Grassland and water resources : recent trends and future challenges in temperate zones

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Key points : Three main components of the terrestrial hydrological cycle are taken into account in this paper : soil , groundwaters and streams , linked by various transfers , such as drainage , throughflow and runoff .

The main result of this literature review is to point out the major positive effects of grassland on all the water quality criteria , with two local problems : nitrate and microbiological parameters . In a short second part , we develop a challenge for the grassland researcher community : to contribute to the international agronomists efforts to improve our water resource quality . To conclude , we propose some research questions for the future .

Key words : water quality , runoff , water infiltration , grassland management , farmer practices

Introduction As focused by Briggs and Courtney (1989) the high yields characteristic of modern , intensive farming systems in temperate areas reflect man s ability to modify the agro-ecosystem in such a way to remove or diminish natural limitations upon productivity , and to provide a more favourable environment to crop growth . We agree with this research on productivity as an effect desired by many farmers in Europe and helped by our Common Agricultural Policy . On the other hand , we propose to explain that farmer practices involved in these modern farming systems have major impacts on hydrological processes (Benoît , 1994) .

In this trend , the grasslands have a particular position , some of them are very intensive , but some of them have for a long time been managed on an extensive way . The geography of the grasslands is also very clear in temperate zones : extensive grasslands are located in mountains (i .e . Alps , Pyrénées , Vosges , Jura , Central Massive , Scotland , Norway , north of Sweden , Schwarzwald , Carpathians , Tatars , . . .) and Mediterranean zones (i .e . east of Spain , centre and south of Italy , south of France , Greece) , intensive in Atlantic zones (Netherlands , Denmark , England , Brittany) and a mix of them in central Europe (Rhine and Danube basins) .

This paper fouses on the relationships between the diversity of grassland management and the main fluxes of water in this terrestrial hydrological cycle (soil , groundwaters and streams , linked by various transfers , such as drainage , throughflow and runoff) , and will confirm recent reseraches on grassland advantages in environment management (C .F .E . Topp , and al ., 2007) .

Grassland in the hydrological cycle
For the terrestrial hydrological cycle , Briggs and Courtney (1989) identify :
— four main components : soil , groundwaters , streams and seas ,
— four main transfers : drainage , throughflow , runoff and seepage .

This cycle is vulnerable to the effects of agriculture , and , for us , in particular , through the impact of grassland management practices upon the transfer mechanism of water and the associated chemical and biological elements .

The focus is on two main management practices : (i) proportion and location of grassland in the landscape , (ii) farming practices on grassland . These practices interact with interception and infiltration (as inputs of water) and evapotranspiration , drainage and runoff (as outputs of water) . This hydrological cycle is a topic point when we try to take into account the global changes and the agriculture adaptations to climate changes , where grassland are central .

Effect of grassland on infiltration As the works of Holtan and Kirkpatrick show , infiltration rates on grassland are generally higher than those on arable land (Briggs and Courtney , 1989) . Nevertheless , marked variations occur in grassland soils due , in particular , to differences in sward age , composition and grazing intensity . In general , infiltration capacity increases as the pasture gets older due to the accumulation of organic material at the surface and the development of an extensive root system and of a stable soil structure . Different types of grass also have different effects , partly because of the way in which they affect soil structure , but also because of their varied resistance to animal trampling (Gifford and Hawkins , 1978) .

The most important factor controlling infiltration capacity in grassland is grazing intensity . Reviewing the hydrological effects of grazing , Gifford and Hawkins (1978) concluded that light-moderate grazing may reduce infiltration capacities by about 25% compared with ungrazed pasture , while under heavy grazing infiltration capacities fall about 50 % . Briggs (1978) , for example , comparing infiltration capacities in different areas of a single pasture on clay soils , showed that in the most heavily trampled areas infiltration rates were zero , whereas in the least trampled areas the infiltration capacity was 7 .6 cm h^{-1} . Similarly , Selby (1972) noted that in New Zealand , grazing may cause severe compaction , which reduces infiltration capacity , promotes surface runoff and encourages soil erosion .

Effect of grassland on the soil moisture budget Farming does not affect the total quantity of water held in the soil in the long term , but it does affect the pattern of retention throughout the year . Thus Keuren *et al* . (1979) found that summer-grazed pastures had higher rates of evapotranspiration than winter-grazed plots but less surface runoff and subsurface outflow .

The lack of knowledge about the grassland situation has to be reduced by new researches focused on grassland management and soil moisture budget evolution in the global changes context (IPCC , 2007) .

Effect of grassland on overland flow and surface runoff Overland flow refers to the movement of water across the soil surface either in the form of thin sheets of water (sheetwash) or as concentrated flow in rills and gullies . Horton (1933) described what has become known as Hortonian or infiltration excess overland flow . Overland flow occurs in two situations : (i) when rainfall intensities are greater than the infiltration capacities of the soil and (ii) when local saturation of the soil in footslope or channel-side areas is created by lateral movement downslope .

Flow velocity is an important parameter in relation to runoff because it affects the time taken by water to enter the permanent stream network , and thus the response time (flashiness) of the stream system . As written by Briggs and Courtney (1989) , for rainfall interception , infiltration capacity , surface roughness and surface moisture retention , grasslands have a very positive effect .

In the temperate zones , the first wave of major researches began around the 1930 s . Early research about the effects of cropping systems and grassland on overland flow in the USA has been summarised by Glymph and Holtan (1969) . Recent European works are focused on the excellent effects of grassland on runoff . Chisi and Zanchi (1981) recorded the effects of different cropping , cultivation and grassland with or without drainage , on runoff and soil loss from silty clay soils in the Vicarello area near Pisa . In each situation , overland flow and soil loss from grass are less that from arable land . A grass sward provides a more or less continuous vegetation cover which intercepts rainfall and impedes any overland flow which does occur . The improved rooting and organic matter accumulation , with the high worm activity as showed earlier by Darwin (1881) , in grassland soils also means that infiltration capacities tend to be higher than in arable soils .

In the same way ,Souchère *et al* . (2003b) show the effectiveness of grassland location in a watershed to reduce soil loss . Using simulations with STREAM model in a Normandy watershed (Bourville) , they evaluated the increase in soil loss after the ploughing of 17 % of grassland surfaces by the farmers : the overland flow increased by 75 % and the soil loss by 85 % . To improve the situation , they simulated the effect of a 1 % increase of grassland located in strategic places : the runoff volume will decrease by 48 % .

Nevertheless , soil structural damage caused by trampling or vegetation removal due to over-grazing may allow overland flow to take place , and in some cases serious losses may be initiated . Costin (1979) illustrates these effects by comparing plots under a range of grazing regimes , from moderate to heavy stocking , in New South Wales , Australia . Higher grazing intensities resulted in lower vegetation cover and higher rates of overland flow and soil loss . Similarly , the effects of herbicides used to control rangeland weeds has been shown by Richarson and Bovey (1979) .

So , grassland strips and optimal grassland location in the landscape are the best strategic options to reduce the overland flow and soil losses in temperate zones . So , a general plan for an ecological infrastructure based on grassland is now to be built at the European scale for next C .A .P .

Effect of grassland on water quality

Nitrate For many authors (Briggs and Courtney , 1989 ; Manion , 1995 ; Benoît *et al* . , 1995) , grassland has a better effect on water quality and water resources than crops .

Under cut grassland , nitrate leaching is very low when fertilizers are applied in accord with the level of yield , until N fertiliser rates of around 400 kg N ha^{-1} . A number of recent works allows us to conclude that water quality is good in respect to nitrate under cut grassland in Europe (Ball and Ryden , 1984 ; Baraclough *et al* . , 1984 ; Decau and Salette , 1994 ; Dowdell and Webster , 1980 ; Garwood *et al* . , 1986 ; Jordan , 1989 ; Simon , 1995) .

Without fertiliser or with low levels (less than 100 kg N ha^{-1} y^{-1}) , no significant nitrate leaching is measured and a low level of nitrate leaching until 250 kg N ha^{-1} y^{-1} . For a 400 kg N ha^{-1} y^{-1} fertilisation rate , the nitrate leaching is lower if the fertilisers are concentrated in spring and summer than when they are spread throughout the year . In this case , autumn fertilisers and soil mineralisation induced an available N amount higher than the plant needs for N . Above 400 kg N ha^{-1} y^{-1} , nitrate leaching increases rapidly .

The relationship between nitrate leaching and nitrogen fertilizer level has been investigated for grazed grassland composed of pure grass stands in a large range of pedological and climatic contexts in temperate zones (UK, France, Netherlands, New-Zealand) (Farrugia and Simon, 1994; Lançon, 1978a; Lançon, 1978b; Ledgard, 1989; Lantingua *et al*., 1987; Macduff *et al*., 1989; Owens *et al*., 1994; Peyraud *et al*., 1995; Richards and Wolton, 1976; Ryden, 1983; Ryden *et al*., 1984; Scholefield *et al*., 1988; Scholefield *et al*., 1991; Sherwood and Ryan, 1990; Simon, 1995; Steele *et al*., 1984).

Comparing with the response curve for cut grassland, the nitrate leaching for grazed pasture is higher. It stays in a moderate level if nitrogen fertilisation rate is low (less than 200 kg ha^{-1} y^{-1}). Then, it is very variable and able to reach very high levels if fertilisation rate is higher than 300 kg N ha^{-1} y^{-1}. This high variability between experiments shows that nitrogen fertilisation is not the single factor responsible for nitrate leaching. Stocking rate is a more synthetic index and gives a better explanation of nitrate leaching.

Any farmer practice which induces a decrease in stocking rate on the pasture decreases the variability in nitrate leaching. But, hay or silage harvesting on a grassland field also decreases the number of grazing days and consequently the nitrate leaching. The main factor influencing nitrate leaching in grazed pastures is the stocking rate.

Pesticides In our research of papers on water quality, we did not find a paper detecting pesticide contamination under grassland. This fact is central for the future of water resources in temperate zones because herbicide, fungicide, and pesticide contaminations are increasing very rapidly in surface and groundwaters. So, the location of grassland in watersheds is a major solution for water managers to decrease such water contaminations (Benoît *et al*., 1995; Mignolet and Benoît, 1999).

Microbiological parameters A more critical point are bacteria, virus and parasite contaminations of water from cattle. A large number of papers recently pointed to this source of water contamination (Vallet, 1994; Brewer, 1997; Crane *et al*., 1983; Larsen *et al*., 1994; Marinova, 1995; Moore *et al*., 1983; Moore *et al*., 1989; Sherer *et al*., 1992). Two main management problems are identified by these works: the animal trampling in the small rivers during drinking, and the direct contamination by liquid effluents from buildings or during the spreading of slurry along the streams. New parasites are developing, as Guardia for example.

On the other hand, we find few papers dealing with the effects of water quality on herd health, but they seem very important (Meijer *et al*., 1999). This feedback effect of water contamination on animal production is a deficiency in our research topics.

How to increase the positive effects of grassland on water resources? The presented results indicate a new position for grassland: their capability to protect water resources and to protect soil from erosion. So, a general trend for the area of grassland to decrease should stop in order to benefit European society. Three challenges for the future are presented:

How to increase the surfaces of grassland? During the last thirty years, there has been a global trend to decrease grassland area through three factors: becoming cropland by ploughing of productive grassland, becoming forest by plantation and becoming urban zones by building.

Now, there is a new challenge to inverse this trend and to increase the grassland surfaces. But, a lot of difficulties have been identified: (i) in Europe, the CAP subsidies induced an increase in crops through high level of subsidies, (ii) industrial cheese factories favoured the use of more maize in dairy cow feeding, (iii) the efficiency of work and the level of investments induced the increase of maize in dairy cows farms (Gall A. Le. *et al*., 1997; Mignolet and Benoît, 1999; Mignolet *et al*., 1997; Mignolet *et al*., 1999; Mignolet et al, 2004). And, we can add that the image of modernity, including our own influence as researchers often gave a qualitative advantage to maize in livestock farming systems.

Only two main arguments are developed to increase the grassland surfaces: (i) for high quality cheeses it is beneficial and sometimes a legal obligation to use grassland, (ii) for water resource protection, grassland should be a major way in Europe (Brouwer and Hellegers, 1996; Oenema *et al*., 1998; Pflimlin and Madeline, 1995).

Where to localise grassland? A major challenge for water resource protection is to locate grassland in sensitive areas for water resources protection. The present proposal is to locate new surfaces of grassland on (grass) strips in valleys, seen as a network of water corridors. This should produce important effects through improving water quality and reducing water runoff (Souchère *et al*., 2003a). So, we have to deal with farmer decision processes.

What is more, understanding individual decisions made by farmers confronted by uncertain situations raises numerous difficulties (Brossier, 1989). The rational nature subtending the farmer's decisions appears to be part of complex process of adaptation to the environment in a situation where information is lacking and where rationality itself is limited (Simon, 1975). This process in fact belongs to an apprenticeship in which the farmer refers not only to the production factors in his possession but also to the family context in which he finds himself, his different objectives, the history of the farm, and the perception each farmer has of the advantages and disadvantages of his system and environment (Benoît *et al*., 1988), (Bonneviale *et al*., 1989), (Dent et McGregor, 1994). It is based on the supposition that the decisions made by farmers are consistent: given their situation and objectives, farmers have reasons for doing what they do" (Brossier, 1989). The work thus consists in discovering these reasons, by basing ourselves on the observation of how farmers manage their farms in reality (Brossier *et al*., 1989). So, what is the perception of grassland in their territory by farmers, is the topic question.

How to build a new image of grassland?

Firstly, we have to know the current images of grassland for the people, mainly for farmers and public decidors. But, as scientists, we also have an influence on this image of grassland: how can we improve the image of grassland through our work? This paper is one of a large number of contributions in this way. But, are we able to give enough arguments, for example in Europe, to change the level of C.A.P. subsidies, and to re-build this common basis for the future of agriculture?

Conclusion

What are the challenges for researchers in the future?

We identified the main favourable effects of grassland on water resources: runoff decreasing, no pesticide contamination, global protection against high nitrate content if moderate stocking rates are used on grazed pasture. But, some new researches have to be developed. In the future, we propose to focus on the following main research questions to improve our knowledge on grassland and water resources:

a. Increasing knowledge on grassland location The evolution of grassland surfaces and the location of these evolutions have to be known and to be related to water data bases. We propose to IGF-and IRF to manage a deal with the Land Use and Cover Changes research programme: Global Land Project (Lambin *et al*., 1999; Lambin *et al*., 2003; Mannion, 1995; Velkamp and Fresco, 1997). All over the world, the grassland areas are one of the major cover in term of challenges for the future (Girard and Benoît, 1990; Girard *et al*., 1990; Benoît *et al*., 1993; Lambin *et al*., 1999; Mignolet et al, 2004). A scenario for future is to re-build a network of grassland along all the rivers. This global grassland corridor network could be a major contribution of grassland for sustainable development.

b. Modelling of farmers choices The question we want to focus is: how to preserve grasslands, where are they maintained? In an other formulation: what are the good reasons for a farmer to keep or to increase grassland? Surveys, economical studies, modelling of farmer s meaning are the main methods to evaluate the possible future of grassland (Le Ber and Benoît, 1998; Le Ber and al., 2006).

c. Increasing knowledge on grassland interests for water resources by two main trends of research *Developing a common organisation for Observational Research*. As we showed above, we need more coordinated data basis to help us to build our research hypothesis. Often, it is very difficult to compare data on an European scale. Three main trends shape this challenge:

— the common development of measuring and monitoring of water quality (field and watershed scales);
— the generalisation of measuring and monitoring of animal health (quality of drinking water for animals, monitoring of parasites);
— the improvement of measuring and monitoring of animal products.

The future of researches in these fields seams to be linked to the developments in Observational Study Methodologies (measuring, surveying, monitoring, statistical analysis, building of common conceptual framework). A very useful initiative could be to initiate a International Network of Experimental Stations: Grassland effects on natural resources. IGF and IRF could be the boosters of this initiative.

Building a common grassland management typology. If we want to compare our results in Europe, the description of grassland management in a multi-criteria typology is a necessity. Until now some of us have precise results on water quantities and qualities (the norms and the laboratory analyses are standardised), but we have large difficulties even in temperate zones to compare an Irish cow pasture with a Lorraine one in a same grassland management typology. A future common challenge could be to build together a European grassland management typology.

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