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RESEARCH ARTICLE

Assessing the impacts of groundwater management policies on farmer cooperation using agent-based modeling

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Supplementary materials

Analysis of selected individual agent results from Scenario I

Table S1 summarizes the characteristics of a selection of agricultural agents, providing details on their location, crop/orchard cultivation areas, access to alternative water sources, well discharge rate, and hydromodule.

Table S1 Characteristics of agricultural agent

Agent's number	City	Cereal cultivated area (ha)	Garden cultivated area (ha)	Has other resource except well?	Well discharge ($Lit{\cdot}s^{-1}$)	Hydromodule ($Lit{\cdot}s^{-1}{\cdot}ha^{-1}$)
58	Tiran	0	3.65	No	4	1.1
124	Tiran	27.4	0	Yes	7.5	0.24
145	Dahaghan	31	29	Yes	12	0.2
331	Dahaghan	10.4	0	No	12.5	1.2
339	Lenjan	0.75	1.3	No	1.5	0.73
344	Lenjan	4.2	0	Yes	11.5	2.73
1327	Mobarakah	15	0	Yes	6	0.4
1334	Mobarakah	24	0	No	8	0.33

Figure S1 illustrates a cumulative representation of the months during the simulation period when the agents encountered water shortages (indicating months where water demand surpassed water extraction from the well) under current conditions. The number of months with water deficit varies based on the characteristics of each farmer. Three key factors influencing the variation in these months include the presence of alternative water sources (such as river or Qanat flows), crop diversity (the concurrent cultivation of farm and garden crops), and the hydromodule for each farmer (referring to well discharge per hectare of land). Notably, the availability of water supplies beyond the well results in a decrease in the number of months experiencing water deficits.

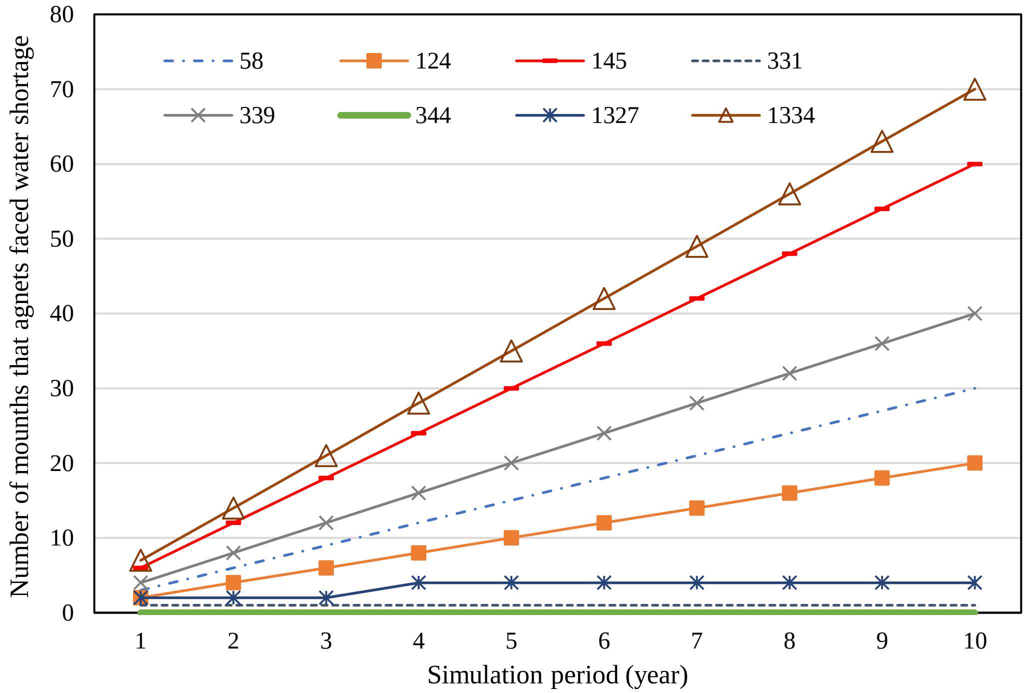

Fig. S1 Number of months of the agents faced water shortage in current condition (10 year period).

Agents 145 and 1334 face water shortage during more than half the simulation period (60 and 70 months, respectively). Agent 1334 relies solely on well withdrawal with a hydrmodule of 0.33. Although water to agent 145 is supplied from two supplies so that it does not merely rely on well water, it faces water shortage during half the simulation period due to its low hydromodule (0.2). Agent 339 also depends solely on the well (with a hydromodule of 0.73) but the simultaneous cultivation of farm and garden crops increases its months with high water demands. In contrast, Agents 331 and 344 never experience water deficits throughout the simulation as they have high hydromodules of 1.2 and 2.73, respectively, even with their farm cultivations. Figure 2 illustrates the number of water deficit months legal agents face during the simulation when Scenario I is implemented.

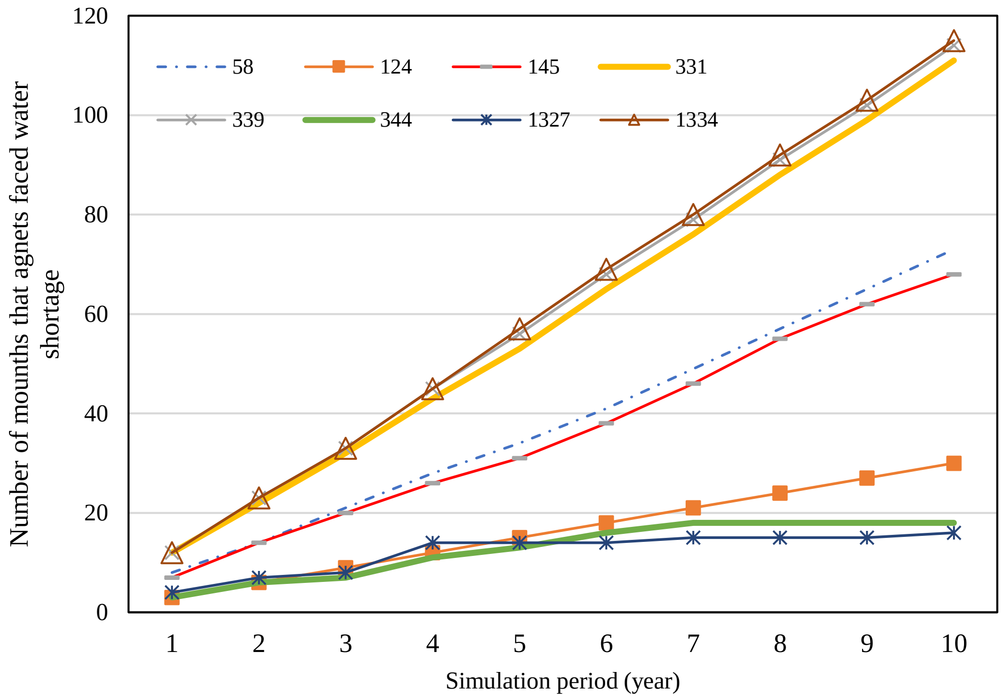

Fig. S2 Number of months that Agent faced water shortage in Scenario I (10-year period).

Scenario I aims at a reduction of 20% (i.e., an annual reduction of 2%) in water exploitation from wells by the end of the simulation period. Agents 331, 339, and 1334 face water shortage throughout the simulation period except a few months. Indeed, these three agents record the highest numbers of water deficit months clearly because of their sole reliance on well water and simultaneous cultivation of both farm and garden crops. Agents 145 and 58 record less water shortages than the above three since they receive water from two water supplies and grow only farm crops (agent 58). Agents 1327 and 344 record the lowest water shortages among the agents investigated mainly because they have two water supplies available that evidently reduce their reliance on well water.

Figure S3 presents the average yield ratios for all the crops throughout the whole simulation period to the maximum yield allowed for each agent under Scenario I. Implementation of this Scenario have different effects on different agents. Agents 124, 344, and 1327 experience the lowest reductions of less than 2% in their crop yields under this scenario. The reason for this might be sought in their reliance on two water supplies and their sole cultivation of farm crops (no garden crop). The other agents exhibit reductions ranging from 15% to 27%, showing considerable differences from the previous three agents, in their crop yields due to their reliance on only one water supply (i.e., wells).

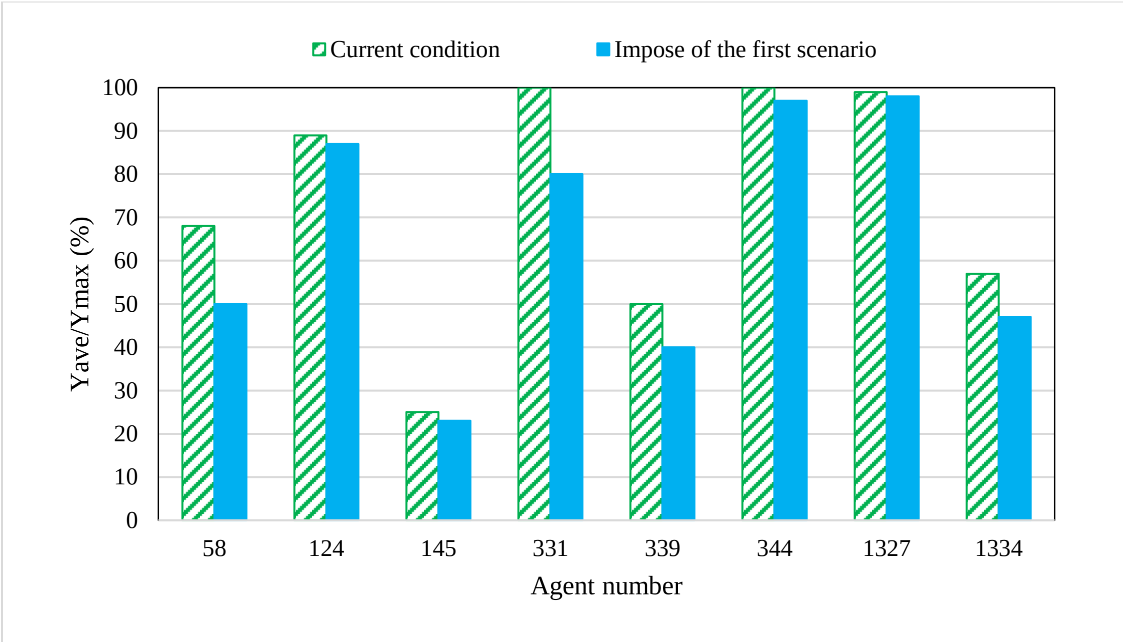

Fig. S3 The average yield ratios for all the crops throughout the whole simulation period to the maximum yield.

Yave is the average of crop yields in the 10-year period; Ymax is the max of crop yields in the 10-year period.

The study seeks to illustrate the evolution of each farmer's circumstances before and after scenario implementation, facilitating a comparison of the resulting effects, as depicted in Figs. S2 and S3. Within this research, a comprehensive depiction of farmers' behavioral influence encompasses factors such as the impact of neighbors' behavior, alterations in benefits, changes in weather conditions, changes in crop yields, and the historical behavior of each farmer. Indeed, paramount parameters have been identified and quantified to show their transformations within the context of farmers' behavior.