Agriculture and Groundwater Resource Protection

A review and discussion of commonly recommended agricultural policies and farming practices aimed at protecting groundwater

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1. Introduction

In the last half century there has been an amazing boom in agricultural groundwater use, improving the livelihoods and food security of billions of farmers and consumers around the world (Giordano, 2009). Nonetheless, these outstanding gains have not come without costs: to date, agriculture stands as a major threat to both the quality and quantity of groundwater resources.

Globally, irrigated agriculture is the largest extractor of groundwater resources, with groundwater-dependent agro-economies having widely evolved (Foster et al., 2000). Since intensive irrigation became widespread it has led to groundwater extraction rates that far exceed recharge, and groundwater tables are lowering with phenomenal rates in many parts of the world (Wada et al., 2010). Those areas of arid and semi-arid climate whose agricultural development strongly depends on groundwater being the most affected; such as: Pakistan, India, China, United States, North and South Africa, the Middle East and also some Latin American countries (i.e. Mexico, Peru, Argentina, Chile) (Figure 1). According to Gleeson and colleagues (2012), 20% of the world's aquifers are being overexploited; although, many more are suspected to be used unsustainably, but it is expensive to document it. Indeed, groundwater depletion is a problem faced by virtually all nations (Brentwood & Robar, 2004).

Agricultural practices also have major effects over groundwater pollution. For instance, agriculture is the main source of nitrogen in groundwater. Aquifer's natural water

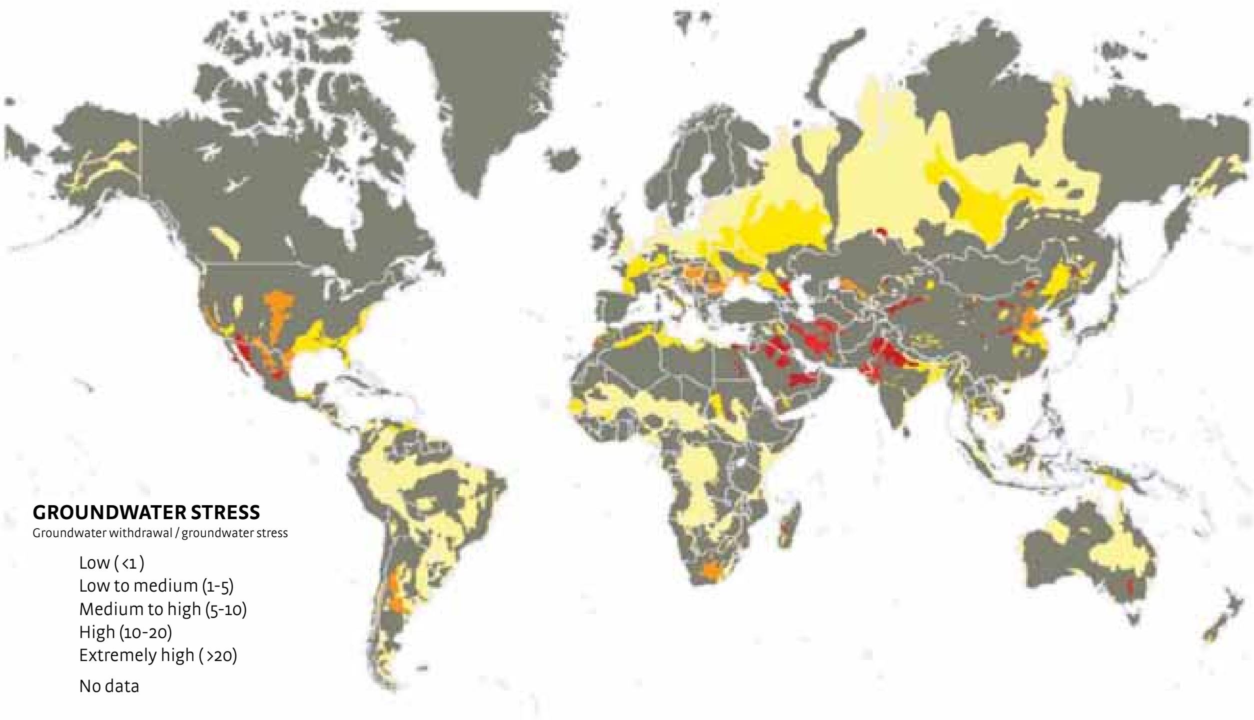

Figure 1: Map of groundwater stressed regions (source: World Resources Institute, www.wri.org).

return flows are being degraded due to the exponential increase in the use of fertilizers, agrochemicals and livestock-keeping; a problem faced by developing and developed countries alike (Brentwood & Robar, 2004).

Protecting groundwater from both pollution and depletion as caused by agriculture is challenging. First, many and different farmers spread over a vast territory are involved; who are often not aware about the importance of protecting groundwater. Therefore, a main challenge is to engage farmer communities into groundwater management, and to spread among them the agricultural practices that protect groundwater best. So far, different agricultural policies and practices have been promoted to be adopted by farmers to better manage groundwater.

This report aims to galvanize the discussion towards agricultural practices commonly promoted to protect groundwater, but that still deserve further attention and understanding. For instance, some practices may have unexpected negative effects, while others need to be improved so farmers can adopt them. Therefore, first, different agricultural practices will be presented. Thereafter, the practices of irrigation technology system, conservation agriculture, mulching and fertilization will be discussed.

2. Effects of agricultural practices on groundwater protection

There are different types of practices farmers can adopt to better protect groundwater from pollution or excessive use (Table 1). In general, these practices are aimed to: i) reduce useless water losses by evaporation; ii) reduce runoff and enhance infiltration, thus helping to better retain the water in the soil; iii) to avoid pollutants leakage into ground and superficial water (Foster & Candela, 2008; Muthamilselvan et al., 2006; Patel, 2004; Logan, 1993).

2.1. Improvements in irrigation technologies

Surface irrigated agriculture is often believed to be wasteful. In response, numerous national governments, international organizations, and scientists have called to support conversion to more efficient irrigation technologies that offer ´water saving´ by reducing non-beneficial evaporation and other water losses (Cooley et al. 2009; Jury & Vaux 2005; Zinn & Canada 2007; Johnson et al. 2001; Evans & Sadler 2008; all in Pfeiffer & Lin, 2013). However, water leakage is not always a loss but a source for aquifers recharge (IWMI, 2002).

It is extremely important to note that irrigation returns often represent a major component of groundwater recharge in more arid climates (Foster & Candela, 2008). In cases where surface water is the source of irrigation, it presents a new source for aquifers recharge. In areas where groundwater irrigation is practiced, irrigation returns represent water that can be recycled by the same or other farmers, and thus a reduction in net groundwater abstraction (Giordano, 2009; IWMI, 2002; Keller & Keller, 1995). Also, according to Foster & Shah (2012), farmers choose micro-irrigation technologies not so much to save water but to improve crop yields or increase the cultivated area. Therefore, in some cases, improvements in irrigation water use efficiency may be largely achieved through reductions in irrigation returns to groundwater, and as such do not result in a 'real water saving' strategy (Foster & Shah, 2012).

Since intensive irrigation became widespread it has led to groundwater extraction rates that far exceed recharge, with groundwater tables falling at phenomenal rates in many parts of the world (Wada et al., 2010). So far, different case studies have shown that a shift into more efficient irrigation methods can lead to higher groundwater extractions. For instance, this is the case in studies from Pfeiffer & Lin (2013) in the aquifer of Kansas in U.S.; Ahmad et al. (2007), Kemper (2004), Rockstrom et al. (2007) in Pakistan; Ward & Pulido-Velazquez (2008) in Upper Rio Grande Basin, in Mexico.

Table 1: Summary of different agricultural practices aimed at the control of agricultural non-point source pollution, or for the enhancement of soil water conservation. The practices that are further discussed in the present report are indicated in bold letters (Source: elaborated by the author; adapted from Logan 1993 and Foster & Candela 2008).

Type of Agricultural Practices	Examples	Objectives and Considerations
Source control	• Rationalising inorganic fertilization and livestock applications • Enhance alternative fertilizers/pesticides development • Combined organic and chemical fertilizer use • Consider the N and P content in applied organic materials (mulch, manures) and groundwater • Restrict or ban specific pesticides (especially in areas vulnerable to superficial or groundwater contamination) • Add leaching potential in pesticides labelling criteria	Objective: reduce the application of harmful fertilizers and pesticides. + Most effective and easiest practice to regulate - Lack of stringent enforcement to restrict chemical and fertilizer application rates
Structural control	• Terraces • Sediment detention basins • Tied-ridges; counter tillage • Grassed waterways • Buffer strips • Type of irrigation system • Livestock waste storage	Objective: modify pollutant transport in water by retaining water in the soil or rerouting water. + Easy to regulate and install - High capital cost - Requires cost-sharing incentives and long-term maintenance
Land management practices	• Mulching • Increasing the soil organic matter content (Composting, Vermiculture) • Timing and placement of chemicals • Irrigation scheduling • Methods and timing for livestock land waste application • Reduce autumn ploughing • Avoid winter farrows (use of cover and catching crops) • Type of tillage practiced • Conservation agriculture	Objective: manipulate the soil to minimize: water use, pollutant losses and excessive pollutants leaching into surface or groundwater. + Do not offer the certainty of either structural or source controls - Specific criteria are difficult to develop, requiring extended education efforts to attain large-scale impact
Pest management practices	Integrated pest management (IPM): • A set of practices which when applied together can help reduce pesticide use. • Require Integrated pest management practices	Objective: reduce pesticide use, and thus potential groundwater pollution. - It has not been adopted readily by farmers, despite extensive educational programs

Also, a global trend has been to reduce the practice of spate irrigation: a traditional irrigation system where agricultural land is deliberately flooded with surface run-off during the wet season. The aim of spate irrigation is to encourage infiltration, groundwater recharge and increase storage availability in the dry season and its practice can be considered sound in terms of water resources conservation (Garduño & Foster, 2010). For instance, in the Ica Valley of Peru – a hyper arid region – a serious decline in groundwater has occurred after abandonment of spate irrigation practices for asparagus intensive cultivation under efficient irrigation methods (Graduño & Foster, 2010).

Summarizing, to what extent, or under which circumstances, irrigation technologies lead to groundwater protection regards more attention; before continuing their promotion as a water saving strategy per se. Despite the fact that water irrigation technologies can make more efficient use of water resources, their adoption should go by hand with the planning of cropping systems according to a watershed's availability of (ground)water resources. Moreover, discussion and awareness among farmers, policy makers, and other stakeholders about the meaning of the concepts 'water saving' or 'water losses' must be raised.

2.2. Practices aimed at reducing soil water evaporation

Different studies have pointed out the reduction of evaporation water losses as a real saving water strategy (Foster & Sha, 2012; Garduño & Foster, 2010; Foster & Candela, 2008; IWMI 2007; Peterson & Ding, 2005). For instance, according to research by Kendy and colleagues (2004) in China, the only means to reduce net water consumption for agriculture is to reduce crop evapo-transpiration. Also, Garduño & Foster (2010) documented significant real water-resource savings in Guantao County-China after efforts were put into reducing evaporation losses. Moreover, water lost by drainage beyond crop roots is usually much less than that is lost by direct evaporation from the soil, except in very sandy soils (Passioura et al., 2005).

Reducing evaporation to save water and reverse groundwater declines can be accomplished either by reducing crop area, reintroducing fallow periods, or by reducing irrigation to the extent that crops become water stressed (Kendy et al., 2004). Although considered a necessity, the problem is that these measurements may lead to reduced crop yields and undesirable economic outcomes for both farmers and governments. Nonetheless, this approach still suggests the importance of planning cropping systems, economic activity and water extraction rates according to the watershed's water availability. However, in the next section, some farming practices that can reduce water evaporation from the soil will be discussed.

2.2.1. Mulching

Mulch is a layer of material applied to the surface soil during crop growing season or furrow periods. This layer can consist of organic residues or plastic (see figure 2). Mulch helps to reduce the soil's water evaporation and enhances water infiltration, especially in dry areas and dry seasons. Different case studies have reported an increase in the seasonal soil water content because of mulch (Stroosnijder et al., 2012;

Figure 2: Plastic mulch with drip irrigation on a pineapple plantation (photo: MetaMeta).

Mupanwa et al., 2007; Jalota et al., 2001; Sharma et al., 1990). Moreover, though not documented in the literature, by reducing water evaporation from the soil, mulching could also help to reduce water and soil salinity, improving the quality of water that recharges into aquifer[1]. Also, crop residue mulch can increase a soil's organic matter content, improving its adsorption and filtering capacity, and reducing pollutants leaching into groundwater.

Mulching stands as a sound water saving strategy, as reduces evaporation and therefore eventually groundwater extraction. Thus, mulch can be considered a real 'water saving' strategy. However, there are practical, economic, and environmental grounds to improve the practice of mulching.

First, at the farm level, organic mulching materials are often in critically low supply. This is due to the fact that mulch competes with other purposes farmers have for crop or organic residues, such as fodder, fuel, and construction (Giller et al., 2009). Therefore, when promoting mulch it is important to provide farmers with flexibility in the management of their crop residues. Also, a better understanding is needed with respect to mulch doses, and about in which circumstances mulch use is effective or not. In this regard, different studies have made the attempt to determine effective mulch doses; suggesting that different mulch doses may be needed according to different field conditions and objectives (Jordan et al., 2010; Nagaya & Lal, 2008; Mupanwa et al., 2007). Moreover, the supply for mulch material in farms could be increased by enhancing organic matter sources in the field and landscape (i.e. by planting more native trees or with agroforestry).

An alternative to crop-residue-mulch is plastic mulch. In the last years the global use of plastic mulch has increased significantly –from 1,200 to 3,200 thousand tons– mainly due to the intensive use of plastic mulch in Asia (Sarnacke & Wildes, 2008). For instance, in some provinces of China the Ministry of Water Resources has subsidized plastic mulch (Brown, 2004). However, plastic mulch usually must be annually replaced and residues pollute soils and the environment; a major concern, even more in countries with inefficient waste disposal systems. Moreover, the overall costs of plastic mulch usage –including the costs of removing it– are high (Olsen & Gounder, 2001). These concerns raised the importance to make more available biodegradable mulch technologies. However, as of yet biodegradable mulch is about one to three times more expensive than plastic mulch (Jiang et al., 2012), while also other issues must be improved as to be adopted by farmers and protect the environment (see Miles et al., 2009).

2.2.2. Conservation Agriculture

Conservation agriculture (CA) is a practice based on three pillars: i) minimum soil disturbance; ii) permanent soil cover with crop residues (mulch); and iii) crop rotation. CA is promoted as a practice to protect soils from erosion; to improve infiltration, reduce evaporation, and better conserve water in the soil; and to reduce labour and costs.

Several international research and development organisations have promoted CA with strong advocacy; but critical debate has been stifled (Giller et al., 2009). For instance, claims for the potential of CA in Africa are based

Figure 3: Intercropping with maize and French beans (photo: MetaMeta).

on widespread CA adoption in the Americas, where the effects of tillage were replaced by heavy dependence on herbicides and fertilizers. Compared to conventional tillage, at least during the five first years, CA demands higher use of herbicides (Wall, 2009). Moreover, it still remains to be confirmed whether or not more fertilizer is needed with CA in smallholder farming, which will depend on the quality and quantity of the mulch applied in each case (Giller et al., 2009).

Already in different regions of the world –especially in rainy temperate and tropical areas– high presence of herbicides in groundwater have been detected (Custodio, 2011; Geissen et al., 2010). The higher use of herbicides –and eventually of fertilizers– required in CA can lead to higher pollution rates of groundwater. Nonetheless, little attention has been spent on the effects CA may have on the pollution of both surface and groundwater.

2.3. Fertilization, agrochemicals and groundwater pollution

The increased and intense use of fertilizers, pesticides, herbicides and pharmaceuticals for livestock is polluting groundwater; a problem faced by both developed and developing countries alike (Brent wood & Robar, 2004). For instance, in China alone fertilizer consumption has grown by almost 21 percent annually over the last two decades (FAO, 2013). The effects of agriculture on groundwater pollution are substantial –especially in developed countries– but these have not been well documented: the evaluation of associated groundwater pollution is costly, problematic and, with more than 600 compounds involved, very complex (Foster & Candela, 2008). Yet, in Europe and the U.S., numerous reports have documented high groundwater concentrations of 'active pesticide compounds' in areas where intensive agriculture is practiced (Foster & Candela, 2008).

In general terms, pollution is worse where the soil is very permeable, which tends to coincide with the most important recharge areas (Foster & Candela, 2008). Moreover, an unobserved trend to groundwater quality degradation in springs and wells does not necessarily mean that the aquifer groundwater quality is not deteriorating in the whole; polluted water already in the ground may not be detected since it is still moving from the unsaturated zone to the aquifer. This also means that when pollution in groundwater is detected the volume the terrain affected may be large (Custodio, 2011).

Mobile pollutants that do not bind tightly to soil particles are more susceptible to leach into groundwater (Foster & Shah, 2012). Thus, a general prescription has been that soluble agrochemicals are prone to pollute groundwater, whereas less soluble pollutants are not. However, it is important to note that soils adsorption and filtering capacity varies tremendously; according to their clay and organic matter content; but also during different times and seasons (Keestra et al., 2012). Moreover, there is a lack of knowledge concerning risk assessment and mitigation practices for emerging agrochemical pollutants (Keestra et al., 2012). Consequently, soil properties must also be taken into account, alongside the characteristics of the agrochemicals used. To protect groundwater from pollution, a general trend should be to promote the increase of the organic matter content of soils, and to replace hazardous substances with clean fertilization and pest control technologies.

Best management practices (BMPs) have been promoted to protect groundwater from pollution (Table 1). However, it is important to note that the main cause for agricultural groundwater pollution remains to be the excessive use of agrochemicals (FAo, 2013; Foster & Candela, 2008; Logan, 1995). For instance, Chinese farmers use between 30 to 50% more than the required quantity for fertilization (FAO, 2013).

[1]) *This is due to the fact that subsequent evaporation from shallow water tables and from water in the soil results in the accumulation of salts in the soil surface layers.*

Experts had emphasised the adoption of 'source control practices' to reduce the source of pollution; thus the use of fertilizers and agrochemicals. Moreover, from all BMPs, 'source control practices' are the easiest to regulate and the most effective in reducing groundwater pollution (Foster & Candela 2008; Custodio, 2011; Logan, 1993).

One method of ´source control practice´ is enforcing the development of clean ways of fertilization, biological pest control and integrated pest management; rather than continuing to rely on chemical fertilization and pesticides. In terms of fertilization, bio-fertilizers and slow release fertilizers (e.g. rock dusts, coated fertilizers) need to be better developed. However, today slow-release fertilizers are still much more expensive than common fertilizers, such as urea and DAP. It is for instance more economical for farmers to apply cheap urea, despite the losses they will incur, instead of buying expensive sulphur-coated fertilizers with insignificant loss (FAO, 2013; Foster & Candela, 2008).

3. Conclusion

In this report, different agricultural policies and practices aimed at protecting groundwater from agricultural activity have been discussed. For instance, irrigation technologies –widely promoted by governments– can reduce irrigation returns to groundwater, accelerating groundwater depletion. Irrigation technologies should not be seen as water saving strategies per se, and their promotion must go by planning crop systems accordingly to water availability, or by practices that reduce evaporation water losses. Different studies have pointed out the reduction of evaporation as a real water strategy. With this respect, the practice of mulch seems sound; thought different issues related to mulch must be improved.

The leakage of water from agriculture is an important source for aquifer recharge. However, water return flows of aquifers are being degraded due to excessive agrochemicals and fertilizers use. Therefore, the use of agricultural inputs must be reduced, while enhancing clean technologies of fertilizers and pest control.

Future frameworks for action should consider both: enhancing groundwater recharge, while also protecting the quality and reducing the pollution burden of the water that returns into aquifers.

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