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Perennial grasses in rainfed Mediterranean farming systems - Current and potential role

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SUMMARY – Past and recent development of perennial grasses is reviewed across environments and under the main types of farming systems. Few adapted cultivars (cvs) are registered and only seeds from French and Australian cvs are available. As a result, there is insufficient use of these grasses. In future developments, a perennial grass-legume mixture is the best model to optimise both livestock nutrition and environmental impacts. In Europe both roles contribute to farm income either via the market or public subsidies. Adapted cvs exist for climates with annual rainfall >500 mm and accumulated water deficit from May to September (late spring to end of summer) <700 mm. The role that perennial grasses can play in maintaining landscape services has also lead to the development of new cvs and associated seed production. Future research programs should: (i) define suitable mixtures and management of pastures; and (ii) further improve drought tolerance. There needs to be further development of the summer dormancy trait exhibited in cocksfoot, tall fescue and phalaris ecotypes from North Africa and desiccation tolerance sourced from the wild species *Poa bulbosa*. It is proposed to strengthen research coordination in the Mediterranean and to structure links with Australia where research and the seed industry actively develop Mediterranean germplasm in similar climates.

Keywords: Perennial grasses, grass-legume mixtures, pastures, farming systems, Mediterranean climates, drought tolerance, perenniality.

***RESUME –** "Graminées pérennes dans les systèmes d'agriculture pluviale méditerranéenne : rôle actuel et potentialités". Cette revue présente un bilan du développement récent des graminées pérennes dans les régions méditerranéennes sèches, par type de système agraire. Peu de cultivars (cvs) sont inscrits et seuls ceux inscrits en France et en Australie ont des semences commercialisées. Ils ne sont significativement utilisés qu'en zones sub-tempérées. A l'avenir, les mélanges graminée-légumineuse à deux ou plusieurs composants s'imposent pour optimiser la production animale et les bénéfices environnementaux, tous deux contribuant au revenu des exploitations. Les cvs existants sont adaptés à une pluviométrie annuelle > 500 mm avec déficit climatique cumulé Mai-Septembre < 700 mm. L'utilisation croissante des pérennes fourragères en couverture dans des systèmes culturaux intensifs pour améliorer leur bilan environnemental va stimuler la sélection de nouveaux cvs pour cet usage. Ces variétés doivent être plus facilement accessibles. Les objectifs prioritaires de la recherche sont l'analyse du comportement en association et la tolérance à la sécheresse, en exploitant la dormance estivale rencontrée chez certains écotypes de dactyle du Maroc, ainsi que la tolérance à la déshydratation d'espèces comme Poa bulbosa. Il est recommandé de renforcer la coordination au sein du Bassin méditerranéen et de structurer les relations avec l'Australie, où la recherche et l'industrie semencière travaillent le matériel végétal méditerranéen sous les mêmes climats.*

***Mots-clés :** Graminées pérennes, mélanges graminée-légumineuse, prairies, systèmes agraires, climats méditerranéens, tolérance à la sécheresse, pérennité.*

Introduction

Perennial grasses may be present on a farm as wild plants in native pastures and rangelands, or as selected cultivars (cvs) sown either as pastures to feed livestock or as cover-crops. Their functions or effects in farming systems should be analysed, like any crop or plant, according to three roles: (i) contribution through harvested (or grazed) herbage to the production of the system given value as auto-consumption and through the market; (ii) impact on the agro-environmental balance directly profitable (or not) to the farm in the short term; (iii) effect on the local environmental balance of collective interest. The second term has been studied by agronomists and taken into account by agro-economists through yield increase of a companion plant or following crop, improvement of organic matter and fertility of the soil, or by reducing the requirement for nitrogen, energy, labour and protein on the farm. The third term includes the effects on water quality, soil erosion, carbon balance, energy saving, and biodiversity conservation (public interest). This last issue is now a key subject of debate between agriculture and society and a subject of research to measure the environmental balance of a farming system and its value. The individual European nations and the European Union (EU) collectively increasingly direct public subsidies to agriculture to pay farmers for environmental services to the society. Economically, the first two groups of functions contribute to the farm net income from the market, while the third group (the environmental balance) determines the level of income originating from public subsidies (or taxes when negative).

The development of current farming systems has been strongly influenced by socio-economic factors, public subsidies being a key tool to orientate them. In the future, the effects of climate change are likely to modify potential yields of crops, mainly in the Mediterranean basin and to have considerable impacts on the socio-economic environment of agriculture. It is the challenge for research to develop innovations necessary for farming systems to be able adapt to the new context.

The limitations in registered plant material

Research orientations

In temperate climates of EU, millions of ha of temporary and semi-permanent pastures are sown, using hundreds of registered cvs of perennial grasses and legumes. A small proportion of these, mainly deep rooted species, are suitable on deep soils of sub-humid (sub-temperate) Mediterranean areas, such as Tuscany and southern France. Except for this intermediate environment, the poor persistence of temperate germplasm in rainfed Mediterranean environments is widely recognized (Talamucci and Chaulet, 1989; Lelièvre and Mansat, 1990; Mousset *et al*., 1992; Piano, 1991, 1993). Mediterranean types of tall fescue and cocksfoot begin to be used in rainfed conditions at latitude > 40°N (line Lisbon-Sardinia). In drier semi-arid and arid environments, grazed cereals (barley, oats) and rangelands are the main forage resources, with minor, local contributions of annual species (vetch, lupins, annual ryegrass and berseem), and an absence of significant use of perennial species. Nevertheless the potential to extend the utilisation of perennial forage grasses to drier sub-humid and semi-arid environments was demonstrated in the 1960's and 1970's in southern Europe (Ferret, 1975; Papanastasis, 1987; Piano and Pusceddu, 1989), Northern Tunisia (Gachet and Jaritz, 1972 ; Jaritz *et al*., 1976) and Morocco (Arif *et al*., 1989; Jaritz, 1992, 1994). These studies, together with extensive Australian development of germplasm collected from around the Mediterranean, showed that perennial material originating from semi-arid environments could express high growth rates during the cool, rainy season and good drought tolerance to survive the long dry summer. In Australia, the North African germplasm was used to breed a few cultivars exhibiting a range of drought tolerance. In Europe, some cvs were registered but were not developed because of limited interest by private seed companies in the Mediterranean seed market (Lelièvre and Mansat, 1990).

During a long recent period (1975-2000), corresponding to the emergence of national research teams in southern countries, research efforts in southern Europe, West Asia and North Africa (WANA), were almost exclusively concentrated on annual speciess and self-reseeding annual legumes. These species had been successfully developed at very large scale in semi-arid regions of Australia as in the cereal based "ley-farming" system and as semi-permanent pastures drying in summer but self regenerating in autumn (Puckridge and French, 1983; Norwan *et al.*, 2000). ICARDA pushed to develop similar systems in the WANA region (Cocks, 1990). Southern Europe was more interested in dryland semi-permanent pastures (Crespo and Romano, 1980; Cocks, Papanastasis and Kontsiotu, 1994; Génier *et al.*, 1992). Despite this significant research effort, development of the two targeted systems has been limited for many reasons, two of the more important being, the lack of adapted cultivars, and the shortage of low-cost seed in the self reseeding legumes (Cocks, 1990; Porqueddu and González, 2006). In WANA, the widespread adoption of monocultures of wheat and barley and collective use of fallows were additional limits (Cocks, 1990). Nevertheless, some limited success, such as the utilisation of complex mixtures in Central Portugal for grazing, and elsewhere as cover-crops give encouragement to continue in this way (Crespo, 2006; Porqueddu and González 2006).

These limitations, as well as unsuitable solutions to stop soil erosion with annual crops, recently led researchers to pay attention again to the native germplasm of perennial grasses and legumes present in Mediterranean pastures and rangelands. In Europe, important possibilities of progress in drought tolerance were demonstrated in cocksfoot and tall fescue (Lelièvre and Mansat, 1990; Mousset *et al*., 1992; Piano, 1993; Vaitsis, 1993; Volaire and Lelièvre,1997; Norton *et al.*, 2006). The research resulted in registering several new cultivars in Australia, France, Italy, Portugal, and Argentina.

Available cultivars

Compared to the hundreds of cvs for temperate areas, the cvs available for Mediterranean environments are very few with a significant number not currently commercialised (NC): These include:

- *Dactylis glomerata* (cocksfoot) : Medly (EU, France), Jana (EU, Italy, NC), Delta (EU, Portugal); Currie (Australia, French/Algerian parentage) are drought resistant but not summer dormant. Kasbah (Australia-Morocco) has complete summer dormancy; a cover-crop type *of D. glomerata ssp. hispanica* : Bacchus, not summer dormant, has been recently registered (EU, France).

- *Festuca arundinacea* (tall fescue), typically Mediterranean types, with incomplete summer dormancy: Centurion (EU, France); Tanit (EU, Italy, NC), Flecha (Argentina and New-Zealand), Fraydo, Resolute and Prosper (Australia), and intermediate between temperate and Mediterranean types, summer active : Lunibelle and Lutine (EU, France); Sisa (EU, Italy, NC),

- *Phalaris aquatica* (phalaris) : Australian, Sirolan, Atlas-PG, Holdfast, Sirosa, Landmaster, Sirocco (NC), El Golea (NC). Australian bred, with material mainly from Morocco; all have incomplete summer dormancy.

These cvs generally persist for several years at appropriate densities, on deep soils, where average annual rainfall is above 500 mm and accumulated water deficits from May to September do not exceed 700 mm. Some cultivars, including the completely summer dormant cocksfoot Kasbah, are adapted to drier conditions. Precise information on tolerance to drought and cultivar x locations x soil depth interactions will be provided from a Mediterranean multilocation trial network, "PERMED" started in 2004 and supported by EU in Portugal, Spain, France, Italy (Sardinia), Tunisia, Algeria and Morocco.

Stipa lagascae and *Cenchrus ciliaris,* two Mediterranean to subtropical grasses widely spread in sub-saharan regions could be suitable for drier semi-arid and arid regions if ecotypes could be commercially developed. Registered cvs of *Cenchrus* exist in South Africa, Australia and USA, although these cvs are of subtropical rather than Mediterranean origin (Lapeyronie, 1982; Oram, 1990).

Legumes to be potentially associated with these grasses are Mediterranean types (*Medicago sativa, Trifolium fragiferum, Lotus corniculatus, Hedysarum)* and self-reseeding annuals originating from the region reviewed by Porqueddu and González (2006) and Crespo (2006). A broad choice of cvs is offered in lucerne, medics and subterranean clovers.

The very low number of Mediterranean cvs and the lack of seed of some of them severely limit development. It is unlikely that two or three varieties of a species have sufficient broad adaptation for the climates, soil conditions, purposes and species of all the Mediterranean Basin.

Recent developments: maintaining landscape services and role of grass-legume sward

The "maintenance of landscape services" (syn. environmental balance) is an increasing component of farm income via governmental subsidies or penalties in the European Union. Most intensive or semi-intensive agricultural systems have a negative effect on landscape services (e.g. soil erosion, nitrate and chemical pollution to water, energy cost, carbon loss). In contrast, pastures, especially grass-legume swards and turf-grass have a positive effect. Consequently, their introduction (or re-introduction) into intensive cropping systems is an important way to correct an unbalanced environment. This use as intercrops or cover-crops, often without the objective of producing forage, has become very important in temperate Europe and is becoming more so in southern Europe. It should stimulate plant breeders to create intermediate cultivars between turf-grass and forage types, targeting environmental benefits more than forage production or the maintenance of an evergreen aspect (turf-grass).

In this new context, it is proposed that the optimal model of improved pasture and forage crop in Mediterranean environments is a semi-permanent pasture associating several cultivars or native populations of legumes and grasses comprising perennials or self-reseeding annuals. The components of the mixture need to be adapted to climatic constraints and balance between objectives of livestock nutrition and maintenance of landscape services. Environmental and economic benefits are generally higher when the pasture duration is longer (semi-permanent or permanent). The pasture can be simply a mixture of one legume (for nitrogen fixation) and one grass (for N utilisation). When soil fertility needs to be restored, it is justified to sow mixtures where the legume component dominates. When biodiversity is of primary concern, the restoration of native flora may be preferred, but yield increase is often less than with resown pastures (Crespo, 2006). In very dry areas, the part of perennials in mixtures has to be reduced. Ley-farming rotations like barley-annual medics, are an example.

In the following parts of this paper, the roles and advantages of perennial grasses are not analysed *per se,* but as possible contributions to grass-legume mixtures, for multiple uses including livestock nutrtion and maintenance of landscape services.

Past and future role of grasses in mediterranean farming systems

In temperate as well as Mediterranean areas, the dominant farming systems at the beginning of the 20th century were small family-based mixed farms integrating agriculture (mainly cultivation of cereals) and livestock breeding. Although largely self-sufficient, there were key community-wide activities, e.g. common utilisation of fallows, stubbles, rangelands, transhumance, and nomadic systems. The evolution of this traditional system is analysed considering the place of perennial grasses.

Farming systems of southern temperate regions of Europe

In temperate regions of western Europe, the traditional system was totally transformed in the short period 1945-75. Factors such as, mechanisation, increasing use of fertiliser and herbicide, greater integration into the market, led to a high specialisation of farms and regions. Perennial grasses disappeared from those systems specialised in crop production where they were perceived as weeds and suppressed by herbicides. In contrast, in livestock producing regions, grasses were emblematic of the "green revolution". They were sown on millions of hectares as pure stands under high nitrogen fertilisation. Silage of grasses and maize was developed for winter nutrition, supplemented by massive importation of protein (soybean) from America. Use of legumes in pure stands (clovers, vetch, lucerne, sainfoin, …), which had been for centuries a centrepiece of rotations both for livestock production and to improve soils before cereals, decreased by 10-20 fold over this period and almost disappeared, except for lucerne. Traditional mixtures of several grass-legumes species sown for long term pastures or leys (5-10 years) also disappeared. Simple mixtures like perennial ryegrass-white clover in humid regions, lucerne-cocksfoot and lucerne-tall fescue in drier regions, could still be found. Perennial grasses became dominant in native pastures as result of nitrogen fertilisation so that perennial grasses are nowadays the centrepiece of livestock production, while the role of legumes is marginal. However, it is now realised that both intensive crop and animal production systems have a negative impact on the provision and maintenance of landscape services so that their sustainability is under question. In recent years, perennial grasses were widely reintroduced into cropping systems as cover-crops (fallows, inter-rows of orchards and vineyards, river banks). Indeed, the potential to return to more integrated mixed farming systems is being studied. In marginal areas (alt. > 500-600 m), at the transition zone into Mediterranean environments, livestock production has become less intensified.

Perennial grasses in subhumid (sub-temperate) Northern Mediterranean Basin

In the northern Mediterranean Basin, the traditional systems also evolved over the 20th century toward greater specialisation. The plains and low hills with good arable soils became irrigated where possible (orchards, maize, locally dairy cows), and the rainfed areas developed into semi-intensive systems (durum wheat and cereals, vineyards, olive and almonds trees), generally without livestock. Livestock production became progressively the main activity in the less favourable areas, from where cereal production essentially disappeared. This coincided with a decline in population which contributed to the decline in farm number, cropping intensity and stocking rate. These systems are mainly based on pastures and rangelands, which are low-input resources having a peak of production in spring (50 to 70 % of annual growth), little growth in summer and winter, where autumn growth depends on the timing of autumn rain. Native perennials are the main components of pastures and rangelands (Volaire *et al.*, 1990). In these systems the use of semi-permanent and semi-intensive pastures of improved Mediterranean perennial grasses and legumes has many advantages:

(i) Early autumn grazing: Mediterranean cocksfoot and tall fescues accumulate water soluble carbohydrates during the early period of summer drought, which assists rapid autumn regrowth. When autumn rains occur before the end of September, forage biomass is sufficient (> 1 t DM/ha) for grazing within three weeks, which is at least 3-4 weeks earlier than poor overgrazed rangelands and 5-6 weeks before grazing of early sown barley is possible. Generally, two autumn grazings can be undertaken (in October and late November), with autumn production between 2 and 4 t DM/ha (Lelièvre *et al.* current publication). This early high productivity is a major advantage in this season.

(ii) High autumn and winter growth rates: Mediterranean types of tall fescue and phalaris have the highest growth rates. When average temperatures are higher then 8℃ without significant frost, they grow through winter and produce one or two grazings in February and March.

(iii) Spring storage: the reproductive cycle in spring (from late March to late April or early May is the most productive period. This forage is easy to conserve as silage or haylage (April, early May) or later as hay (May). Grasses or grass-legume mixtures are easier to harvest and to dry than legumes alone.

(iv) High water use and high water use efficiency (WUE): perennial C3 grasses grow well in wet cool seasons (autumn, winter, spring). Due to their deep root systems, these grasses reduce water loss by deep drainage, especially in regions with intense winter rainfall. In addition, rapid growth in mild periods, when potential evapo-transpiration is relatively low, maximises WUE. When all growing factors are favorable, especially nitrogen nutrition, average WUE over the whole growing season (October to May on average) is between 1.5 and 3.0 g DM/kg H_20 (Lelièvre *et al.* current publication). This combination of high winter activity and root depth is the justification of the Australian nationwide project to limit deep drainage and rising saline water-tables (Connors, 2004).

(v) Improvement of drought tolerance and perenniality of pastures: Mediterranean varieties of tall fescue, cocksfoot, and phalaris are able to tolerate summer droughts of 3-4 months and accumulated water deficits of 600-700 mm without significant effect on plant density over several years. However, survival over the dry period requires at least 70 to 80 mm which is not directly productive (sum of soil evaporation and transpiration during this non-growth period). Because this quantity increases slightly with the duration of the drought, it reduces the attractiveness of these species in semi-arid regions with low annual rainfall. The cv Kasbah and ecotypes of cocksfoot originating from Morocco have complete summer dormancy which confers higher drought tolerance, but with reduced yield potential (Kallida *et al*., current publication).

(vi) Other advantages of perennial grasses: these include flexibility of use; palatability; grazing tolerance; reduced establishment costs because of perennial habit; provision of a permanent soil cover preventing the encroachment of woody species; friendly to the environment.

The most common mixtures used in these regions (40-45°N) are simple associations of cocksfoot-lucerne or tall fescue-lucerne, grazed in autumn and winter, and conserved (hay, silage) in late spring and summer. Since a large range of species and cultivars is available for these latitudes, more complex mixtures can be developed, e.g. in the case where the main utilisation is grazing.

Agro-pastoral systems derived from cereal based systems in Southern Europe (eg: Central Portugal, Extremadura, Sardegna)

These regions suffer from two major constraints, water deficit (semi-arid climate) and poor quality soil, which limit productivity of cereals and intensification. Through high value-adding to products (e.g. cheese, quality fresh meat, smoked ham), grazing and livestock breeding have become the main activities of farmers, except where subsidies result in ongoing cereal production even with low yields. These regions have in the main completely turned to livestock production, cereal production becoming one component of animal nutrition (Roggero *et al*., 1990; Caredda *et al*., 1993). Depending on government subsidies and research efforts, the systems could evolve in two opposite directions: either degraded rangelands complemented by cereals (partly grazed, partly conserved) using imported protein; or semi-permanent pastures as already present in Portugal (Crespo, 2006). In these areas, perennial grasses have a limited role in native pastures and rangelands, but new drought tolerant cvs could contribute to mixtures with annual and perennial legumes, where their advantages are the same as in subhumid regions. Their presence is also useful to prevent encroachment of woody weeds. Sown pastures become rare south of 40°N (line Lisbon-Sardinia).

Cereal based farming systems in North Africa and Near East

In the southern Mediterranean Basin, the traditional agro-pastoral system has survived much longer. It was described by Papy and Lelièvre (1979) in Moroccan semi-arid environments. They showed that livestock were essential for the economic viability of farms because animal grazing gave value to the forage produced off collective rangelands, fallows, by-products of cereals (stubble, straw) and failed crops. Livestock were the farm "bank" which buffered income variations from cereal cropping from year to year. These integrated systems were remarkably self-sufficient in energy, nitrogen and protein. Nowadays, small cereal based farming systems are still important across the WANA region, but have evolved somewhat. Rising population has led to increased needs for cereals, privatisation of the land, and mechanisation, which has led to the discontinuation of fallowing. Monoculture of winter cereals has became widespread and has been extended to marginal lands and slopes of low productivity and high susceptibility to wind and/or water erosion. The dramatic decrease in area of fallows and rangeland was not associated by a decrease of livestock because of the availability of subsidised imported feed (cereals, soybean, and bioindustry by-products). These new integrated cereal-livestock systems have little self-sufficiency, as they import 30 to 100% of animal nutrient requirements. This results in excessive livestock densities with continuous overgrazing on the remnant rangelands, particularly those that are collective and forests. Combined effects of overgrazing and intensifying drought have severely degraded these rangelands, effects include: erosion of biodiversity in more palatable species, loss of soil organic matter and fertility, erosion of soils, disappearance of forests. Therefore, it is unlikely that these agropastoral systems are sustainable in the long term (Nefzraoui and Ben Salem, 1999).

To reverse this trend depends not only on scientific or technology but also on regulation. Rangelands and forests should be protected by laws and the education of users, and opened only to a limited number of herds. On slopes, cereal monocultures must be substituted by permanent pastures (restored rangelands) to stop soil erosion. Where annual rainfall is > 500 mm, perennial grasses should include legumes in the mixtures because of their capacity to fix N. Under 500 mm, few commercial cultivars are adapted, but small quantities of perennials locally selected should be integrated in mixtures of annual legumes, to fix N for the soils as well as to provide pods and seeds of annuals and protect the soil during windy periods in summer.

Concluding questions deal with cereal monocultures: are they sustainable, and if not how should they be modified? How should the combination of cereal cropping and forage crops with pastures and livestock production be optimised in economically and environmentally sustainable ways? One way is certainly to continue to try to promote adapted "ley-farming" systems. An other way, studied in the PERMED project, is to propose short-term dryland pastures (2-4 years) to be used as occasional "break-crops" from the monoculture. In these situations, drought resistant tall fescue and cocksfoot cvs should be integrated in the mixtures, with rapid establishing species to obtain significant forage production in the first year. These two approaches correspond to the systems in Australia promoted previously as "ley-farming" and nowadays "phase farming" (Connor, 2004).

Alternative uses (cover-crops in intensive systems; inter-cropping and land rehabilitation)

Agriculture has to correct the negative environmental impacts resulting from continuous intensification of the last sixty years. Such a strategy will impose a rapid reduction of the use of external energy and chemicals, to be substituted by the management in farming systems of biological functions like nitrogen fixation, nitrate entrapment, non-chemical weed control. These technologies, encouraged by policies, are in full development in Europe. Grasses, both pasture and turf and legumes are used in such large scales for this purpose that plant breeders have begun to create plant cvs for this purpose.

In rainfed agriculture in the Mediterranean, a general question is, how to reduce use of herbicides as well as the continuous ploughing across millions of hectares of vineyards, orchards and olive groves. The average cover-crop ideotype is a grass-legume mixture with prostrate or rhizomatous habit, shallow root system and limited aerial biomass (except seeds for self-reseeding species), early flowering, drought tolerant and persistent. The cover-crop must be able to cover the soil rapidly, to prevent soil erosion and control weeds, fix nitrogen but also entrap nitrates and pesticides while increasing organic matter and fertility. However, it should not compete significantly with vines or trees for water and minerals. It has been demonstrated that, except in deep alluvial soils in sub-temperate regions, the solutions of the temperate regions (mixtures of temperate perennial pasture or turf-grass) are not adapted to Mediterranean rainfed systems. These compete too strongly for water in spring and early autumn and often die in the dry summers. Annual medics and subterranean clovers, or mixtures of annual legumes are currently used from Italy to Portugal as cover-crops in the inter-rows (Masson and Ginzburger, 2000; Longhi *et al.,* 2002). Nevertheless, available material is generally of a pasture type, with substantial development from February to late June, thereby depleting the soil with negative impacts on rainfed vineyards in dry years, especially on shallow soils. *Dactylis glomerata ssp. hispanica* cv. " Bacchus" and the completely summer dormant cv. Kasbah have some minor use in southern France for this purpose. Bacchus competes too strongly with the vines in dry years and is not persistent enough. In contrast, the completely summer dormant Kasbah fulfills well the criteria of the ideotype. This suggests two conclusions : (i) the development of cultivars of grasses and legumes specifically for cover-crops is needed; (ii) in grasses, early and completely summer dormant types like cv. Kasbah (but more prostrate) native from Morocco, could provide adapted material. Their autumn regrowth is less abundant than non dormant grasses which is a favourable trait in association with annual self reseeding legumes.

In Mediterranean regions of Australia, summer active, vigorous and deep rooted forage plants (lucerne, tall fescue, phalaris) are at present promoted with the main objective to maximise transpiration and limit deep drainage to prevent from the rise of saline water tables. Lucerne is used to take the place of annual medics in legume-wheat rotations (Connors, 2004). Perennial grasses are also used successfully as firebreaks. When correctly grazed, these grasses prevent encroachment of woody weeds and thereby reduce fire risk during summer.

Prospects and conclusions

Adding value to existing knowledge

A range of actions could accelerate forage and pasture development in Mediterranean regions, with the use of perennial grasses. A first action would be to add value to the substantial knowledge accumulated at the international level. This requires first that policies and subsidies be adapted to promote the adoption of good practises. That may have a strong impact since livestock production in these areas is of low profitability which should react to policies and subsidies. Considering the lack of selected cultivars, easy access to the existing ones from abroad is important in different countries.

Considering all the knowledge on establishment and management of grass-mixture crops, acquired across Mediterranean countries, efforts should be made to adapt this to ensure good dissemination among technicians and farmers across the regions and countries.

Research priorities

(i) Within the Mediterranean Basin, the effort to develop perennial species is too limited. Further work must be carried out through exploitation of native germplasm present in semi-arid and arid regions, to create more drought resistant genotypes suitable for semi-arid regions. Perennials must combine improved winter growth (high WUE) with high summer drought tolerance. The exploitation of summer dormancy and desiccation tolerance traits should improve drought tolerance and limit water requirements for summer survival. Such low water consuming perennials are also ideotypes to be used as cover-crops in northern regions. Moreover, the development of plant material which is prostrate, of limited growth, early flowering, of long summer dormancy and shallow rooted, could contribute to the development of covercrops suitable for many situations in dry areas. Completely summer dormant grass cultivars, are suitable for pastures in dry North African environments and for intercropping in vineyards and plantations in northern areas to protect soils, as demonstrated in Australia.

(ii) With the most recent developments in molecular genetics and biology, it is necessary, to evaluate if significant new progress in drought tolerance and water use efficiency can be incorporated into genotypes. The inclusion of traits such as summer dormancy and the dessication tolerance as exhibited in *Poa bulbosa* (Volaire *et al*., 2001) could be a way to create perennial grasses adapted to very long droughts, without requiring water in summer. The *cocksfoot* germplasm collected in arid regions of Morocco is certainly a source of drought resistance traits in this species. Its rapid evaluation is of general interest (*Bellague et al*., current publication). The lack of water being an issue of major concern throughout the Mediterranean, these studies like breeding for drought tolerance, should be conducted in cooperative programs.

(iii) The knowledge and the tools to define optimal grass/legume mixtures, according to various objectives (grazing, hay/silage production, landscape service maintenance), and average climate and soil conditions, is insufficient. This knowledge is also necessary to manage mixtures and to maintain optimal grass/legume composition. Modelling competition between genotypes in multi-specific or multi-genotypic swards, especially water competition between the components, needs to be developed.

(iv) In the context of rapid increase of the impacts of global climatic change and probable development of appropriate measures, good environmental and energy practises may constitute a significant part of the income of agricultural systems. Consequently, agronomists and plant breeders must integrate yield and income from a cultivar (or a mixture) into a sum of "harvested yield" (synonymous to dry matter or milk/ha/year) and "environmental benefit". This should be systematically measured and evaluated in their experiments.

Cooperation and organisation of work

The Mediterranean Basin accounts for sufficient livestock and environmental issues to warrant active research in genetic resource evaluation, plant breeding, seed technology and development in several grass and legume species. However, the means to do research in Mediterranean countries in pasture and forage science is declining, even though the extent of Mediterranean climates are growing with climate change. The markets of each nation are too small to implement breeding work in each. The question, what would be the state of Mediterranean pasture research without Australia and its plant breeders and seed industry, is relevant? This limited capacity should push us to develop a stronger trans-national organisation of research and long term cooperation, with links also organised to Australian groups. In addition, evaluation of elite material and new cultivars at this enlarged scale is likely to increase the potential size of the market and the interest from seed companies in forage seed production of these new cultivars adapted to rainfed areas.

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