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PAPER

The key role of supply chain actors in groundwater irrigation development in North Africa

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Abstract The role played by supply chain actors in the rapid development of groundwater-based irrigated agriculture is analyzed. Agricultural groundwater use has increased tremendously in the past 50 years, leading to the decline of water tables. Groundwater use has enabled intensification of existing farming systems and ensured economic growth. This "groundwater economy" has been growing rapidly due to the initiative of farmers and the involvement of a wide range of supply chain actors, including suppliers of equipment, inputs retailers, and distributors of irrigated agricultural products. In North Africa, the actors in irrigated production chains often operate at the margin of public policies and are usually described as "informal", "unstructured", and as participating in "groundwater anarchy". This paper underlines the crucial role of supply chain actors in the development of groundwater irrigation, a role largely ignored by public policies and rarely studied. The analysis is based on three case studies in Morocco, Tunisia and Algeria, and focuses on the horticultural sub-sector, in particular on onions and tomatoes, which are irrigated high value crops. The study demonstrates that although supply chain actors are catalyzers of the expansion of groundwater irrigation, they could also become actors in adaptation to the declining water tables. Through their informal activities, they help reduce market risks, facilitate credit and access to subsidies, and disseminate innovation. The interest associated with making these actors visible to agricultural institutions is discussed, along with methods of getting them involved in the management of the resource on which they depend.

Keywords Groundwater management · Over-abstraction · Socio-economic aspects · Agriculture · North Africa

This article is part of the topical collection "Groundwater-based agriculture in the Mediterranean"

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Introduction

Irrigated agriculture provides more than 40% of world food (OECD 2002) and accounts for 70% of total water withdrawal (Madramootoo and Fyles 2010). Worldwide, a third of irrigated land for agriculture (113 million ha) depends on the exploitation of groundwater resources (Margat 2011). Due to the rapid development of new wells and boreholes (Lopez-Gunn and Llamas 2008; Shah 2009) in the last 50 years, the groundwater extraction rate has been multiplied by 10 (Margat 2008). In many parts of the world, groundwater overexploitation has led to increasing concern about the sustainable use of this resource in the context of declining water tables (Siebert et al. 2010), quality degradation, land subsidence, or biodiversity degradation and social inequity (Llamas and Martínez-Santos 2005). On the other hand, many positive economic and social impacts are attributed to groundwater irrigation, which has boosted economic growth and transformed rural economies in many countries in the Americas and Europe, in Asia through the Green Revolution (Shah 2009), and more recently in North Africa (Kuper et al. 2016). In sub-Saharan Africa, groundwater irrigation supports rural livelihoods by promoting poverty alleviation, food security, land and labor productivity, as well as rural employment and general economic development (Giordano 2006; Villholth 2013).

A range of interconnected factors was necessary to support the development of groundwater-based irrigation: available and accessible groundwater resources, fertile land and soil, accessible energy for pumping, policies supporting groundwater irrigation, but also markets for agricultural products, the availability and accessibility of labor and technical means, people with the skills and hardware needed to drill wells, a supply of irrigation equipment, agricultural inputs and the support of financial services and extension services (Villholth et al. 2013). The availability of land and water resources, the role of agricultural, energy and environmental policies and the question of energy have been widely studied (e.g. Mukherji and Shah 2005; Shah et al. 2006); however, the factors and actors directly linked to the structure of the food supply chain, i.e. the full range of activities required to bring a product through the different production stages (the agricultural inputs, the market, and ancillary services such as financial or extension services), require further analysis, as they can be either assets in or constraints to the development of groundwater irrigation (Villholth et al. 2013).

Recent studies have shown that individual access to groundwater has structured food supply chains, especially product marketing and the supply of inputs and agricultural equipment, including irrigation equipment (Llamas 2010; Bouarfa et al. 2011; Lejars et al. 2012). The supply chain actors have become increasingly dependent on groundwater for irrigation, particularly as it secures not only the quality and quantity of production but also their business (Lejars et al. 2012). These actors could amplify groundwater abstraction by enabling access to global, local or "niche" markets or alternatively, they could support water sustainability through innovative standards that take irrigation practices into account (Vos and Boelens 2014). Studies on innovation systems have also shown that some of the supply chain actors promote and support the extension of groundwater abstraction by facilitating access to groundwater and by improving the diffusion of irrigation innovations (e.g. Poncet et al. 2010). Supply chain actors can be considered as "innovation intermediaries" (Ayele et al. 2012) when they support innovation processes, by providing information, knowledge, advice, funding, or by acting as a mediator (Howells 2006; Stewart and Hyssalo 2008). For instance, in irrigated areas, suppliers of irrigation equipment may continuously improve the functioning and the diffusion of groundwater extraction techniques or resource-saving technologies through the "translation" (Garb and Friedlander 2014) or "domestication" (Ameur et al. 2015) of a somewhat "standard" technology to fit local circumstances, thus making it available to a wide range of farmers (Moss 2009a, b). This "intermediation" can be formal or informal, it can be a core or a side activity (input suppliers vs. extension services), and can be bilateral, multilateral or even systemic, when the intermediary creates and sustains innovation networks (Klerkx and Leeuwis 2009). Supply chain actors thus contribute not only to the positive impacts of groundwater use such as increased productivity, job creation, livelihood diversification, but also to the negative impacts the economic development may have on the environment, and on socio-economic inequity (Ameur et al. 2017).

In North Africa, the groundwater revolution started in the 1980s and boomed after 2000 (Kuper et al. 2016). Today, groundwater is delivered through hundreds of thousands of mostly private tubewells to more than 500,000 farm holdings in Algeria, Morocco and Tunisia, irrigating more than 1.75 million ha and opening new irrigation frontiers every day (Kuper et al. 2016). While major uncertainties remain about the hydrological impact of recent rapid agrarian changes, including groundwater pumping, hydrogeologists agree that the present development of groundwater-based agriculture is not sustainable (Leduc et al. 2017). Yet, there are very few local initiatives to protect the aquifers, and states have remained "tolerant" because the agricultural boom promotes economic growth (Petit et al. 2017). At the farm level, many investors jumped at the economic opportunities created by the boom in groundwater development by buying land and investing in agriculture (Dugué et al. 2014). Downstream from these farms, a network of wholesalers, retailers, and brokers emerged to handle the irrigated products, especially in the horticultural sector (Lejars and Courilleau 2015; Derderi et al. 2015; Ouendeno et al. 2015). On the farm supply side, many providers of agricultural inputs (crop seed, fertilizers, and pesticides), providers of irrigation equipment (pumps, drip irrigation, motors, etc.) and fitters have not only benefited from, but also significantly contributed to this rapid development by providing technologies that are appropriate for a wide range of contexts (see for instance Benouniche et al. 2014 for the case of drip irrigation systems).

Despite their dependence on water and their role in groundwater irrigation development, these supply chain actors, upstream and downstream from the farms, and their interactions, have rarely been analyzed. Their role is not even acknowledged in water management and water policies. This can be explained by the fact that these actors operate in a context in which access by farmers to production factors (land, water, inputs) and markets is highly informal (Amichi et al. 2012, 2016; Fofack et al. 2015; Daoudi and Colin 2016; Daoudi 2016). There is even a tendency in the literature to link "informal" with "unstructured" and "disorganized" (Guha Khasnobis et al. 2006). These supply chain actors, whose number has increased very rapidly although not in official records, thus appear to contribute to what Shah (2009) called "groundwater anarchy". They are embedded in socio-economic networks that extend well beyond the frontiers of the aquifer and are generally invisible to public policy makers (Schlager 2007).

However, like in the case of other resources, these supply chain actors may be contributing to more intensive or even

unsustainable use of resources on the one hand, while on the other, they could be vectors of innovation or give their support to regulations aimed at increasing sustainability (Biénabe et al. 2016). Characterizing their activities, analyzing their role, their interactions and how they are connected to groundwater is thus indispensable to grasp the economic stakes involved, to identify key actors and their strategies, and ultimately, to find new ways to moderate or enhance the development of groundwater irrigation.

The purpose of this article is thus to analyze and render visible the key role played by supply chain actors in the development of groundwater economies resulting from the expansion of groundwater-based irrigation in North Africa. The paper analyzes the network of supply chain actors upstream and downstream from the farm, their economic weight and their roles. The analysis uses two different analytical frameworks. First, the value or supply chain concept (Porter 1990; Beamon 1998) adapted to developing countries (Trienekens 2011) and to groundwater irrigation development (Villholth et al. 2013), is used to analyze the structure of the supply chains. Second, the specific nature of the relationships between actors of the markets in North Africa is described through the lens of the "bazaar economy" proposed by Geertz (1978, 1979) in a study on Morocco.

The analysis is based on an empirical study of the main irrigated vegetable supply chains that have developed thanks to access to groundwater in three areas in North Africa: Saiss in Morocco, Chbika in Tunisia, and Biskra in Algeria. The focus is on horticulture, which is a key irrigated high value crop sector in these regions. The role and the informal organization of these actors based on groundwater are analyzed and discussed. Finally, the advantages and the way to include these actors in water management are addressed.

Study areas and methodology

Analytical framework

The analytical framework used in this study is based on the food supply chain, or food value chain (FVC) concept. A value chain refers to the full range of activities required to bring a product or service through the different stages of production (including processing and the input of various producers and services), in response to consumer demand (Porter 1990; Beamon 1998). The terms "supply" and "value" chains can be used interchangeably, although some scholars distinguish between forward supply chains driven by producers and backward value chains driven by customer demand (Feller et al. 2006). Trienekens (2011) adapted the framework for developing countries and demonstrated the importance of three key elements: network structure of horizontal and (vertical) market channel relationships; added value, linked to the key competitive aim of any food chain; and governance, covering organizational arrangements between value chain actors. Trienekens showed that, particularly in developing countries, these elements should always be considered as embedded in the value chain's environment and social networks. Relationships between supply chain actors are not only shaped by economic considerations but also by network relations that may enhance the "social capital", by making it possible to obtain access to information, technical know-how and financial support (Burt 1997) and by encouraging knowledge transfer between network partners (Humphrey and Schmitz 2002).

In North Africa, the importance of sociocultural factors in regulating economic relationships between actors was underlined by Geertz (1978) in his studies of the Moroccan peasant market. Playing on the paradox of the apparent "mess" inside the bazaar and the highly structured underlying socio-economic links between the actors of this market, he termed such socio economic functioning, the "bazaar economy". The bazaar is characterized by extreme division of labor, the specialization of markets, a system of credit and debt where debtors and creditors spend time building mutual trust and finding arrangements, a place where capital is dispersed in a multitude of small and informal exchanges to limit risk and maintain networks. Geertz showed that economic relations in the bazaar are embedded in highly structured social networks, personal interactions, and interdependent institutions. While today, the context of groundwater irrigation development and supply chain organization is different from the peasant market described by Geertz, the methodological lens of the bazaar economy is useful to analyze the organization and the interactions between supply chain actors in North Africa's groundwater economies. Some of the characteristics of the current groundwater economy indeed recall Geertz' paradox: under the apparent disorder (large number of supply chain actors, numerous small-scale transactions, lack of formal information), a highly organized albeit informal sector exists.

In studies on groundwater irrigation development, supply chain aspects were first proposed as factors to explain constraints related to the supply of tubewells and pumps (Lundqvist et al. 2008; Harvey 2011; Abric et al. 2011). Villholth et al. (2013) proposed an integrated approach, based on a food value chain extending from the water source to the marketing of agricultural products, to analyze the constraints and enabling factors for groundwater development in sub-Saharan Africa. However, this study did not take into account the network of actors or the specific role of the actors involved in both the supply chain and in the development of groundwater irrigation.

The analytical framework proposed in this study focuses on the backward and forward linkages in the chain, i.e. actors and processes that move products toward end consumers, and

Fig. 1 Locations of the study areas. Source: d-maps.com

considers groundwater irrigation as an input to individual food-crop value chains as well as the outcome of its own chain. It takes into account three main aspects of the value chain: economic added value, chain network structure, and the relationships between the actors of the chain, rather than the factors or processes that explain its functioning. Actors' relationships and networks are specifically studied through the lens of the "bazaar economy".

Three study areas: the Saiss plain (Morocco), Chbika region (Tunisia) and the Biskra region (Algeria)

The study was conducted in three irrigated areas in North Africa (Fig. 1; Table 1): the Saiss plain in Morocco, Chbika area in Tunisia and Biskra in Algeria. The use of pumped groundwater became widespread from the early 1980s on and boomed in the 2000s. The expansion of individual boreholes and the agricultural boom resulted from a combination of (1) the availability of land and water resources combined with a favorable climate for high value crops, especially early vegetables, (2) public policies that initiated and enabled the development of these economies directly through land reforms and subsidies for agricultural development or irrigation (Kuper et al. 2016; Doukkali and Lejars 2015; Daoudi and Lejars 2016), (3) a considerable domestic market for fruit and vegetables, and (4) farming systems that are mostly based on the pooling of productive resources through sharecropping arrangements, thereby enabling different actors to find solutions for limiting factors such as lack of capital, labor and access to land and water (Amichi et al. 2015; Ameur et al. 2015). This increase in the irrigated production of vegetables attracted new actors including farming investors and young farmers, and generated new activities and new jobs (Dugué et al. 2014). At the same time, in each area, groundwater pumping increased and accelerated water table declines (Leduc et al. 2017). In the countries concerned, the state initiated and stimulated access to the confined aquifers through deep tube-wells, as the agricultural boom matched its objective to promote agricultural development (Petit et al. 2017). Groundwater is officially public property and the state is a central actor who provides the authorization to obtain access to and use of groundwater, and often subsidizes the physical infrastructure (tube-well, pump, motor and tubing, and even water saving techniques). In the field, there is no control over the volumes pumped; obtaining an authorization requires a solid network of contacts and illicit private tube-wells are tolerated by local authorities (Daoudi and Lejars 2016; Petit et al. 2017).

More particularly in the Saiss, the rapid growth of irrigated horticulture and arboriculture was encouraged by liberal agricultural policies, which aimed to intensify cropping systems by providing subsidies and encouraging private investment. Thanks to groundwater irrigation, onion production has been multiplied by 10 in 15 years and the region now accounts for 50% of national production. Particularly since 2007, land policies have enabled people to obtain private land titles thereby favoring the installation of private investors, which, in turn, amplified the dynamics of groundwater use. According to the river basin agency, water tables have declined considerably (ABH 2011) in the last 20 years. In the phreatic aquifer, water tables went down by about 10 m from 1980 to 2005, with a sharper decline after 2000 when water levels dropped by about 1 m/year. Before 2000, farmers mainly had access to the phreatic aquifer through wells (15–50 m in depth) but, from 2000 onwards, also to the Lias confined aquifer through tubewells down to a depth of 120–200 m.

In Chbika, the development of irrigated agriculture was less spectacular. Only 10% of groundwater storage has disappeared in the last 40 years of exploitation although water levels dropped by up to 30 m (Leduc et al. 2007). Intensification through irrigation was moderated by more limited land and water resources and by the gradual transfer from public water management to private irrigators. The absence of the state control since the 2011 revolution made it possible to increase the rate of informally drilled tube-wells. This opportunity has allowed some farmers to expand their irrigated area. It also allowed the arrival of new investors who rent lands due to the lack of land available for sale (Amichi et al. 2016), which led to a significant increase in vegetable crops, especially tomatoes.

In Biskra, farmers were confronted with decreasing water tables, and frequently deepened their tube wells (Kuper et al.

Table 1 Main agricultural characteristics of the three study areas

Characteristic	Study site		
	Saiss (Morocco)	Chbika (Tunisia)	Biskra (Algeria)
Aquifer system and groundwater-level decline	Medium-sized aquifer with rapidly declining water tables; water levels have dropped by up to 1 m/year since 2000	Medium-sized aquifer; water levels dropped by up to 30 m in the last 40 years	Huge but not very actively recharged sedimentary Saharan aquifers; the water level in the Mio-Pliocene aquifer dropped by 70 m over the past 50 years
Number of farmers practicing horticulture	4,000	750	2,200
Surface areas under horticulture	9,100 ha of onions out of a total of 45,000 irrigated ha	1,800 ha of tomatoes out of 11,500 irrigated ha	4,900 ha of greenhouses out of 86,250 irrigated ha
Average rainfall	500 mm/year, but extremely irregular	300 mm/year	Sahara, dry climate < 100 mm/year
Main products	Irrigated onions, potatoes, fruit trees, forage crops, livestock (milk, meat), rainfed cereals, olives	Irrigated tomatoes, chili peppers, eggplant, arboriculture and silage, rainfed olives, cereals (but declining), sheep herding for meat and milk	Greenhouse horticulture (tomatoes, peppers, eggplant), *Deglet Nour* dates (extension of traditional oases), olives, cereals and silage in the oases (but declining)
Irrigation	Groundwater wells and boreholes (from 30 m to > 150 m deep) and some springs (surface canals)	Groundwater wells (70 m) and boreholes (< 200 m)	Groundwater at great depth (90–400 m)

2016). Groundwater use for irrigation was estimated to be around 1.2 km^3/year, which amounted to almost five times the volume of the renewable groundwater resources that can be exploited (0.26 km^3/year; MRE2009). Nevertheless, the different actors continue to overexploit the different aquifers, including the Continental Intercalaire aquifer, which is not at all, or only slightly, renewable, but represents an enormous reserve (91,900 km^3). Since 2000, vegetable crops grown in greenhouses combined with traditional date palms have expanded rapidly on new land along a wide pioneer front. This pioneer front, based on the exploitation of very large, but not very actively recharged, sedimentary Saharan aquifers, remains a pole of attraction for private investors. In 10 years, the province has become the main production area for fruit and vegetables, especially tomatoes, encouraged by a generous policy of subsidies. The state allocates lands to investors and also provides funding for tube-wells, drip irrigation, cold storage and greenhouses (Daoudi and Lejars 2016).

Data and survey

The study was conducted in two main stages between 2012 and 2014 (see table 2). In each study area, the focus was on the main irrigated vegetable crops: onions in the Saiss, and tomatoes in Biskra and Chbika.First, using the classical framework for value chain analysis (Trienekens 2011; FAO 2013), a functional and an economic analysis was conducted of each chain. The functional analysis made it possible to set the boundaries of each chain in each area, to identify the different stakeholders involved, together with their activities and their relationships. The aim of the economic analysis was to assess the revenues, costs and margins (added value and net profits) of each activity and segment of the value chain on the basis of the prices actually paid and received by economic agents. As the activities of the chains and of their actors were generally not included in public and official records, these analyses were performed by crossing official data and surveys conducted on farms, and local markets, with data obtained from the suppliers of inputs and drip irrigation equipment through observation and during interviews. The stakeholders were identified and a map was compiled of the whole network of actors from the suppliers of inputs to the wholesale markets identified in empirical studies conducted in Saiss in 2012 and in Biskra and Chbika in 2013.

Second, a specific analysis was performed of the key actors in both the groundwater and horticultural sectors: suppliers of drip irrigation in Saiss, suppliers of inputs and seeds in Biskra and Chbika. This second analysis was conducted through the lens of the "bazaar economy" proposed by Geertz (1978). These focused surveys collected information on the amount of credit provided by the actors, their role in the diffusion of innovation, and their relationship with farmers. The round of surveys that focused on the role of key actors was conducted

Table 2 Number of people interviewed in each case study and each type of actor

Survey	Type of actors	Study area		
		Saiss	Chbika	Biskra
First survey to map network of actors and assess economic stakes (2012–2013)	Farmers	60	83	110
	Upstream actors	83	10	30
	Downstream actors	35	15	10
	Total	188	108	150
Second survey on the role of actors (2014)	Irrigation, suppliers of inputs and/or seed	34	15	50

in 2014 and was exhaustive, as all drip irrigation retailers in the Saiss and all seed and input retailers in Cbika and Biskra were interviewed.

At each stage, the quantitative assessments depended on the limits of the systems studied, at the interface of the supply chain and land irrigated with groundwater. In this paper, only the actors active within the geographic limits of the study area were taken into account (i.e. local suppliers, but not sales representatives of national suppliers who had dealings with the intermediaries in the study area) or those whose main activities depended on horticultural products produced in the study area (i.e. wholesalers).

The three areas are contrasted in terms of main horticultural subsectors studied (onions in Saiss; crops grown under plastic greenhouses, especially tomatoes, in Biskra and Chbika), in terms of dynamics (extremely rapid development in Algeria, slower development in Tunisia) and in size (Saiss, 9,100 ha; Chbika, 1,800 ha of tomatoes; Biskra, 4,900 ha of greenhouses). A comparative analysis of the three study areas was nevertheless possible because of the existence of the same type of actors and subsector organizations and similar dynamics around groundwater overexploitation and intensification.

Results

A wide range of supply chain actors and high segmentation of their functions

The horticultural subsectors studied here involve a large number of actors and high segmentation of their roles (Fig. 2).Broadly speaking, supply chain actors upstream from the farms are those who provide inputs (seeds, pesticides, and fertilizers), agricultural equipment (especially greenhouse equipment in Biskra and Chbika), irrigation equipment (including drip and pump) and services in response to the farmers' needs. These actors include, at national level, manufacturers, importers and national resellers. At regional and/or local level, the main actors are retail sellers of inputs, irrigation equipment, and seeds. Drillers (from firms to individual owners of drills) may have a local set up, or operate at national level.

Supply chain actors downstream from the farms are responsible for marketing horticultural products. Whatever the study area, the products are mainly sold through a local or national wholesale market, or in rare cases, directly to retailers. Products may be sold directly to the wholesale market by farmers (like in Biskra), or through a wide range of intermediaries (like in Saiss and Chbika).

This schematic and rather classical presentation of supply chain actors does not adequately express the real diversity and the many and very different actors involved in the sector. The chain is extremely fragmented and each actor can be highly specialized. For instance, there are no cooperatives or collective collection centers downstream from the farms in any of the three study areas.

The most striking example is the onion market in Saiss. The majority of the onions produced go through a long and fragmented marketing chain involving a large number of actors whose activity is generally extremely specialized. Traders and sellers include (1) local collectors and transporters who work only in the Saiss region (2) national transporters-collectors (3) field resellers, who buy and sell in the field (the products do not leave the field) (4) and wholesalers on wholesale markets. Brokers are the witnesses of the transactions and ensure compliance with the verbal contract plus serve as arbitrators if one of the two parties considers the original verbal contract was not respected. The evaluation showed that there are nearly 400 in Saiss, for the majority of whom it is a full time job. No specific skills or capital (except a cellphone) are needed to become a trader or a broker, so many people just took the opportunity and tried to build on their own network. Brokers can be divided into three categories: (1) brokers involved in the sale of the products, (2) truck rental brokers for transport, and (3) brokers specialized in land transactions (rental and sale). The actors involved in onion storage are rarely specialized in storage, but are usually farmers or resellers. Independent hauliers are also involved, and may be (1) truck rental companies (2) owners of scooters, (3) truck owners who rent out their vehicle, possibly with a driver.

In Chbika, the market organization is less fragmented than in Saiss. Although some farmers take their produce to the wholesale

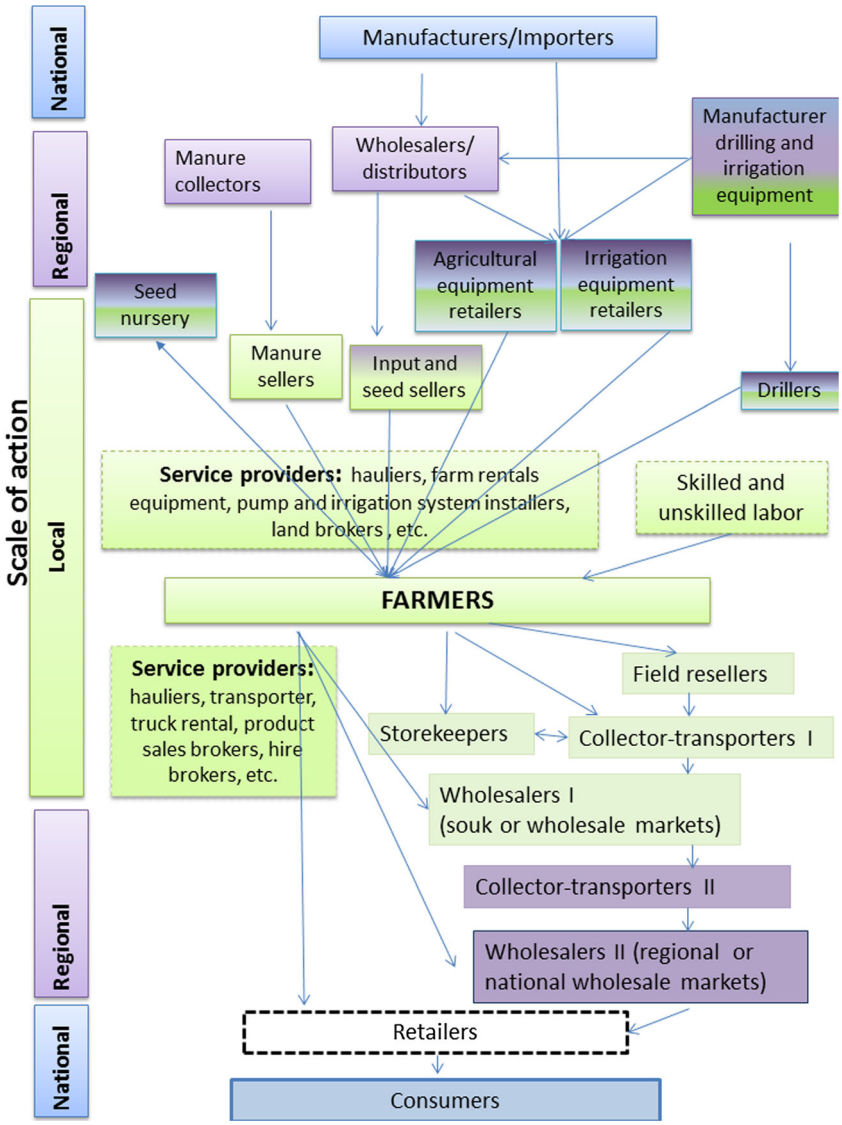

Fig. 2 Actors involved in groundwater irrigation development and in horticultural supply chains from local to national scale

market themselves, the majority use brokers, traders and transporters. Conversely, in Biskra, the farmers take their own products directly to wholesale markets, and wholesalers subsequently transport the products to consumer markets in the big cities (mainly Algiers).

Similarly, in Chbika and Biskra, suppliers upstream from the farms are less specialized than in Saiss. In Saiss, some input suppliers are specialized in drip irrigation equipment, others in fertilizers and pesticides. In Chbika and Biskra, local retailers are not as specialized, drip equipment is simply another product sold by input retailers. In these two study areas, most farmers already have the know-how they need to install and maintain their irrigation system.

Thus, like the peasant markets described by Geertz (1978), the relationships between supply chain actors are characterized by high division of labor, and a multitude of small exchanges that limit the risk for each actor and make it possible to build and maintain networks. Actors actively look for contacts, exchanges and information, which are, like in the bazaar economy, *intensely valued* (Geertz 1978).

Organization resulting from rapid changes and lack of services

The supply chain actors described here appeared during the rapid expansion of production that boomed in the 2000s. In Saiss, onion production multiplied 12 fold between 2000 and 2014. In Chbika, land under tomatoes increased from 125 ha to 1,800 ha between 1999 and 2014. In Biskra, the amount of land under greenhouses multiplied 8 fold between 2000 and 2013. As a result, local markets appeared, multiplied and expanded. The market in Biskra, which was created in 1992 due to increasing production, now sells nearly half the tomatoes

Table 3 Ratio of farmers to supply chain actors in each study area

Supply chain	Study area		
	Saiss	Chbika	Biskra
Upstream from the farms	1:50	1:55	1:60
Downstream from the farms	1:2	No data available	1:4

produced in the area. Traders come from all other parts of the country to buy tomatoes. Surveys showed that between 100 and 150 traders from 16 Algerian provinces meet between 650 and 700 farmers every day. In contrast, in the Saiss, only 30% of total production is sold through local wholesale markets. Informal local markets emerged alongside formal markets, and a huge number of informal merchants trade directly with the farmers (Lejars and Courilleau 2015).

During the same period, the number of suppliers of drip irrigation and of inputs also increased. In Saiss, the first drip irrigation supplier arrived in 2000 and in 2014, there were 32. In Biskra, in 2006, there were nine suppliers of seed and inputs, while in 2014, there were 50. In Chbika, the first local suppliers arrived in 2002 and in 2014, there were 15.

In this context, new and niche activities emerged and developed rapidly. A set of new service providers appeared in the form of local manufacturers, each actor targeting different farmers' needs. For instance, the number of fitters of pump and irrigation equipment increased rapidly in Saiss. Some work full time as independent installers or are employed by regional or national companies. Others are farmers or farm workers who provide the service intermittently to fellow farmers. A number of local manufacturers also emerged. In Saiss, local welders started to build hydro-cyclones from butane gas bottles; local mechanics started to adapt old automobile engines so they could be used with butane to pump groundwater. In Biskra, local drillers recycled old petroleum drilling equipment to build drills for wells. These craftsmen provide more appropriate and cheaper solutions by tinkering with technologies and adapting them to farmers' needs or demand. Their role is crucial in the process of innovation and "bricolage" (Benouniche et al. 2016), and is partly made possible by the wide range of equipment and artifacts that are needed to make a drip irrigation system work in practice.

A large number of actors who generate added value

For agriculture as a whole, in Saiss, the value of primary production was estimated at USD 400 million, and in Biskra at USD 280 million, 30% of which was generated by the onion sector in Saiss, and 30% by greenhouses in Biskra. The number of supply chain actors involved in the onion and tomato chains was estimated by crossing the results of the surveys and local actors' expertise (Table 3). Regardless of the study area concerned, the ratio of farmers to supply chain actors was around 50:1. More precisely, there was one supplier for every 50 farmers in Saiss and one supplier for 60 farmers in Biskra. The number of downstream actors also differed with the study area. The ratio was 1:2 in Saiss, while it was closer to 1:4 in Biskra because farmers took their products to the wholesale market themselves.

The distribution of costs and margins among these actors also differed with the study area and with the type of actor (Fig. 3). Production costs (not including the farmers' income) accounted for 20 to 25% of the consumer price. In Saiss, the number of supply chain actors involved in the market chain increased the wholesalers' and retailers' margin. In Biskra, the distribution of margins was more proportional: wholesalers charged a margin corresponding to 34% of the consumer price of tomatoes, while the farmers' margin was 32%. However, whatever the area, margins were shared between a large number of actors, dispersed in a multitude of small exchanges.

Finally, it is important to note that there are major differences in the three cases: there is more division of labor in Saiss than in Biskra or in Chbika. How can these differences

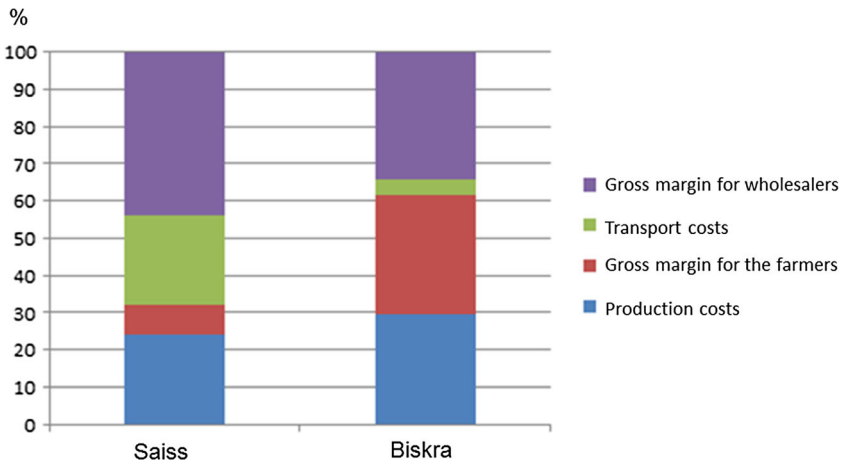

Fig. 3 Margins and costs shared between farmers and wholesalers in the onion chain in Saiss and the tomato chain in Biskra (as a % of the consumer price)

between regions be explained? Is the market segmentation observed in Saiss a stage in the evolution of the local market or a structural characteristic? Further analyses will be required to answer these questions.

Key actors in accessing credit and in disseminating information and innovation

In addition to their structural role in helping farmers access production factors and markets, the supply chain actors also provide ancillary services. Formal support services for agriculture are insufficient in all three study areas. Despite the diversity and the dynamism of the agricultural sector, institutions such as banks, insurance companies, and agencies responsible for agricultural extension and training are lacking or their services are not adapted to the functioning of a bazaar economy. Consequently, in addition to their core activities, supply chain actors provide ancillary services to farmers. Two main categories of ancillary services can be distinguished: access to credit and subsidies, and the dissemination of information and innovation, in particular around irrigation technology (mainly drip irrigation), new crop varieties, inputs, and agricultural practices including water management at the farm level. In the three case study areas, the development of groundwater irrigation has consequently been organized and structured around actors who take advantage of opportunities and capitalize on the lack of institutional organization for training and advisory institutions and banking systems.

Access to information and diffusion of innovation

Depending on the area and on the case study, suppliers may only be sellers who provide occasional advice to farmers on each product, but may also test the products and conduct trials on their own land or in partnership with farmers. The majority provided technical advice (Table 4). In Biskra, all seed resellers provided technical advice and over 30% of farmers obtained information from seed suppliers on agricultural practices, while in Chbika, the ratio was a little lower, 70% of seed suppliers provided technical advice and 20% of the farmers benefited from it, whereas in Saiss, 60% of drip irrigation suppliers provided ancillary services and 20% of farmers benefited.

Table 4 Ancillary services provided by suppliers in each area (%)

Services	Study area		
	Saiss	Chbika	Biskra
Percentage of resellers who provide technical advice or monitor plots	60%	70%	100%
Average % of customers who benefit from ancillary services provided by resellers	20%	20%	30%

Farmers perceive suppliers as providers of both information and technical support. In many cases, it is not only a simple commercial relationship that is established between these two actors, but rather a relationship leading to a process of building knowledge, new techniques, and a search for the most reliable solutions. In Biskra and in Chbika, seed suppliers update their product lines in response to changing demand. They anticipate changes in demand and regularly offer new agricultural inputs and equipment. The expansion and updating of the range of products sold by seed companies, including seeds, fertilizers and pesticides, is evidence for their active role in supporting the development of horticulture. They also themselves encourage change by providing new seeds or pesticides at reduced cost; however, the continuous updating of inputs and seeds is also due to competition for the market among suppliers. In Saiss, surveys showed that the sales strategies of drip irrigation suppliers depend on when they first set up. The two first suppliers, who settled in 2000, targeted large-scale farmers (farms more than 15 ha in size) and imported all the equipment from Europe. In contrast, the most recent suppliers, who set up in 2012 and 2013, targeted small-scale farmers (farms less than 5 ha in size), and consequently sold locally produced or second-hand equipment. Providing advice and monitoring plots is also a way to build customer loyalty, to observe, attract and keep their customers. This core group of "loyal" customers generally benefits from credit.

Credits and subsidies, a driving factor of dynamics

Input suppliers offer financial services (credit and insurance) to their customers in addition to commercial transactions. The most illustrative examples are the credits offered by seed companies in Biskra, by seed and input suppliers in Chbika, and by suppliers of drip irrigation equipment in Saiss (seeds are not used for onion production). Credit is part of a marketing strategy used by suppliers in competitive markets. The percentage of suppliers who provide informal credit, the number

Table 5 Credits and services provided by suppliers of inputs in the three study areas (seed companies in Biskra, suppliers of seeds and input in Chbika, and suppliers of drip irrigation in Saiss)

Services	Study area		
	Saiss	Chbika	Biskra
% of suppliers who provide credit	60%	80%	100%
% of customers who receive credits	40%	25%	100%
Average % of credit in resellers' turnover	24%	25%	26%

of people who receive such credit and the amount of the credit vary from one supplier to another (Table 5).

Like formal credit, informal credit is reserved for creditworthy and valued customers. The difference between the two systems is how the creditworthiness of farmers is assessed. While banks and the state limit access to formal credit by requiring official documents (such as a land title), informal credit providers have their own strategies to minimize risks of non-payment. In such an informal context, agents do not rely on the court to enforce a contract, formal guarantees are irrelevant, and contracts do not even need to be written (MacLeod 2007). Suppliers in the three study areas had their own criteria to select and monitor those to whom they gave credit, by combining technical advice and support on the farm. Visits to the farms are a way to collect information on customers' skills and hence creditworthiness and reliability ("good" farmers are able to make money and reimburse their loan). In fact, through these visits, the inputs suppliers do a very thorough job of scrutinizing their client and incrementally build a relationship of trust. In the beginning, there are occasional customers without credit, but gradually these clients become regular clients. In parallel, farmers can diversify their points of purchase and credits.

In Saiss, the situation is a little more specific: it is the suppliers of drip irrigation equipment who offer payment facilities linked to the state subsidies for drip irrigation that cover 80–100% of the investment cost. As applying for a subsidy can be a long and complex process, some drip irrigation suppliers (60% of the retailers) fill in the application forms on behalf of the farmers and provide credit to farmers while waiting to be reimbursed by the state. Drip irrigation suppliers are thus intermediary actors between the state and the farmers whom both parties trust enough (or at least know sufficiently well) to make the deal.

Finally, suppliers play an important role in the extension of groundwater irrigation by facilitating access to technologies, inputs and credits for irrigation and intensification. They also participate in the diffusion of new irrigation equipment, along with new farming techniques that could lead to more efficient water use, at least at plot scale. They are thus intermediaries who play a central role in innovation processes, in improving the connectivity of the different groups (Klerkx and Leeuwis 2009), and in supporting the development of groundwater-based irrigation.

With the generalization of drip irrigation and the diffusion of knowledge, most retailers had to diversify their services and adapt to farmer demand. The production of ancillary services, the capacity to become a facilitator of access to subsidies and to be a link between the state and farmers have become essential if retailers are to remain key actors in an innovation system that can change very rapidly. Maintaining one's place in the system requires the capacity to adapt to farmers' needs, to be aware of new innovations and also to invest and be able to ensure sufficient funding, all of which is unlikely to be within reach of some of the actors currently operating in the region.

Discussion

Is North Africa's groundwater economy a modern remake of the "bazaar economy"?

In all three case study areas, the groundwater economies resulting from the rapid development of groundwater-based irrigation involve a large panel of actors upstream and downstream from the farms. How the actors are organized and their links recall what Geertz (1979) called the "bazaar economy". As already mentioned, Geertz characterized the bazaar by the extreme division and specialization of labor and markets, a system of credit based on mutual trust, and a multitude of small and informal exchanges to limit risk and to maintain networks. Contracting with each other has the social virtue of establishing mutual trust or at least of allowing relative predictability of their mutual expectations. The institutional peculiarities of the bazaar thus appear less like mere accidents of custom and more like the interconnected components of a global system connecting economic relations and social networks.

The groundwater economy in North Africa can thus be considered as a bazaar economy that has been redeployed to enable the development of groundwater irrigation. However, the context of today's groundwater economy is very different from the context of the peasant marketing studied by Geertz (1978) from the mid-1960s on. In particular, new actors and "outsiders" are incorporated in the groundwater economy every day. Integration can be selective: many attempts are made to enter the market, and some fail. The turnover of actors in the groundwater economy can also be quite rapid. Benouniche et al. (2016) describe how fitters played an important role in installing drip irrigation systems for about 10 years, but were then progressively abandoned by farmers who no longer needed them, since, in the meantime, they had acquired the necessary know-how themselves. The social network around irrigated agriculture is continuously evolving and is linked to the very dynamic nature of the groundwater-based farming systems compared to the peasant mode of agriculture observed by Geertz (1978). The situation in Biskra is particularly eloquent in this regard. Every season, new farmers arrive to cultivate new territories, often using new inputs provided by the support sector to produce new horticultural varieties. Supply chain actors also have to face increasing competition among themselves, as well as rapidly changing demand (for drip irrigation for instance), as farmers' knowledge increases or as farmers search for new opportunities to diversify their products. The strategies implemented to face these changes differ considerably among actors, depending on their area of activity

and on their mobility. Local collectors or transporters, local craftsmen, and farmers who only work in the production area will be more dependent on local dynamics than national transporters-collectors or seed companies that supply different regions. Some supply chain actors thus look for new opportunities in the agricultural sector and/or in other sectors. They explicitly told the interviewers that they were saving money to start an alternative activity, not only in the irrigation sector, in the medium term. Others try to target quality, new equipment, or to diversify their services. In all cases, they continually had to adapt to rapid changes, and as a result, the social network around groundwater irrigation is constantly changing.

Yet, this evolving bazaar economy also recalls the "groundwater anarchy" described by Shah (2009), who referred to South Asia's groundwater economy as a functional anarchy with a certain order to it. Attempting to formalize such an informal water economy would lead to "administrative and political transaction costs" which are "simply insurmountable in South Asia today" (Scott and Akhter 2010). Instead, as a protagonist of *realpolitik*, Shah (2009) proposed more indirect measures operating through the environment of conduct, which concern "strengthening nascent institutional arrangements by providing space for innovation and the evolution of irrigation socio-ecology" (Scott and Akhter 2010). If, for social, economic or environmental reasons, the groundwater economy is to be brought under some sort of control, it is necessary to understand its entire functioning, including supply chains effects and actors. It is consequently surprising that the supply chain actors, who are as active in North Africa as in South Asia, have been ignored for so long. Studies conducted in sub-Saharan Africa (Kulecho and Weatherhead 2005; Villholth et al. 2013) showed that the lack of ancillary services such as financial or extension services, but also the lack of dynamic networks distributing equipment and disseminating technology, were huge constraints to the development of groundwater irrigation. This is not the case in the case studies reported here; however, both cases underline the importance of the dynamic networks of supply chain actors in promoting groundwater irrigation.

The scope for integrating key supply chain actors in water management

In North Africa, the supply chain actors and their interactions with farmers are "invisible" to public policy makers in a context of rapid change and informality. In practice, despite their key role in the development of groundwater irrigation, these informal actors and their interactions are rarely part of formal water management processes (Shah 2009). They are not included in the traditional toolkit of instruments for managing water demand (all the instruments such as volumetric prices, intersectoral allocation water, water rights, involve only the state and farmers), widely understood as being part of the integrated water resources management (IWRM) paradigm. Nor are these actors taken into account by the state in their agricultural policies, because here the state calls on formal structures such as banks or advisory services, which only target farmers (and generally only "officially" established farmers), but fail to take the whole supply chain that has been constructed around them into consideration. Finally, actors are rarely taken into account in processes targeting sustainable standards that require environmentally friendly practices from farmers but generally concern only large-scale agro-export companies (Vos and Boelens 2014).

The main challenge is thus how to reach and include these actors in water management processes. Three steps appear to be necessary. The first is to make the actors and their network "visible" so as to be able to accompany them. In the literature, there is a tendency to link "informal" with "unstructured" and "chaotic", or to refer to the analytical framework used in this study, a "bazaar". Following the work of Guha-Khasnobis et al. (2006) and that of Geertz (1978), this paper shows that such word associations are weak, since this particular bazaar is tightly structured around key actors, personal interactions, and economic relations. Such associations could lead to policy disasters if the state tries to provide formal "structures", based on the assumption that none previously existed. As underlined by Shah (2009), "when countries try to force the pace of formalization, interventions come unstuck". The terms informal–formal should only be used as a description, leaving the issue of judging whether or not they are desirable to be decided on a case-by-case basis. It is more useful to directly tackle policy interventions by accounting for the self-organizing structures that communities are capable of producing, within or beyond the official structures. Rather than trying to structure and formalize the sectors, or create new institutions to regulate groundwater irrigation, a complementary approach would thus be to accompany these actors directly, while taking social and interpersonal links into account.

The second step is to analyze the relationships between the state, the farmers, and the supply chain actors, and to identify key supply chain actors who could help enhance or limit further extension of groundwater irrigation. Mobilizing key supply chain actors has the practical advantage of dealing directly with a few individuals, who could then convey the messages to the thousands of farmers with whom they usually interact. In the three case studies reported here, it would be more advantageous to accompany local suppliers (seed companies, drip irrigation suppliers) rather than downstream supply chain actors, who move from one region to another more easily. Of course, these actors profit from irrigation expansion and for some of them, it is merely a temporary opportunity leading to other activities or business outside the area or outside their sector. Nevertheless, the study showed that, in the medium and long term, most remained dependent on water availability and local development.

The last step, and the most challenging, is finding practical ways of enhancing agricultural water management in collaboration with the key actors of the supply chain identified. Some early experience obtained in developed countries revealed that actors of food processing sectors are interested in creating standards and certification towards more sustainable practices (Vos and Boelens 2014) or in participating in negotiations concerning volumetric management of groundwater (Lejars et al. 2012). Of course, such processes involve negotiations, transparency or at least information sharing. It also implies that these actors accept becoming "visible". Yet, in the North African groundwater economy, the quest for information and the possession of information is an economic activity in itself. As Geertz (1978) noted, the very idea of organizing and structuring is foreign to a system where what counts is the capitalization of dysfunctions and not their reform.

Nevertheless, the results showed that some of these key actors could become major nodes for the dissemination of information and innovation, as they not only have personal relationships with farmers, but also close links with state representatives. They could facilitate the adaptation of water-saving techniques (such as drip irrigation) or, as is already the case for some seed producers, facilitate the introduction of new varieties or products that consume less water and fewer inputs.

Another option would be to promote an innovative framework for water use certification within a site or a catchment basin, and not only at the supply chain level. Such initiatives have already been tested, including in developing countries, and could be adapted for a water stewardship standard and certification system to guide and reward sustainable water resource use at a local level (AWS 2014). Such processes, which reward participatory approaches at a site level rather than agricultural practices, could become a marketing asset at regional or national scale for all the stakeholders in the catchment, including farmers and supply chain actors.

Conclusion

The development of groundwater-based irrigation in North Africa involves a large panel of supply chain actors, extreme division of labor, and major differences in profits. The ratio of supply chain actors to farmers can reach one full time employment for every two farmers. The development of their activities depends on irrigated agriculture and groundwater resources. While some of them further their own interests and can rapidly switch activities, others play key roles, provide ancillary services, ensure the dissemination of information and innovation, and facilitate access to credit or subsidies. These actors are the driving force behind the extension of groundwater-based irrigated agriculture and ensure its continued profitability, a goal shared by all supply chain actors. Just like farmers, these actors face the potential consequences of a decline in available water resources (as the water tables drops) and in market prices (due to over production and market congestion). They are potential catalyzers of the further expansion of groundwater irrigation, but could become actors in adaptation to declining water tables.

Incorporating these actors in processes that aim to regulate groundwater management would be more than expedient. Studying the whole network and identifying the actors who represent the main nodes in the network and those who represent possible bottlenecks in the system is the first step. Another step is to get them involved as vectors of innovations leading to more sustainable agricultural practices, or in the design of innovative standards, that would reward sustainable water uses and participatory approaches at the local scale. The main challenge will be how to incorporate them in such processes, not only taking advantage of their particular relationships and organization, but also acknowledging their particular economic strategies.

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