.

Field experiments at several FNAMS sites.

Indirect financial support through hosting the trials for INRA's programme on seed production.

ACVF, Coop de France Déshydratation and FNAMS are all linked to end-users (alfalfa growers for the first two, seed growers for the FNAMS) and have contributed to reinforcing the scientific choices made by INRA.

Research outputs

(1) Identification of breeding criteria: For feed value, the ADF (Acid Detergent Fibre) content, which correlates negatively to digestibility, was shown to be the most heritable trait and displayed the most genetic variation. For seed production, the seed weight per inflorescence (or more easily in a breeding programme, the inflorescence weight) is a highly heritable trait that is very well correlated to seed production.

(2) An NIRS equation was built to predict protein content, digestibility and ADF content on dried alfalfa samples. This equation was based on the numerous findings of several experiments conducted by INRA, private breeding companies and Coop de France Déshydratation.

(3) An original breeding method to exploit within-population variation:

This method includes recommendations to assess energy value and seed production during the first breeding step (the nursery) on individual plants. It requires numerous measurements (because the individual plants and not the population are assessed) but enables the exploitation of within-population variation. The evaluation of forage yield and quality requires the harvesting of plants at a vegetative stage several times a year (as alfalfa is grown on farm). Contrastingly, for the evaluation of seed production, the plants must be allowed to flower and ripen. It is therefore complicated to breed for the two traits simultaneously. It is recommended to score seed production on the planting year in the nursery and then measure forage quality over two consecutive years. In this way, a single nursery is sufficient to breed for both seed and forage traits. This method was tested during INRA's demonstrative breeding programme. It has not generally been adopted by breeders, but they have included some aspects in their own programmes.

(4) Registration in 2013 of two INRA alfalfa varieties, Lukal and Ludelis, both improved in terms of forage quality and seed production. They are marketed by Agri-Obtentions.

These outputs are based on scientific results arising from international publications:

Bolaños-Aguilar E.D., Huyghe C., Julier B., Ecalle C. (2000) Genetic variation for seed yield and its components in alfalfa populations. Agronomie 20, 333-345.
Bolaños-Aguilar E.D., Huyghe C., Djukic D., Julier B., Ecalle C. (2001) Genetic control of alfalfa seed yield and its components. Plant Breeding 120, 67-72.
Bolanos-Aguilar E.D. (2001) Etude génétique de la production de graines chez la luzerne (Medicago sativa L.). ENSA de Rennes, Biologie et Agronomie, 133 p.
Julier B., Huyghe C. (1997) Effect of growth and cultivar on alfalfa digestibility in a multi-site trial. Agronomie, 17, 481-489. Julier B., Huyghe C., Ecalle C. (2000). Within- and among-cultivar genetic variation in alfalfa: forage quality, morphology and yield. Crop Science 40, 365-369.
Julier B., Barre P., Hébert Y., Huguet T., Huyghe C. (2003) Methodology of alfalfa breeding : a review of recent achievements. Proc 25th Eucarpia Fodder Crops and Amenity grasses section Meeting, Czech J. Genet. Plant Breed. 39, 71-81.

Knowledge flow and intermediaries

INRA:

Transfer agreements with all ACVF members and Coop de France Déshydratation were signed in 1999 to make the NIRS equation available to these partners for use in their breeding programmes. This transfer was free of charge because the partners contributed to the projects during which the equations were developed. During subsequent years, two breeding companies started to use these equations. For Desprez, a subset of samples is analysed each year by INRA at the Lusignan chemistry laboratory to ensure that the equations produce adequate results compared to their own samples. For Jouffray-Drillaud/GIE Grass, whose breeding station is close to Lusignan, they use an NIRS apparatus belonging to INRA. A Jouffray-Drillaud technician comes to INRA to collect NIRS spectra. The equations are used to predict the chemical composition. This situation was reinforced by the establishment of a joint "PTIV" (Varietal Innovation Technology Platform, or *Plateforme Technologique d'Innovation Variétale*) for INRA and Jouffray-Drillaud since 2006. This PTIV aims to provide access for Jouffray-Drillaud/GIE Grass to INRA equipment and facilities and to share technical and scientific knowledge.

INRA participates in the Forage and Turf Crop Division of the CTPS. During the 2000s, it drove strategic and technical efforts regarding the evaluation of alfalfa feed value and seed production. This mainly concerned two scientists working on these issues, Christian Huyghe and Bernadette Julier, who are respectively president and a member of the legume expert group in this section.

After adding the ADF content in the list of parameters for variety evaluation by the CTPS, the GEVES chose to subcontract feed value measurements (both protein and ADF contents) to INRA in Lusignan which therefore performs these analyses each year using NIRS.

INRA has a representative on the Agronomic Committee (CERA) of Coop de France Déshydratation.

Several technical publications or oral communications targeted extension services (in French and English) during these studies or more recently, and included:
Julier B., Guines F., Ecalle C., Emile J.C., Lila M., Briand M., Huyghe C. (2003) Eléments pour une amélioration génétique de la valeur énergétique de la luzerne. Fourrages, 173: 49-61
Julier B., Huyghe C. (1998). Variabilité génétique pour la digestibilité de la luzerne : relation avec la production de matière sèche et la proportion de feuilles. Fourrages, 154, 261-268.
Scotti, C., Julier, B. (2014). Improving alfalfa forage quality. Legume Perspectives, 4, 31 (http://ils.nsseme.com/assets/LegumPerspect4.pdf)
Julier B. (2012) La luzerne: la reine des fourrages à redécouvrir. Journée technique nationale luzerne déshydratée, Coop de France Déshydratation, Reims.

CTPS:

The different sections of the CTPS comprise representatives (experts) from three sectors: public research, breeders and end-users, together with administrative staff from the GEVES (the body responsible for evaluation on behalf of the CTPS). The CTPS proposes to the Ministry of Agriculture the registration of valuable varieties, as well as changes to the registration regulations so as to adapt the catalogue to current uses. Based on the results obtained by INRA, the GEVES decided to evaluate the feasibility and usefulness of including a feed value criterion in the evaluation of alfalfa varieties. A contract, supported by the Ministry of Agriculture, was established between GEVES, INRA and ACVF to do this. During field trials organised by the GEVES, INRA and ACVF, forage samples were collected and analysed for forage quality. This study concluded that forage quality could be evaluated through the ADF content as an estimation of digestibility, alongside the protein content that was already taken into account for variety evaluation. Following discussions by CTPS experts in 2003, it was agreed that the ADF content would be included in the evaluation, with a scoring equal to 0.6. The scoring of protein content was also adapted to 0.6, compared with the previous system which was equal to 1.0 for protein content only. This change was applied to varieties submitted as from 2004 whose evaluation was completed in 2006.

For seed production evaluation, FNAMS and INRA experts argued in the CTPS section that seed production should be evaluated for variety registration because it is an agronomic trait for seed producers. Most of the other experts, and particularly breeders, thought that seed production is an internal question that needed no advice from the CTPS. This opinion had the majority. After this decision, seed production trials by the FNAMS were stopped, meaning that evaluations were no longer publicly available. Several breeders mentioned that they would find it interesting to obtain this estimation of seed productivity of different varieties, but others pointed out that the seed yield evaluated in trials may be poorly correlated to seed yield in production fields.

Agri-Obtentions, a subsidiary of INRA:

This company multiplies both INRA varieties. It has signed contracts for delegation with two seed companies. Ludelis is delegated to DLF Trifolium worldwide (DLF Trifolium, with its headquarters in Denmark, is the principal company for forage and turf species in Europe, and probably the world. This company has no alfalfa breeding programme, although it has recently purchased companies or stations in Eastern European countries that are breeding alfalfa. Lukal is delegated to Plan for France and to NPZ Lembke (Norddeutsche Pflanzenzucht Hans-Georg Lembke KG, Germany) for other countries.

Seed companies (ACVF):

The ACVF wanted to evaluate the potential of genetic progress for forage quality. A single company was not able to support this type of study. They all contributed to the experimental work and interpretation of its findings. They then included the methods in their own genetic material. The output of each company was to produce improved varieties with improved energy value using NIRS equations and ADF criteria, possibly better than those of other companies. For all recent varieties, energy value has at least been checked before registration. One variety registered in January 2015 by Jouffray-Drillaud/GIE Grass originated from the parallel breeding programme conducted by INRA and breeding companies. During the registration trial, it displayed a protein content and ADF content at 104.5% and 98.6% versus the control varieties, respectively [a reduction in the ADF content constitutes progress]. This advance was achieved with a good forage yield (104.7% of the control varieties).

Coop de France Déshydratation (formerly SNDF, Syndicat National des Déshydrateurs de France):

This body is conducting post-registration trials in the Champagne region (where most dehydration factories are located) in order to advise alfalfa growers regarding the best varieties as a function of their management practices and uses. The varieties are chosen from those most disease resistant and are evaluated for forage yield and protein and ADF contents. The results are communicated to the advisers who recommend varieties to alfalfa growers. Until now, alfalfa growers (who also produce grain but not livestock) are paid according to tons of forage. These growers are therefore demanding high forage yielding varieties but are not interested in high quality varieties. Until 2010, the European Common Agricultural Policy required a minimum protein content of 15% for dehydration crops in order to receive subsidies. This threshold has now been removed.

Coop de France Déshydratation publishes a booklet (Luzerne Références) that is amended and re-edited every 4 years. In this booklet, the changes in forage quality with growth are explained. Genetic progress on forage quality is also stressed.

Coop de France Déshydratation is involved in a prospective study for Dehydration2020. A few dehydration factories (cooperatives operated by livestock farms) are suggesting the payment of alfalfa growers as a function of tonnes of proteins or tonnes of digestible matter. Such factories represent about 20% of dehydration production.

FNAMS, a professional organisation:

In addition to changes in management practices, seed producers have benefited from the genetic lever to increase alfalfa seed yield. As the coordinator of seed producers, FNAMS offers technical advice through meetings, booklets, teaching and letters.

The **FNAMS** had always wanted alfalfa seed production to increase further and estimated that genetic progress was an additional lever for agronomic practices. It therefore worked with INRA from the start on this subject. Until 2007, the FNAMS carried out the evaluation of seed production for varieties for the GEVES. These data were not used to decide on registration but were available for information. Seed yield rose markedly between 1980 and 2010, from 2 qx/ha to 5 qx/ha on average, mainly because of improved agricultural practices. The current objectives are to rank the factors (soil, climate, pests and diseases, pollination, vegetative development, date of clipping) that limit seed yield and are responsible for major variations in seed yield at different scales: years, regions, fields.

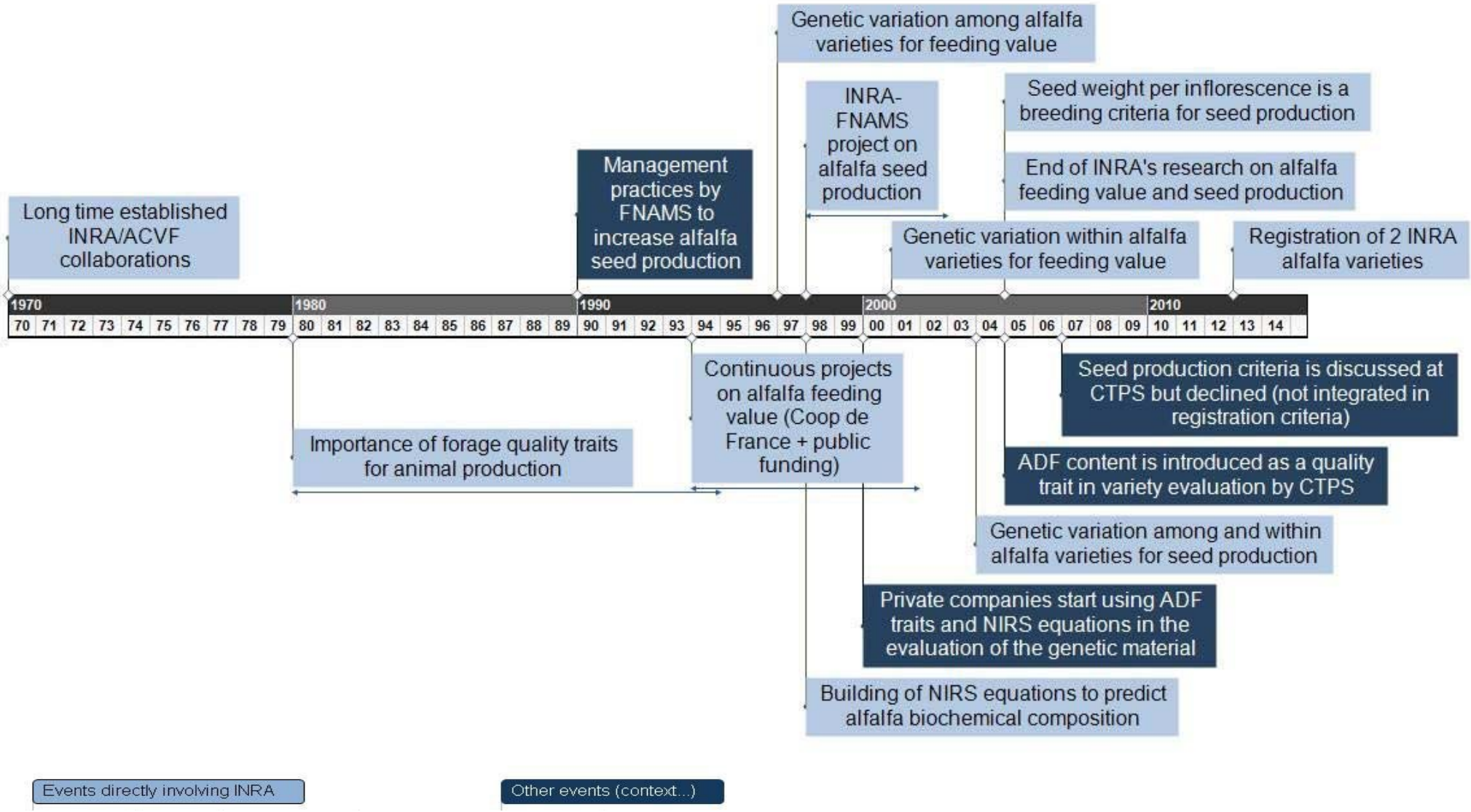
AFPF (French Association for Forage Production, or *Association Française pour la Production Fourragère*):

This association publishes a journal in French specifically dedicated to forage crops and their use. The main results obtained during INRA studies are published in synthetic reports. It also organized seminars twice a year on specific themes, during two of which (March 2003 and March 2005), alfalfa forage quality was presented.

Arvalis-Institut du Végétal:

This technical institute was not involved in the project on energy value. However, it has integrated the interest in this trait, as can be seen in a booklet edited with the technical centre CETIOM on forages (http://www.cetiom.fr/fileadmin/cetiom/kiosque/arvalis-info/2011septembre/arvalis_cetiom_infos_septembre_2011_complet.pdf). It also participates, alongside the AFPF, GNIS (the French Association for Seeds and Seedlings, or *Groupement National Interprofessionnel des Semences)* and GEVES in the edition of Herbe-book.org. This website gives the characteristics of the varieties registered since 2001 for the main traits evaluated for variety registration. It is dedicated to the choices of variety made by end-users. For alfalfa, it includes the protein content but not the ADF content, but this was because few varieties had been tested when Herbe-book was set up (2011). The coordinator of Herbe-book is now considering the addition of ADF content to the list of traits. Experts in the CTPS section debated this point in June 2015.

Chronology


Genetic variation among alfalfa varieties for feeding value
INRA-FNAMS project on alfalfa seed production
Seed weight per inflorescence is a breeding criteria for seed production
Management practices by FNAMS to increase alfalfa seed production
End of INRA's research on alfalfa feeding value and seed production
Long time established INRA/ACVF collaborations
Genetic variation within alfalfa varieties for feeding value
Registration of 2 INRA alfalfa varieties
1970 1980 1990 2000 2010
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14
Continuous projects on alfalfa feeding value (Coop de France + public funding)
Seed production criteria is discussed at CTPS but declined (not integrated in registration criteria)
Importance of forage quality traits for animal production
ADF content is introduced as a quality trait in variety evaluation by CTPS
Genetic variation among and within alfalfa varieties for seed production
Private companies start using ADF traits and NIRS equations in the evaluation of the genetic material
Building of NIRS equations to predict alfalfa biochemical composition
Events directly involving INRA
Other events (context...)

Impacts 1

Political

The identification of simple and robust breeding criteria for energy value and the seed production helped to set the political agenda regarding their consideration for the registration of new alfalfa varieties. The CTPS registration regulations have evolved regarding the evaluation of the quality. An energy value criterion was introduced for the registration of new varieties. The NIRS equations developed by INRA and made available to the seed companies that participated in the Institute's work, and methods to ensure compliance with the new rules, have facilitated their implementation and hence the creation of better quality varieties.

For the seed production criterion, the scientifically credible knowledge developed by INRA has also opened and fed a sectoral debate among members of the CTPS regarding socioeconomic usefulness and the possibility of selecting varieties for seed production. The FNAMS was confirmed in its position with support from INRA experts, but the alfalfa section of CTPS voted against adopting a seed production test in the registration regulations. The spread of interest of this criterion among breeders has been slow and enabled through interactions between the FNAMS and breeders or informal relations with INRA researchers. This criterion is also available and applicable for routine selection.

Economic

Seed breeders/ACVF:

All breeders now determine forage quality in their breeding programmes. It is either taken into account at the early stages of a breeding programme or at later stages on the progeny of polycrosses. Three companies are now using INRA NIRS equations (Barenbrug, GIE Grass, Desprez). The fourth company (R2N) continues to use its own NIRS equation.

The performances of alfalfa varieties during the CTPS trials performed for registration have been analysed. Since 2006, forage yield has tended to rise while protein and ADF contents have remained constant. Taking into account the negative correlation between forage yield and quality, maintaining the quality of the varieties means that there has been a significant selection effort regarding these traits.

Among the different varieties available, some specifically meet the requirements of dehydration companies. These varieties have good resistance to lodging, disease tolerance and a high forage yield. Surprisingly, even though the chemical composition of commercial products is indicated, dehydration companies do not pay alfalfa growers for high quality alfalfa. For the traditional use of alfalfa by farmers, marketing campaigns mainly target forage yield results. The breeding sectors of these companies have problems in convincing their own market sectors about forage quality.

The use of breeding criteria for seed production is contrasted. For one breeder (Jouffray-Drillaud/GIE Grass) who considers that seed production is not a limiting trait when compared to others, candidate varieties are simply checked prior to registration in order to eliminate poor seed yielding varieties. Jouffray-Drillaud/GIE Grass had initially tried the criterion, but without significant progress. The other three companies (Barenbrug, Desprez and R2N) are very active in breeding for seed production and they mentioned this trait as being important to variety development. For Desprez and R2N, the INRA results did not change their objectives and methods as they were already breeding for seed production. R2N had little knowledge of these INRA-FNAMS results, which were obtained at a time when the company had sold its alfalfa breeding programme to another breeder. Conversely, Barenbrug modified their breeding method to increase seed production after the INRA results were released. For both breeding programmes carried out in France by Barenbrug (one for northern varieties, the other for southern varieties), seed production is actively taken into account from the early stages of selection, and the breeding criterion of seed weight per inflorescence is used. The breeders all mentioned genetic progress in their varieties, but this is not assessed by external trials.

Livestock technicians and farmers – Arvalis / Coops:

The people in charge of forage sectors have sufficient knowledge of the importance of feed value. Introduction of the ADF trait into the registration process has helped to raise awareness as to the importance of quality.

By contrast, livestock technicians and farmers tend to have little technical knowledge of alfalfa in general, and they do not perceive the impact of forage quality on animal performance. The number of technical managers (Arvalis, Coops) is still too small to create enthusiasm regarding interest in alfalfa. In this context, they report that it is difficult to offer a specific message on genetic improvement (including quality) when agronomic and zootechnical general aspects are not sufficiently known.

Seed growers/FNAMS:

Because the seed production of varieties is no longer evaluated for registration, the FNAMS no longer performs seed production trials to test for differences between varieties, except as a service when requested by a seed company (two recent trials). The FNAMS' interest in genetic variation has consequently decreased. Nevertheless, the "seed weight per inflorescence" trait is still used by FNAMS technicians to evaluate seed yield potential when precise measures are not possible. And trials are still performed to understand the reason for fluctuating seed yields.

The number of farmers involved in alfalfa seed production (1000 to 1500) and the surface area used for seed production in France (10,000 to 12,000 ha) has remained relatively constant during the past twenty years. The FNAMS considers that the seed production of most varieties can ensure a sufficient return for farmers and seed merchants.

It is extremely difficult to determine whether INRA research has an impact on alfalfa cultivation for forage or seed, the exports of seeds or forage or dehydrated pellets, the price of alfalfa seeds, the use of concentrate in diets or the use of farm seeds. On this last point however, INRA-private sector research was key to ensuring the ongoing investment of private companies in alfalfa, leading to the registration of new varieties. For farmers, this situation constitutes a message that demonstrates the importance of alfalfa crops and the role of breeding to deliver improved varieties.

Environmental

Improving forage quality has a positive environmental effect: a smaller proportion of the harvest is lost, and less forage is needed to feed one animal. The efficiency of animal production is thus increased. As a result of this improved efficiency, animal production will generate less waste. In addition, using a locally-sourced, protein-rich and digestible forage reduces the need for concentrates that are partly produced using non-sustainable practices in other countries and shipped across the world.

Each time alfalfa is grown, there is a positive environmental impact compared to an annual non-legume crop (no nitrogen fertilization, little nitrogen leaching, soil quality, GG emissions, etc.). INRA research has probably contributed to maintaining or increasing alfalfa cultivation, and has thus contributed to a positive environmental effect.

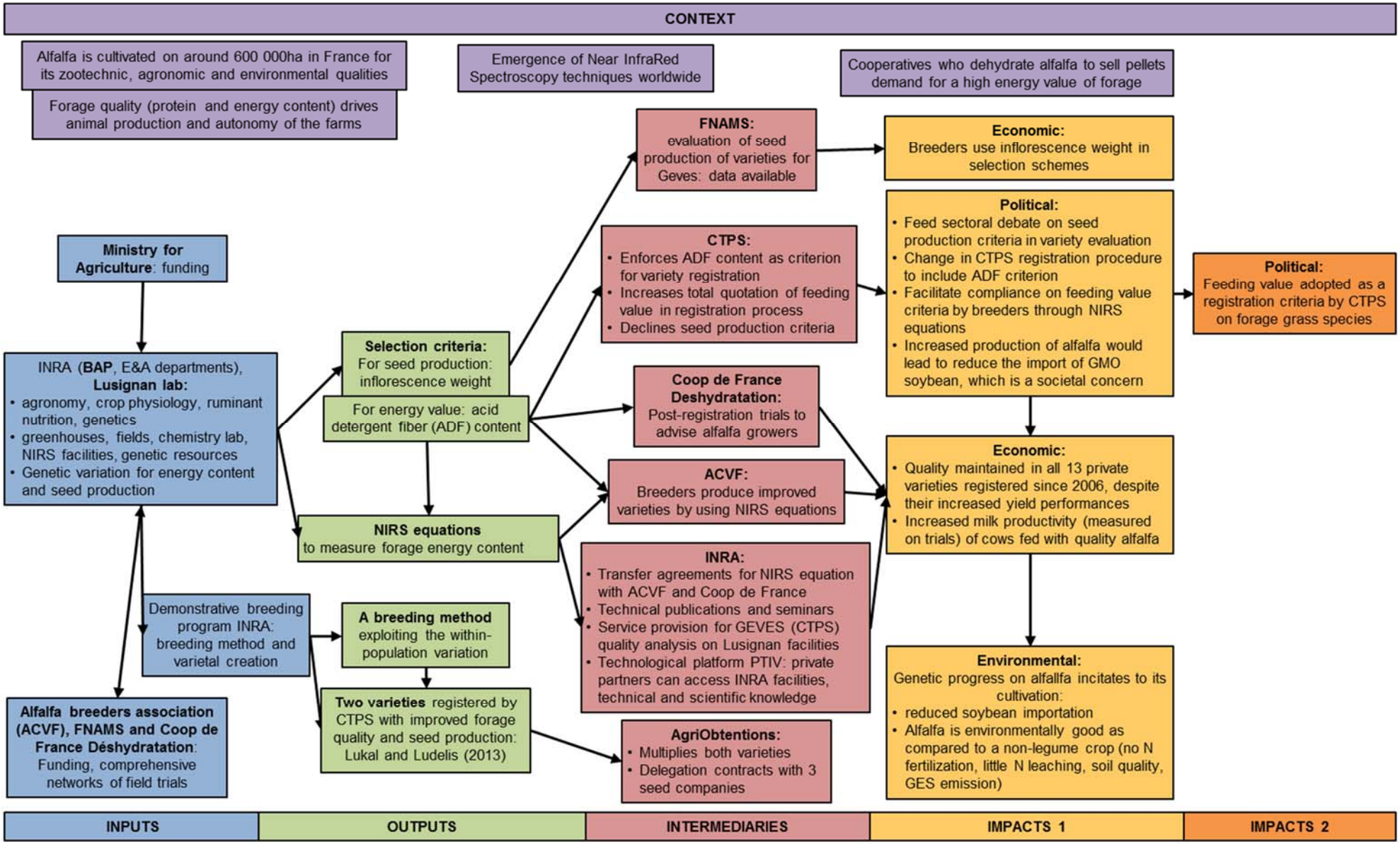
Impacts 2

The fact that energy value, added to protein content, was included in alfalfa variety testing encouraged the CTPS to work on the quality of forage grass species. Indeed, no feed value trait was previously tested in these species, after an appetibility trait at grazing was cancelled for scientific reasons during the 1990s. Experts reported a need for the quality testing of forage grass species. The feasibility of feed value measurement using NIRS equations, as demonstrated in alfalfa, opened the way to this possibly being applied to grasses. This transfer was achieved quite easily because the companies and institutes involved were basically the same for both alfalfa and grasses. As for alfalfa, a project coordinated by the CTPS and funded by the Ministry of Agriculture was approved to carry out a feasibility study. After this 3-year project (2007-2009), three traits were retained: protein and ADF contents (in the same way as for alfalfa=, and also soluble sugar content. These criteria were officially adopted by the CTPS for cocksfoot, tall fescue, meadow fescue, perennial ryegrass, hybrid ryegrass and non-alternative Italian ryegrass in 2011 (the first varieties were registered in 2013).

In Europe, forage quality is tested in some countries for some species, with little coordination among the institutes responsible for registration. This question of quality testing at the European level will be soon debated during the Eucarpia Forage plants and Amenity grasses Congress in September 2015, and INRA scientists will contribute to this debate. The GEVES and other institutes in charge of registration have completed a form to describe how quality traits are taken into account for variety evaluation, as defined by the committee to which INRA experts contribute.

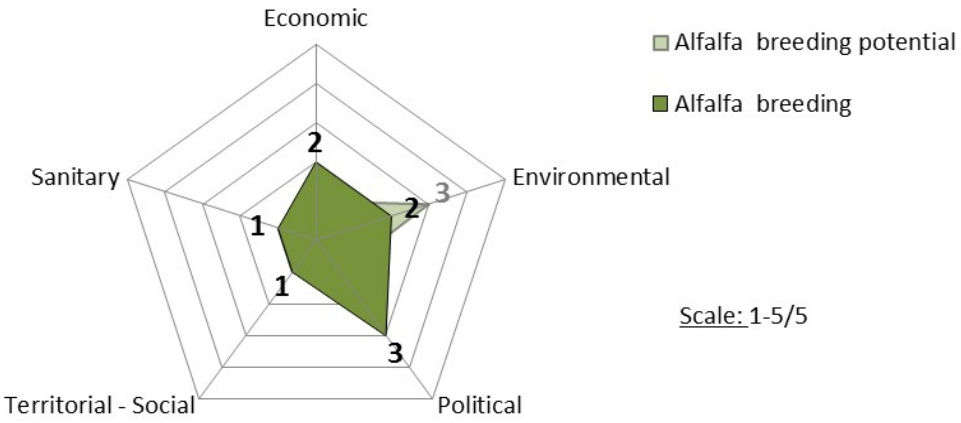
The impact of this research in Europe is difficult to measure. However, when a French variety is developed in another country, its agronomic and feed value (evaluated in France) constitutes a strong marketing argument. As an example, Agri-Obtentions negotiated a license for the development of the two INRA varieties in other countries. In addition, when a French company has close links with foreign companies or affiliates (as in the case of Barenbrug), methods and tools discovered in France may disseminate accordingly.

Impact pathway



Impact vector

Impact dimension	Importance	
Economic	2 / 5	The quality of all varieties registered in France since 2006 has been maintained despite increased yield performance. Three of the four French breeders now use the seed production criterion to select alfalfa varieties. The use of high quality alfalfa forage to feed ruminants may increase ruminant milk production by 1.4 kg/day More and more varieties specifically meet the requirements of dehydration sectors (high lodging, disease tolerance and forage yield)
Environmental	2 / 5 Potentially 3 / 5	- Increased French alfalfa production would induce reduced soybean imports from America and positive environmental impacts compared to an annual non-legume crop (no N fertilization, little N leaching, soil quality, GHG emission, etc.). -Improved digestibility increases milk and meat productivity in cattle, thus reducing their forage consumption and waste production.
Political	3 / 5	- Agenda-setting of issues related to energy value and seed production traits at the CTPS - Contribution to the sectoral debate among CTPS members on breeding criteria regarding the seed production and energy value of alfalfa - Adoption of energy value criteria in the CTPS registration process based on the ADF content - Increased French alfalfa production would limit the imports of GM soybean meals which is a concern expressed by society.



References - Data sources

Seed breeders:

- Marie-Christine Gras, R2N, manager of the alfalfa section at ACVF
- Vincent Béguier, Jouffray-Drillaud/GIE Grass
- Dominique Noël, Barenbrug
- Philippe Lonnet, Desprez

End-users:

- Pierre-Vincent Protin, Arvalis-Institut du Végétal (technical institute)
- Bruno Perroteau, Terrena (cooperative)
- Michel Straebler (GNIS, coordinator of the Herbe-book website)
- François Deneufbourg (FNAMS)
- Thierry Maleplate (Coop de France Déshydratation)
- Thierry Bourgoin (Agri-Obtentions)
- Vincent Gensollen (GEVES)