Simulating Negotiations over Limited Water Resources: A Multi-Agent System Approach for Irrigation Systems Facilitates the Analysis of the Decision-making Process [1]

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Abstract

Efficient water resource management is a topic of major importance in the field of sustainable development. In arid and semi-arid regions characterized by limited and irregular water availability, the agricultural sector is under constant pressure to receive and ensure water for their crops. Finding an optimal way to share this limited resource requires numerous negotiations between water suppliers and farmers. A multi-agent system, as presented in this paper, is a computer simulation that models the interactions between different types of agents in order to gain insight into the group's behavior as a whole. This paper claims that such a system can be used at the beginning of the agricultural season to predict potential outcomes of the interactions between water suppliers and farmers, which can inform management on how to optimally plan for the allocation of water. One objective was to take an interdisciplinary approach in order to simulate imagined consequences to complex decisions and to suggest new ways of maximizing water resources while improving income when reaching final

[1] Reference to this article on the web is: http://conductual.com/content/agent-based-modelling-negotiation-irrigation-systems-under-water-stress

compromises. To accomplish this objective, the present computer simulation performed a multi-agent approach using the open source Java Agent Development Framework (JADE) platform.

Keywords: *ABM, simulation, water, management, decision-making, negotiation, flood, irrigation, JADE*

Resumen

La administración eficiente de los recursos de agua es el tópico de mayor importancia para el desarrollo sostenible de naciones. En las regiones áridas y semiáridas que se caracterizan por tener recursos hídricos bajos e irregulares, asegurar la seguridad alimenticia de una población en rápido crecimiento causa estrés a los miembros del sector agrícola. Son numerosas las negociaciones entre granjeros y proveedores que se requieren para encontrar formas óptimas para compartir los recursos limitados de agua. En los sistemas de irrigación por inundación las negociaciones para la repartición del agua se facilitan utilizando múltiples agentes para representar escenarios de interacción entre granjeros y proveedores de agua. En este estudio, un programa de computadora simuló múltiples agentes negociando consecuencias a decisiones que podrían optimizar recursos de agua, maximizar ganancias para alcanzar los compromisos finales de los granjeros. La presente simulación de computadora se implementó utilizando una plataforma de fuente abierta para la estructura de un desarrollo de agente Java (JADE).

Palabras clave: *ABM, simulación, agua, administración, negociación, inundación, irrigación, JADE*

Sustainable development consists of the management and rational use of renewable resources (Guesnier, 2010). Water is one of the most important renewable resources requiring sustainable management. In arid and semiarid areas, which currently cover more than 30% of the world, an increasing demand for water impacts the already limited and inconsistent supply used by farmers in the agricultural sector. Despite this limited resource, farmers who are motivated by personal interest and financial gain are tempted to overuse the available water shared between them. Farmers are thus stuck in a classic commons dilemma where inefficient water use negatively impacts the entire group as a whole (Hardin, 1968). In this case, they fall into a contingency trap where short-term gains (water resources) negatively impact long-term consequences (overall profits and sustainability) (Baum, 1994). To address these issues, many have turned to flood irrigation systems where farmers with competing interests negotiate with a supervisor who attempts to fairly distribute water over flood networks based on need and environmental conditions. Despite these efforts, large volumes of water are still inefficiently used in south Mediterranean countries where water is mainly allocated to agriculture using such a flood irrigation system (PAPNEEI, 2009).

Flood irrigation is easier to implement and less costly than other methods of irrigation in terms of material resources at plot scale, but it has some drawbacks. Firstly, planning irrigation is difficult due to large variations in the types of crops, sowing dates, soil, and climatic conditions (Belaqziz et al., 2013a). Secondly, the schedule for water delivery is affected by irregularities and problems with the irrigation network such as differences in flow rates, irrigation intervals, travel times, working times, and overlaps (Belaqziz et al., 2013b). Thirdly, the programmed number of irrigation rounds (i.e., the course of each spatial-scale-irrigation lasting approximately 15-days) is decided before the agricultural season begins. This decision is justified on the total water available from dams without considering rain forecasts, types of crops, or the allocated volumes of water. Lastly, water shortages and wasteful water excesses occur because farmers rely solely on the visual inspection of their crops to determine their desired flood irrigation schedule.

The current drawbacks behind flood irrigation systems are due to an aggregate of individual human decisions and are exacerbated by technical limitations, such as when crops are affected by water constraints due to restrictions or scarcity. Finding an optimal way to share water resources throughout these flood irrigation systems is a complex process requiring a negotiation between all concerned shareholders while taking into account the real needs of each crop, predicted environmental conditions, possible constraints on the irrigation network, agronomic conditions, and individual goals. Since these variables must be predicted at the beginning of each agricultural season, it is useful to develop a predictive model of human behavior in order to successfully optimize this distribution of water.

This paper introduces a computer simulation designed to reproduce the results of the decision-making process when sharing limited resources of water in arid and semi-arid regions, and also explores ways of improving this process. One aim is to model negotiations between water suppliers and farmers while capturing the elements of translational research that examines sensitivity of human behavior to imagined consequences, verbal mediation, and instructions (e.g., Baron, Kaufman., & Stauber, 1969; Holland, 1958; Kaufman, Baron, & Kopp, 1966; Weiner, 1965). Our computer software simulates imagined consequences, such as improving income and optimizing water resources, that affect the farmers' decision of choosing between taking and not taking the risk of keeping the same irrigated area. The goal of the present computer simulation is to show that taking a multi-agent system approach facilitates the negotiations of limited water resources in flood irrigation systems.

Multi-agent systems, such as the agent-based modelling (ABM) approach are computer simulations of group behavior, which have been increasingly employed in biology, ecology, and the social sciences (Niazi & Hussain, 2011). These systems simulate the actions of and interactions between autonomous agents with the purpose of analyzing how these agents affect the collective behavior of the system as a whole. Each agent represents either an individual or a collective entity, with behavioral rules that define the complexity of the whole system. The participation of each agent is constrained by its limited perception of the whole system, an incomplete set of decision rules, and actions pursuing its own interests (e.g., economic benefits). One assumption is that some agents can learn faster and adapt better to the whole system than other agents. Another assumption is that the agents are located into a space (e.g., over a matrix) constraining their perception and capabilities to communicate. The last assumption is that all agents can communicate by sending and receiving messages to and from other certain agents. Accordingly, the ABM approach can be conceptualized as a computerized application of game theory (Axelrod, 1984). In this sense, this would be a zero-sum game where individual agents are competing over a single resource.

Research using multi-agent systems generates efficient models for water irrigation management, examining complex scenarios requiring negotiations to solve conflicts and reach agreements among stakeholders on the distribution of water resources. One example is the simulator SHADOC, which is comprised of a set of structured farmers organized into several groups to act, communicate, and negotiate according to predefined rules, which has improved an irrigation system in the Senegal River Valley (Barreteau, 1998; Barreteau & Bousquet, 2000). Another example of a multi-agent approach is the simulator SINUSE; it studies water demand management, allowing the analysis of overall dynamics of the system accounting for direct and indirect interactions between farmers, their socio-economic behaviors, and the social impact of their negotiations (Feuillette, , Bousquet, & Le Goulven, 2003).

Similar research has been successful in creating multi-agent models for water irrigation management systems (Abrami, Barreteau, & Cernesson, (2002). For example, an Agent Based Model

(ABM) was developed to improve the management of water resources at the watershed scale in a project known as Freshwater Integrated Resource Management with Agents (FIRMA; Barthelemy Moss, Downing, & Rouchier, 2001). FIRMA was produced by social psychologists taking a cognitive approach to integrate hydrological, ecological, cultural, social, and economic aspects of agents participating in negotiations; FIRMA improves the cooperation between managers and experts, allowing the analysis of hydro-social aspects determining negotiations improving the distribution and management of limited water resources (Barthelemy et al., 2001).

Recent studies using multi-agent approaches and simulation platforms were conducted in the context of the MAELIA project; these studies examined environmental, legal, and socio-economic impacts; identifying various scenarios regarding water, climate change, and land use management strategies (e. g., Gaudou et al., 2013; Mayor et al., 2013; Mazzega, Boulet, & Libourel, 2012; Taillandier Therond, & Gaudou, 2012; Therond et al., 2014). Multi-agent approaches using the utility tool of the model MANGA have been executed to solve problems of water resource management in regions with limited water resources (Le Bars, 2003), showing that MANGA allows the assessment of rules for sharing water resources, simulating differences between supply and demand (Le Bars et al., 2004; Le Bars et al., 2005).

Despite the increasing use of multi-agent systems to model behavior, there has been surprisingly little interdisciplinary work that consults the field of behavior analysis. The present paper is a cooperative effort between practitioners of several disciplines including behavior analysis, agriculture, climatology, and computer science with the goal of developing a preliminary model of group behavior in flood irrigation systems using a multi-agent simulation. The multi-agent system presented here was developed using the behavioral principles of decision-making under the influence of variables that vary under numerous environmental factors including water availability, agricultural conditions, and the behavior of others. It is aimed to facilitate negotiations among shareholders (Ferber, 1995), offering alternative methods of irrigation by generating simulations that are contingent upon the decisions of the negotiators, their behaviors, and strategies to reach their final goals; it will show that a multi-agent system approach is an effective method to develop new policies and agricultural practices, reducing consumption and waste of water resources while maximizing utility.

Method

Design

Implementation of the present computer simulation was piloted with the integration of six synthetic agents replicating the following roles: (1) the supervisor agent (SA) distributes global amounts of water among the farmers. Each year, the SA receives the volumes of water to negotiate with the farmers at the beginning of the agricultural season, providing information on estimated water requirements and total incomes to improve the cropping plans of the farmers. This information is stored in a database. (2) The farmer agent (FA) develops cropping plans and negotiates with the SA the amount of water that each farmer requires. The crop area of each FA is divided into plots corresponding to different categories of farmers representing preferences, objectives, and willingness to take risks; the cropping plan of each FA is stored in a database. (3) The scheduler agent (SCHA) defines the plan for irrigation rounds producing efficient schedules maximizing water resource management (Belaqziz et al., 2013b); then SCHA sends to the SA the final schedules for irrigation describing distribute quantities (q1,…qn.), plots (p1,…pn.), and times of irrigation events (t1,…tn.). (4) The operator agent (OPA) tracks the adequate implementation of the irrigation calendar that SA transmitted. (5) The main canal agent (MCA) opens the main canal according to the flow that SA requested. And (6) farmer's graphical interface (GIA) interrelates with each farmer agent, specifying the cropping plans and including sowing dates, crop type, and the area to be irrigated. This communication is based on FIPA-ACL protocols (FIPA TC C, 2002). Table 1 displays the agents' classification of the current ABM simulation where SA, FA, and SCHA are the cognitive agents, OPA and MCA the reactive agents, and GIA the farmer's graphical interface agent (for a detailed description of agents' communication, see Appendix 4).

Agent	Type	Number
SA	Cognitive	1
FA	Cognitive	n
SCHA	Cognitive	1
OPA	Reactive	n
MCA	Reactive	1
GIA	Interface	1

Table 1. Agent classification.

Apparatus and Materials

The study's area that is modelled in the present computer simulation was an agricultural sector of 9 km², located in the eastern part of the semi-arid Tensift plain, 40 km away from the city of Marrakech. This region has a typically South-Mediterranean climate, where the average temperature is 38 °C during the summer and the lowest 5 °C in the winter (Er-Raki et al., 2010a). The average annual precipitation is about 250 mm, whereas the evapotranspiration demand is about 1500 mm/year (Duchemin et al., 2006).

Figure 1 shows the flood network irrigating this sector called R3, where 2800 hectares composed of 745 individual fields are primarily used for the production of cereals (45% in 2011–2012 and the remainder of the irrigated area corresponds to annual crops and tree crops). The detailed data on irrigated plots can be obtained from a regional public agency, "the Office Régional de Mise en Valeur Agricole du Haouz" (ORMVAH). Previous studies (Jarlan et al., 2015, Er-Raki et al., 2010b; Belaqziz et al., 2013a, Duchemin et al., 2006; Hadria et al., 2007) monitored this area during the agricultural seasons of 2002 to 2003 and 2008 to 2009.

Figure 1. The flood network of the study-area (sector R3).

In the Tensift watershed, water resources allocated to flood irrigation networks are limited, with amounts of water differing from one agricultural season to the next season due to weather conditions (rainy or dry season). Figure 2 summarizes the current flood irrigation network operating at Haouz, Marrakech (the study-area in the present ABM simulation). At the beginning of each agricultural season, the Agency of the Tensift River Basin (ABHT) assesses the volume of water accumulated in dams from summer to early winter, deciding the total amount of water that will be allocated to the agricultural sector. With this information, the managers and farmers negotiate the amount of water available to irrigate the plots of corresponding sectors; after that, the managers prepare the seasonal schedule for each irrigation round and operators perform the irrigations. Because the type of crop and cycle of irrigation are not taken into account during the negotiation process, one of two outcomes is expected: (1) a significant amount of water will be lost for the crop due to an excessive water intake, and/or (2) a water shortage will cause water stress impacting the cultural growth and yields.

In keeping with dam supplied irrigation systems, the irrigation governance in Tensift is organized according to an offer and demand system, with one or more agents managing the offer (supply management) and irrigated subareas called districts or sectors controlling the demand. A number of farmers and administrators establishing an association define a specific irrigation sector, and its organization differs from associations defining other irrigation sectors (Burton, 2010). All sectors, however, pursue the same objective of optimizing the cropping plan according to the limited volume of water offered before negotiations. These real life scenarios and corresponding data were used to model the present computer simulation.

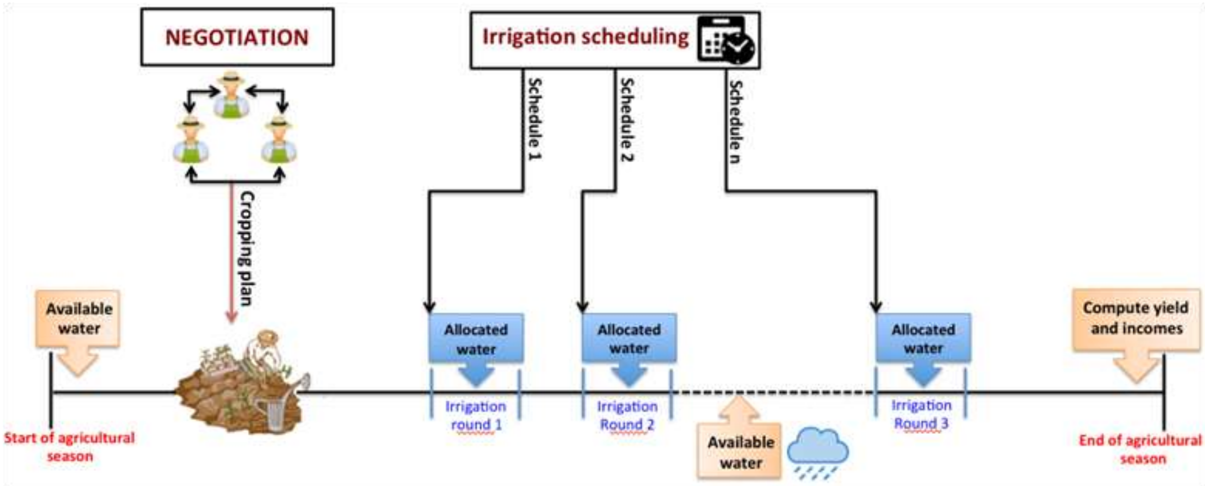

Figure 2. The flood irrigation network operating at Haouz, Marrakech (the study-area).

Procedure

In this computer simulation, a classification following the objectives of the system was proposed to gather all tasks strongly dependent on subsystems, regardless of whether or not the tasks were related to one another (El Fazziki & Nejeoui, 2008). Figure 3 shows the current computer simulation of a flood irrigation system composed of the three subsystems: (1) a supervisor subsystem to manage the agricultural season and negotiate water resources between four farmer agents (FA) and one supervisor agent (SA), with one farmer's graphical interface (GIA) communicating with each of the four farmer agents; (2) A planning subsystem with one scheduler agent (SCHA) programming irrigation rounds according to the amount of water that each plot requires; and (3) an executive subsystem to process and execute the irrigation schedules, with one main canal agent (MCA) opening the primary canal of the flood irrigation network to deliver volumes of water to agricultural sectors and one operator agent (OPA) tracking the irrigation calendar. (Note that MCA, OPA, and SCHA perform according to SA's information).

In the simulated negotiation process, the SA is not bound to the same reward contingencies of income gain as are the FA and is therefore designed to rationalize the use of the limited water resources when considering the FA's requests, climatic constraints, types of crops, and constraints on the irrigation network. The SA has a global vision of the irrigation system to negotiate and resolve conflicts. Different scenarios are assessed, allowing agents to change cropping plans and assess the imagined consequences to reach an acceptable compromise. For these purposes, we used Müller's (1996) proposal to include three fundamental elements in the negotiations processes: (1) the negotiation object defining the range of criteria to reach the solution; (2) the negotiation protocols describing the rules governing the interaction; and (3) the decision-making process addressing the needs and suggesting alternatives for each decision.

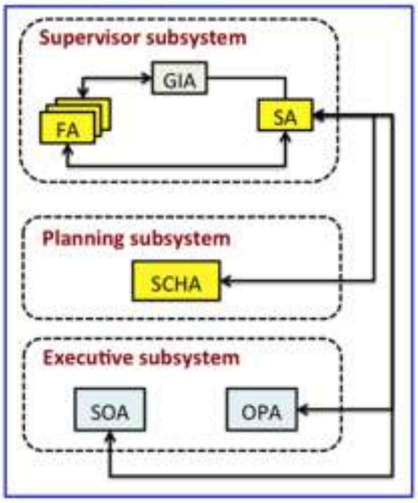

Figure 3. The ABM's simulation of a flood irrigation system consisting of three subsystems.

In the implementation of the current computer simulation, the negotiation object is the cropping plan to negotiate the actions reaching a satisfactory agreement between the SA and FA agents. The cropping plan describes the type of crop, the area to be irrigated, and the sowing date criteria; the SA and FA negotiate one or more of those criteria. The negotiation protocols are simulated verbal mediation; specific sequences of messages organized in multi-agent systems, facilitating the specification and implementation of exchanged messages and contents (sender vs. receiver). The negotiation protocols model verbal mediation by containing interactions rules, roles of participants, negotiation stages, events causing the negotiation stage to change, and some possible responses.

In order to model verbal mediation and instruction, our computer simulation employed the Contract-Net protocol because it is the most widely used protocol for interactions in multi-agent systems (Smith, 1980). Contract-Net is based on communication exchanging messages (see Appendix 4) between an initiator (i.e., the Manager) and agent (i.e., the Contractor). The Manager is responsible for monitoring the execution of a task and processing the results of it, and the Contractor is responsible for the actual execution of the task; in the present simulation, the Manager was the SA and the Contractor the FA.

To model the exchanged messages and contents required to implement the Contract-Net protocol, five stages were defined as follows: (1) The SA sends the instruction "define initial crop" to a set of farmer agents (FAs) indicating the task to be performed; (2) Each FA choosing to cultivate the plot, replies to the SA with the message "propose" and describes the crop's plan with sowing date, cultivated crop, and irrigated area; FAs deciding not to cultivate the plot, reply to the SA with the message "refuse" opting out from initial negotiations; (3) For each FA deciding to cultivate the plot, the SA assesses the proposal and compares it with the amount of water assigned to its plot; then, the SA interacts with the GIA to compute the volume of water estimated to irrigate the FA's plot according to the corresponding cropping plan. After the assessment process, the SA sends two successive messages for water requirements exceeding the available volume of water, one message rejecting the initial FA's proposal ("reject-proposal") and a second message ("inform") comprising a feasible cropping plan. (4) Upon receiving the new cropping plan, FA assesses the objectives including expected risks and replies with the message "accept-proposal" accepting SA's alternative cropping plan, otherwise FA replies with the message "reject-proposal;" FA can send a second message ("cancel") to withdraw the cropping plan from negotiations and receive the available amount of water originally assigned to its plot. (5) In the last stage, the SA re-assesses the new FAs' proposals with feasible cropping plans (stage 3); for accepted proposals, SA sends a message ("done") to both agents, FA and GIA, stopping the negotiation process.

We also modelled the farmer's decision requiring individual knowledge about human, mechanical, financial, and time factors. These factors are important in the decision-making process characterizing the farm (i.e., soil and distances among plots), the expertise of certain set of crops, and the assertion about external uncertainties like climate. Given the number and complexity of factors involved in the farmer's decision, assessing the knowledge of all of them on a per capita basis is practically impossible. Consequently, the present computer simulation made two assumptions: (1) the availability of water constrains the farmer's goal to maximize its income; and (2) the limited water amount regardless of the source (i.e., hypothetical rainfalls or future storage in dams) decreases the likelihood of achieving a fully developed crop production due to water scarcity. The reduction of the farmer's reinforcer (water which leads to income) reduces the probability of the farmer choosing to accept the supervisor's proposal.

Because suboptimal yields are observed often in semi-arid areas, farmers need to bet on upcoming water availability. The bet depends on the imagined consequences of expected gain and risk factors that farmers estimate when developing the cropping plans. The gain can be modeled as a function of sowed surface, yield, and market price (Appendix 1 shows the corresponding farmer's algorithm).

In the present computer simulation, the supervisor is in charge of gathering the farmers' proposals and evaluates the overall cropping plan according to the water volume available for the irrigation sector. (The corresponding algorithm is synthesised in Appendix 1).

Data Analyses and Computations

To facilitate the farmers' decision about scheduling the irrigations of water during the negotiation process, our computer simulation estimates the volume of water required to irrigate each plot and the total income that each farmer needs, predicting the production (yield) of each plot at the end of the agricultural season.

The volume of water required for each plot was computed with Equation 1.

$$Water\ needs_i = ((k_c * ET_0) - R) * \ Area_{i.} \qquad (1)$$

Where Kc is the Crop coefficient (Allen, Pereira, Raes, & Smith, 1998) varying with the type of culture and begins its cycle according to the sowing date; ET0 is the reference evapotranspiration and R the effective rainfall, depending on the type of agricultural season (i.e., wet, normal or dry); and Areai is the sector irrigated for each plot (i). Note that Equation 1 was extremely simplified to implement the current computer simulation; a full soil water budget would require a more operational setting (Le Page et al., 2014).

The following linear function introduced in previous research about irrigation and drainage (Doorenbos & Kassam, 1979), was used to compute the productivity of the crop (yield).

$$\left(1-\frac{y_a}{y_m}\right) = k_y\left(1-\frac{ET_{cadj}}{ET_c}\right). \quad (2)$$

Where ya is the actual yield of the crop [kg ha -1], ym the maximum productivity (yield) expected in the absence of any possible environmental or water stress, and ky the response factor; values of ky have been documented in previous studies (e.g., Doorenbos & Kassam, 1979).

For each plot (i), ETc was computed with Equation 3; ETc is the potential crop expected for evapotranspiration in the absence of environmental and water pressures.

$$ET_c = (k_c * ET_0) * Area_i \quad (3)$$

The actual or adjusted crop evapotranspiration (ETcadj), resulting from environmental and water stresses, was computed with Equation 4.

$$ET_{cadj} = (Water\ allocation + R) * Area_i. \quad (4)$$

Where water allocation is the volume of water assigned to the plot (i) at the beginning of the agricultural season and before the negotiations. Equation 4 is functional for a negotiation scenario, assuming that the soil-plant complex consumes all input water and that no water is lost by deep percolation.

In the present computer simulation, the crop sowing dates were estimated using the crop calendar tool of the Food and Agriculture Organization (FAO). Figure 4 shows the cereals' sowing date calendar at the Haouz zone. Accordingly, the best sowing date was the interval between October 20 and December 10.

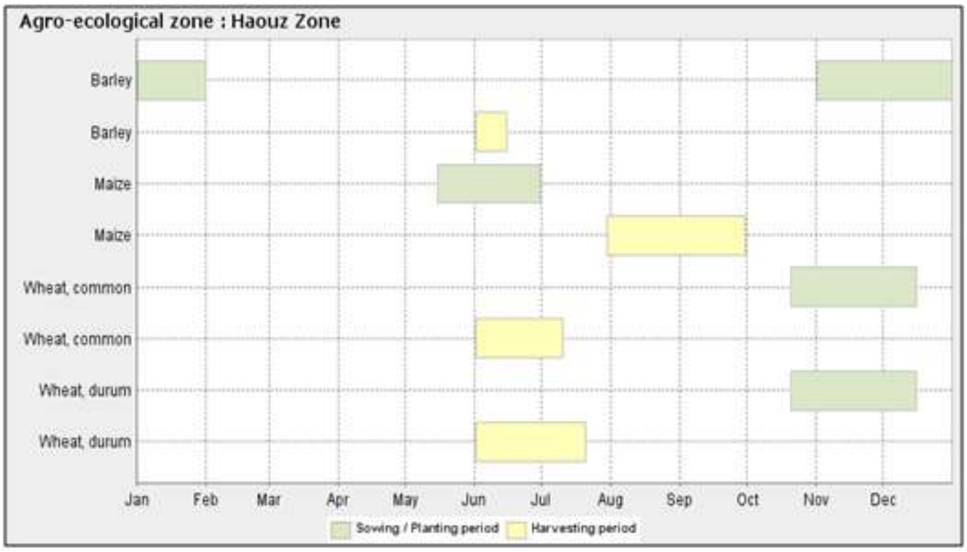

Figure 4. Cereals and calendar at the Haouz zone from the FAO.

We used Equation 5 to estimate the total income of each plot and Equation 6 the raw income.

$$Total\ income = Raw_{income} - Input_{Variables} - Input_{Fix} \quad (5)$$

$$Raw\ income = Yield * CropPrice * Area \quad (6)$$

Because Crop Price is subject to worldwide market fluctuation, particularly wheat, in the present computer simulation the Crop Price was set to the selling value of wheat in 2012 (soft wheat = 35 USD/q; durum wheat = 40 USD /q). The problem of using a fixed cost for Crop Price, however, is that it might include other aspects like pay-offs and land lease; to prevent inaccurate computations and simplify the cost of sowing, the present computer simulation used a classical technical itinerary; only plowing, seeds, fertilizer, and pest control were comprised to compute Crop Price. In the region currently studied, this cost is about 572 USD/ha for the soft wheat and 583 USD/ha for the durum wheat.

To execute the present computer simulation, the input variables were irrigation rounds, human workforce, and water; these factors were calculated with Equation 1 and were related to the cropped acreage, the number of water rotations needed, and other adjustments that depended upon the type of irrigation technique (for example, flood irrigation is associated to an inherent loss of 30% of water for the plant evapotranspiration).

Results

The results presented here are based on a synthetic simulation where the agents described afterward are not real humans but simulated computer agents. Congruently, the left panels of Figure 5 (Appendix 2) show 4-farmer agents (FA) and the right panels 1-supervisor agent (SA) interacting to negotiate the volumes of water that will be allocated to each farmer. Our current system used an instance of the runtime environment of the JADE platform (Appendix 2) to execute this set of agents. The implementation started with SA interacting with the database to compute yield and incomes, sending a request to each farmer at beginning of the agricultural season (for a detailed description, see JADE in Appendix 3).

Each farmer had a graphical interface (Figure 5, left panels) to input the initial cropping plan consisting of the plot's number (e.g., P1), type of crop (e.g., wheat), area to be irrigated (e.g., 20 ha), and the sowing date (e.g., 10/11/2013). Each FA sent the cropping plan to SA, clicking the request button. Upon receiving the cropping plans, SA analyses the information about yield and incomes corresponding to the initial plan that each farmer submitted, launching a second interface (i.e., GIA, the right panels of Figure 5, Appendix 2).

For each FA, Table 2 shows the cropping plan with corresponding computations before negotiation (BN) and after negotiation (AN). The SA's computations clearly indicate that before negotiations the FAs' water requirements exceeded (Sum = 43816.5 m3) the available amount of water (Sum = 37260.0 m3). The SA started the negotiations with each FA, applying the rules of water allocation (defined above); accordingly, risk values in this computer simulation were randomly initialized for each farmer (column 2). The negotiations ended when the total amount of water allocated to the FAs was equal or less (column 10) than the volume of water available to it (column 8).

A comparison between water requirements before and after negotiations (columns 9 and 10, respectively) reveals two remarkable results: (1) a considerable reduction in the amount of required water, from 43816.5 to 35832.3 m3, to supply the needs of the FAs, and (2) a saving of 1427.70 m3 in the amount of water; i.e., the difference between the available water and required water after negotiations. A Paired Sample t-Test, however, indicated that the average amount of water that the FAs required before negotiations (M = 10954.1) was not significantly different ($t(3) = 1.659$, $p = .196$) from the mean amount of water allocated to the FAs after negotiations (M = 8958.1). Similarly, the mean of the yield after negotiations (M = 5.6) was not significantly different ($t(3) = 1.426$, $p = .249$) from the mean of yield before negotiations (M = 4.6); nor it was the mean of income after negotiations (M = 1489.52 USD) significantly different (t (3) = 1.112, p = .347) from the mean of income after negotiations (M = 1214.01 USD). But these results are more likely due to the small n (4) that the Paired Sample t-Test analyses used.

Results in Table 2 also illustrate possible consequences to the FAs' decision of taking or not the risk of keeping the same cultivated area after negotiations. For instance, column 2 shows FA-1 and FA-3 choosing to keep the same irrigated area (column 5) after negotiations (remember that in the present computer simulation risk value was randomly initialized for each FA). The consequences for that decision are: (1) FA-1 and FA-3 will receive the same amount of water (column 10) that was initially granted to them (column 8), and (2) their incomes is subject to good rainfalls (compare column 13 with column 14), particularly for FA-3 choosing a sowing date (column 7) that is out of the range of sowing dates that SA proposed.

In contrast, with risk-value = 0, Table 2 (column 2) shows FA-2 and FA-4 choosing to change their irrigated areas, discarding the risk of keeping the same cultivated area after negotiations. The possible consequences for that choice are: (1) FA-2 and FA-4 will reduce the water requirements from 8625.7 to 7188.1 m3 and from 10417.7 to 4884.2 m3, respectively, and (2) their incomes will improve from 1291.6 to 1377.4 USD and from -188.0 to 898.2 USD, respectively; mainly for FA-4 moving from a deficit to profit by being willing to change the sowing date in keeping with the SA proposal.

			Area (ha)		Sowing Date		Water (m^3)			Yield (t/ha)		Income (USD)	
			Cultivated		2013			Required					
FA	Risk	Total	BN	AN	BN	AN	Available	BN	AN	BN	AN	BN	AN
1	1	20	16	16	11/10	11/10	10800.0	11085.0	10800.0	5.2	5.2	2104.5	2104.5
2	0	15	12	10	11/15	11/15	8100.0	8625.7	7188.1	5.0	6.1	1291.6	1377.4
3	1	24	14	14	1/1	1/1	12960.0	13688.1	12960.0	5.2	5.2	1578.0	1578.0
4	0	10	10	8	1/15	10/10	5400.0	10417.7	4884.2	2.8	5.8	-118.0	898.2
						Sum	**37260.0**	**43816.5**	**35832.3**	**18.2**	**22.3**	**4856.1**	**5958.1**
						Mean	**9315.0**	**10954.1**	**8958.1**	**4.6**	**5.6**	**1214.0**	**1489.5**
						SD	**3281.0**	**2097.7**	**3611.9**	**1.2**	**0.4**	**949.7**	**499.4**

Table 2. For each FA, cropping plan before negotiation (BN) and after negotiation (AN)

Discussion

In the present computer simulation, the implementation of the negotiation process is based on the analysis of the whole irrigated system including the supply of water, the management of an irrigated district, and the farmers who are the end-users of the resource. At the beginning of a cropping season, a negotiation between farmers and managers takes place to decide what crops and surfaces will be sowed. In semi-arid areas, water shortages are not so uncommon. The negotiation process takes place when a limited amount of water is stored into the dams; it is assumed, however, that the dams can be refilled if a good rainfall occurs during the cropping season. During the negotiation, the farmers have to imagine the potential consequences and bet on rainfall and the refilling of the reservoirs to increase their incomes; accordingly, they can choose the crop to be sowed, the area to be sowed, and the date of sowing.

To simulate the negotiation process, the main stakeholders were modeled into different kinds of agents, and a simple risk term was introduced to the farmer agents. At this stage, the farmer agents only communicate with the irrigated district supervisor. They don't learn from the past (no memory), nor do they adapt their level of risk; their decisions are based on the information given by the manager and their willingness to take the risk. The manager, on its side computes the expected yields according to the information given by the farmers and the expected climatology. If the total amount of water is less than that stored into the dams, the manager accepts the farmers' information and the negotiation is closed; otherwise, another round of negotiations is conducted. The complex behavior of the real stakeholders is therefore highly simplified for the only purpose of simulating a negotiation to share water. Accordingly, in the present simulation the negotiation process was modelled using a limited number of artificially created agents (in terms of risk, area owned, and initial sowing date), showing that a multi-agent approach is a feasible method to simulate negotiations for water sharing in a flood irrigation system at the beginning of an agricultural season. At the present stage of development, however, the present study can be considered a preliminary work because only theoretical data were used to validate the multi-agent approach. It was suggested that imagined consequences, such as improving income and optimizing water resources, could be used to facilitate the negotiations of limited water resources in flood irrigation systems. Overall, the present computer simulation remains as a simple model open to suggestions to improve and serves as a foundation for future research. For example, a farmer agent showing certain reluctance to change from one crop to another could be incorporated into the model to simulate the lack of knowledge about the specific technical itinerary or the distribution market. Similarly, the risk to expand the farmers' cropped area is coded binary, when a more refined approach to risk could be considered. Particularly, the farmer agent could be built into the system with its own yield to compute and compare the risk with the manager's evaluation. Another limitation of the present study is that our farmer agents did not communicate to one another, when in practice farmers copy the sowing pattern of their neighbors. Ideally, we suggest further research be conducted on the actual decision-making behavior of the real farmers who participate in flood irrigation systems. These data can be used to refine our multi-agent system to further improve its predictive capabilities.

From the present computer simulation, it can be concluded that multi-agent approaches: (1) offer a systematic way to analyze the contribution of multiple actors involved in the negotiation process, (b) present different scenarios facilitating interactions between them, (c) provide possible consequences representing complex decisions, and (d) give the ability to change strategies and decisions to reach optimal final compromises, improving income and maximizing sustainable water resources development in accordance with water management policies.

Future studies applying behavioral principles to multi-agent systems approaches are needed to more accurately analyze the variables affecting the negotiation process, with the aim to improve decision-making processes in flood irrigation networks. For example, the impact of agricultural policies such as water pricing, sowing dates and land use on decision-making should be analysed in systematic way to propose mechanisms facilitating negotiations between the FA and SA agents. More research using multi-agent approaches is needed to address plausible consequences to unchanged cropping plans and to describe systematic ways of dealing with predictable changes in weather conditions (i.e., temperature, rain); these research efforts will assist farmers in adopting new cropping plans and develop behavioral strategies in agreement with information provided during the negotiation process. Particularly, we are suggesting here to conduct research addressing the analysis and modeling of different types of forecasted events (climatic, organizational, technical or economic) that might occur during the agricultural cropping season. Other efforts aimed to enrich the application of multi-agent systems should conduct field surveys investigating the behaviors and attitudes of farmers that govern the decision-making process. For instance, research assessing the farmers' preferences for immediate consequences over delayed consequences (e.g., Green & Myerson, 2004; Rachlin & Green, 1972), is necessary to identify factors controlling choices for cropping plans and to also account for contingency traps where short-term gains to an individual negatively impact the water distribution system as a whole.

Conclusion

The creation of a database containing information about potential problems and doubts that farmers face in everyday life is necessary to communicate efficient ways to optimize water resources while maximizing utility during the negotiation processes. Meanwhile, it is safe to conclude that multi-agent systems, when supported by the experimental analysis of behavior, are viable approaches to model and validate the management of limited water resources, of capturing real scenarios, and allowing the study of variables determining successful negotiations between farmer and supervisor agents at the beginning of each agricultural season. In this way, we can use this information to optimize the fair and efficient distribution of limited water resources. The research presented here is the foundational first step of further research that can contribute to the development of a refined multi-agent system that can significantly impact agricultural sustainability in arid and semi-arid areas. We encourage further contribution from practitioners of the experimental analysis of behavior in these efforts, as the knowledge of behavior principles is critical in the computational modelling of real-life behavior.

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Appendix 1

Farmers' algorithm bet on upcoming available water

```
If [Supervisor] accept the cropping plan and propose a new sowing date
   If [Farmer] takes risk
      [Farmer] changes the date of sowing according to the [Supervisor] proposal => Yield and Earning are improved
   Else
      [Famer] does not change the date of sowing => yield and earnings will be low unless the season will be rainy.
Else if [Supervisor] refuses the [Farmer] cropping plan
   If [Farmer] takes risk
      [Farmer] changes the Sowed area according to [Supervisor] proposal => Yield and Earning are improved
   Else
      [Farmer] does not change the sowing plan => Yield and Earnings will be low unless the season will be rainy.
End If
```

Supervisors' algorithm to gather the farmer's proposals and evaluate the ocropping plan.

```
If Total Water Required < Total Water Available
      If proposed Sowing Dates = Good Sowing Dates
            Accept the Cropping Plan and propose new Sowing Dates
      Else
            Accept the Cropping Plan
Else
      If Proposed Sowing Dates = Good Sowing Date
            Propose a new Cropping Plan
      Else
            Refuse the Cropping Plan
```

Appendix 2

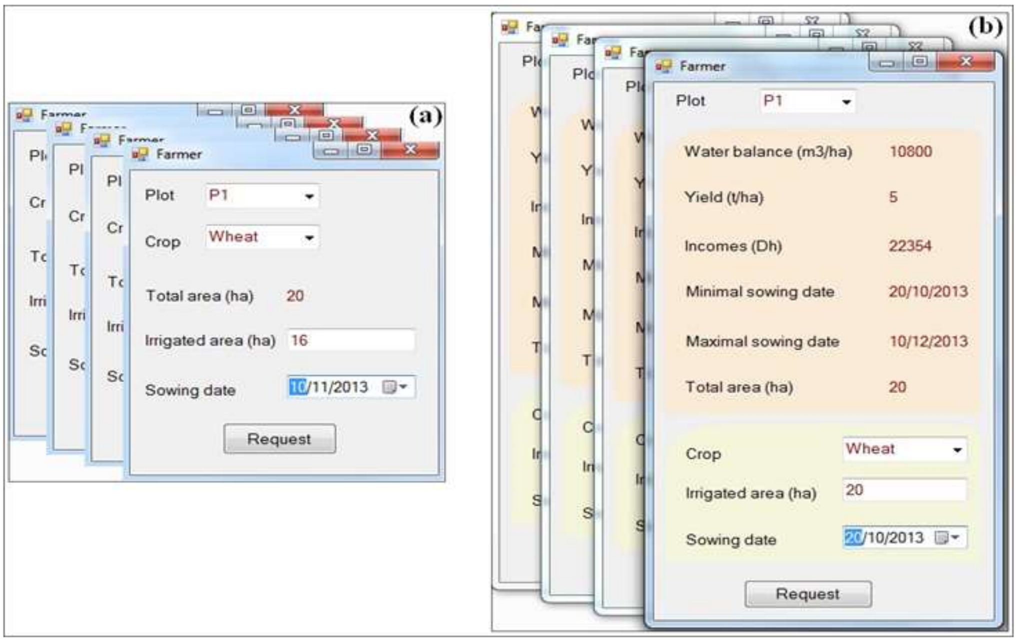

Figure 5. Four farmers (FAs) and one supervisor agent (SA) negotiating.

Appendix 3

JADE-Platform

The Java Agent Development Framework (JADE, v 4.3) agent platform (Bellifemine, Caire, & Greenwood, 2004) used to implement the projected environment. This platform was chosen because JADE is one of the best modern agents providing an open-source environment. The Foundation for Intelligent Physical Agents (FIPA) established JADE with specifications to assist the development of agent applications (FIPA TC C, 2002); JADE sees the concept of agent as an autonomous and independent process with identity that requires interactions (i.e., collaboration, negotiation) with other agents. Each instance of JADE is called a container, corresponding to several agents that communicate exchanging messages represented in FIPA-ACL protocols; each agent has mailbox containing the messages that other agents sent.

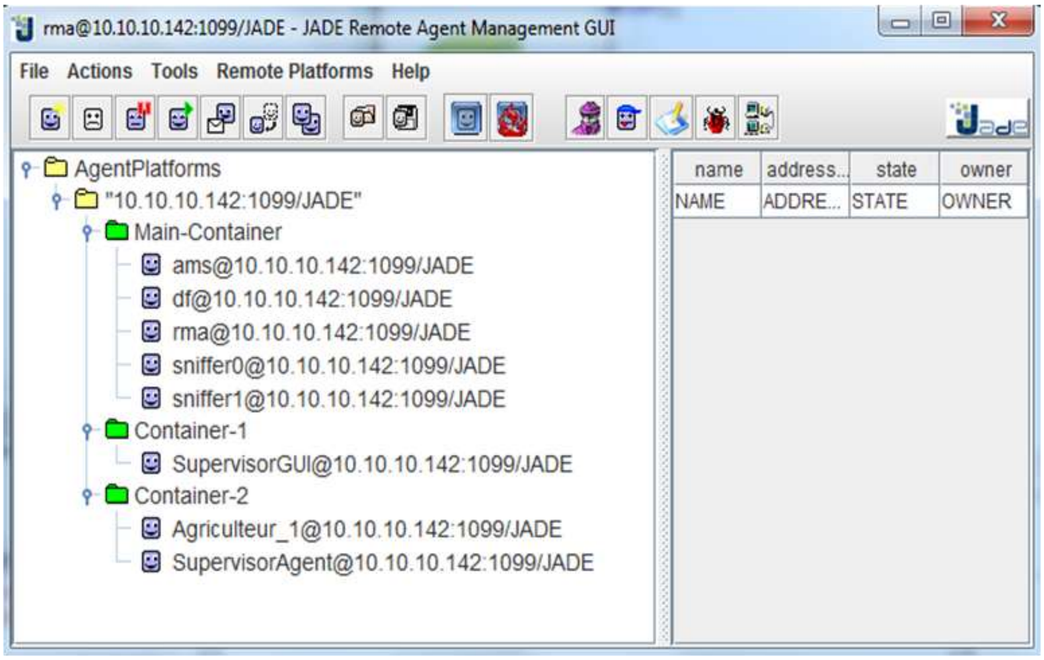

Figure 6. The agents in the proposed ABM under the JADE platform.

Appendix 4

Agents Communication

Each agent has a Mailbox containing the messages that it receives. Each message consists of an envelope and a body. The envelope contains information required to transmit and deliver the messages using the Message Transport Service (MTS), and the body is the FIPA-ACL's courier. Agent Communication defines the sequence of exchanges between agents allowing to structure interactions. The message's format is defined in jade.lang.acl.ACLMessage class composed of: (1) Sender, (2) Receiver, (3) Content, and (4) Protocol.

A FA sending a message creates a new ACLMessage object, fills the fields with appropriate values, and calls the send method. Otherwise, a FA receiving a message uses the receive method, or it can click on the blocking-receive method to skip it. The following is an example of FA sensing message to inform SA that the initial cropping plan was defined.

```
ACLMessage message = new ACLMessage(ACLMessage.INFORM);
message.addReceiver (new AID("SupervisorAgent", AID.ISLOCALNAME));
message.setContent ("Crop plan initialized");
send(message);
```

Under JADE, this message takes the following form:

```
(INFORM
:sender (agent-identifier :name Agriculteur_1@SALWA:1099\JADE :addresses (sequence http://10.10.10.136:1695/acc ))
:receiver (set (agent-identifier: nameSupervisorAgent@SALWA:1099\JADE))
:content "Crop plan initialized"
:language fipa-sl
:protocol Contract Net
```

On example of message received.

```
ACLMessage messageRecu = receive();
```

Under JADE, this message takes the following form:

```
(ACCEPT-PROPOSAL
:sender (agent-identifier :name SupervisorAgent @SALWA:1099\JADE :addresses (sequence http://10.10.10.136:1695/acc ))
:receiver (set (agent-identifier :name Agriculteur_1@SALWA:1099\JADE :addresses (sequence http://10.10.10.136:1695/acc )) )
:content "Crop plan received"
:reply-with Agriculteur_1@SALWA:1099\JADE1298373540944 :protocol fipa-query)
:language fipa-sl
:protocol Contract Net
```