FARMERS' SCHEDULING PATTERNS IN ON-DEMAND PRESSURIZED IRRIGATION

Salvador, R.[1], Latorre, B.[2], Paniagua, P.[3] and Playán, E.[4]

ABSTRACT

Irrigation scheduling results from the irrigator's integration of meteorological, environmental and crop information. In this paper, the irrigation scheduling patterns of a group of irrigators in the Candasnos Water Users Association (WUA), located in north-eastern Spain, were analysed. Scheduling sprinkler and drip irrigation in this WUA shows additional complications due to the sharing of a collective pressurized irrigation network and to the need to file water orders two days in advance of its foreseen use. The database created by a Remote Surveillance and Control System was mined to obtain the time evolution of hydrant operation time during the 2004-2008 irrigation seasons. Records were selected for clearly identified crops and irrigation systems, and for verified water allocations. Hydrant operation showed a relationship with meteorology (precipitation, wind speed, relative humidity and air temperature), although this relationship was often not evident when hydrants were individually analysed. Statistical analyses were run to classify irrigator's scheduling practices, leading to the establishment of ten different groups. The adopted classification criteria included the average number of weekly irrigations, the SD of the number of weekly irrigations and the modal range of the irrigation starting time. The irrigation pattern was determined by the irrigator (56 %), the irrigation system (33 %), and the crop (11 %). Only in a fraction the cases (22 %) the time change in the scheduling pattern responded to a clear time trend; in 39 % of the cases, changes in time appeared random. Further, 45 % of the irrigators used the same irrigation pattern in at least half of their hydrant-years, independently of the crop.

---

[1] Corresponding author. Dept. Soil and Water. Aula Dei Experimental Station, EEAD-CSIC. P. O. Box 13034. 50080 Zaragoza. Spain. rsalvador@eead.csic.es

[2] Dept. Soil and Water. Aula Dei Experimental Station, EEAD-CSIC. P. O. Box 13034. 50080 Zaragoza. Spain. borja.latorre@csic.es

[3] Dept. Soil and Water. Aula Dei Experimental Station, EEAD-CSIC. P. O. Box 13034. 50080 Zaragoza. Spain. pilucap@eead.csic.es

[4] Dept. Soil and Water. Aula Dei Experimental Station, EEAD-CSIC. P. O. Box 13034. 50080 Zaragoza. Spain. enrique.playan@csic.es

Only 14 % of the irrigators applied different irrigation scheduling patterns to different crops. Our results suggest that irrigators do not find value or do not have the capacity to develop irrigation patterns more consistent and adapted to the local environment, the crops and the irrigation systems.

1. INTRODUCTION

On-farm irrigation scheduling is an important topic of study at two different levels. At the farm level, irrigation scheduling will determine crop yield in both quantity and quality. At the collective level, the addition of the irrigation flows demanded at the hydrants of an irrigation network (resulting from farmer's irrigation scheduling), will determine the network demand and operating conditions throughout the irrigation season.

Designing an on-farm irrigation schedule in a pressurized irrigation system implies selecting the timing, duration and frequency of the irrigation events (Clemmens, 1987). The search for maximum uniformity and efficiency in each irrigation event is an additional constrain to irrigation scheduling. On-farm irrigation system design determines maximum irrigation uniformity and application efficiency. Reaching maximum performance in each irrigation event will depend on the adequate selection of irrigation time and duration. These variables are selected at the beginning of the irrigation event, although irrigation duration can be modified at any time. In the case of sprinkler irrigation, the environmental conditions (subjected to relevant inter- and intra-day variability) will strongly determine irrigation uniformity and wind drift and evaporation losses. Selecting the most adequate irrigation time and duration will minimize the negative effect of environmental conditions on the performance of each irrigation event (Playán et al., 2005) and will maximize irrigation efficiency and/or crop yield. In pressurised irrigation systems requiring electrical energy input, irrigation timing may result in different costs. For instance, in the current conditions in Spain, energy costs can be tripled during a 24 h period.

Collective pressurized irrigation networks are designed to meet certain simultaneity, characterized by the number of open hydrants in each network segment (Lamaddalena and Sagardoy, 2000). During network operation, the time evolution of the number of open hydrants is determined by the physical design of the on-farm irrigation systems, crop water requirements, energy costs and the Water Users Association (WUA) organizational rules. However, the approach of individual farmers to on-farm irrigation scheduling strongly determines hydrant operation, and can provide valuable information for the optimization of irrigation network design and maintenance.

In collective pressurized irrigation networks, design decisions often pose relevant constraints to farmer irrigation scheduling. Relevant limitations derive from the installation of flow limiting valves at the hydrants. Flow limits determine the maximum number of sprinklers or drippers in simultaneous operation or the pivot size. Flow limits also determine the maximum crop water requirements that can be met by the irrigation system. This may result in continuous irrigation operation during the period of peak crop water requirements, regardless of the intraday and interday changes in environmental conditions or energy costs. Regarding the WUAs organizational rules, rigid schedules deriving from the planning of pumping stations or energy use can result in severe limitations to farmers' capacity to respond to crop water requirements.

On-farm irrigation controllers have been designed to implement farmers' scheduling decisions. However, on-farm controllers have often been reported to complicate the implementation of optimum, environment-sensitive irrigation scheduling (Zapata et al., 2009). Users should master their advanced irrigation controllers in order to implement all features leading to scheduling flexibility. Most of the agricultural irrigation controllers in the market have very limited possibilities in this respect, and have been designed to produce rigid irrigation schedules.

If the characteristics of the collective pressurized irrigation network, the on-farm irrigation system and the controller are important for an adequate irrigation schedule, the human factor stands as the most decisive factor. It is the farmer who judges the available information and produces the schedule leading to the execution of an irrigation event. The farmer may also decide to interrupt irrigation when agrometeorological conditions are not suitable for the irrigation system. In order to make these decisions, a farmer can count on several information sources. Web pages have been created to publish current irrigation requirements for the most common crops in a given region (Department of Water Resources, 2011; Government of Aragón, 2011). Additionally, continuous education programs are available to farmers, particularly to those established in large irrigation projects. As a consequence, most professional farmers are aware of the effect of agrometeorological conditions on irrigation scheduling (regarding crop water requirements and the effect on sprinkler irrigation performance). This is particularly important in areas characterized by strong winds, since wind speed is the agrometeorological factor most limiting to sprinkler irrigation performance (Tarjuelo et al., 1999; Zapata et al., 2007; Sánchez et al., 2010). In drip irrigation, farmers' scheduling decisions are not so directly influenced by the environment, and often respond to fertigation requirements or to regulated deficit irrigation strategies (Zapata et al., 201Xa and 201Xb).

Researchers have paid attention to the effect of farmers' decision making on several aspects of agricultural production. The most common target of these research works is the influence of human factors on decision making about cropping patterns. Research works have focused on issues such as water scarcity (Faysse, 2003), wastewater irrigation (Styczen et al., 2010), or fluctuations in the price of agricultural commodities (Cortignani and Severini, 2009). The effect of the human factor on irrigation decision making has received limited attention in the literature. Clemmens and Dedrick (1992) analyzed a list of candidate factors (including human factors) affecting farm water use in the surface-irrigated area of Maricopa (Arizona, USA). Dechmi et al. (2003) used the same methodology to assess the effect of farmer related variables on seasonal irrigation depth and crop yield. Merot et al. (2008) studied the relationship between irrigation practices and crop management in a surface-irrigated area specializing in hay production. Finally, Brown et al. (2010) developed tools to predict the influence of farmers' irrigation decisions on the final crop yield.

The analysis of detailed on-farm pressurized irrigation schedules has not been the target of recent research efforts. Scientific works have often been oriented to simulating and/or recommending irrigation schedules (Cancela et al., 2006; Liyuan et al., 2010). Other studies have focused on monitoring on-farm irrigation, proposing optimum irrigation calendars (Chopart et al., 2007). However, detailed studies of farmer irrigation scheduling can be used to elucidate current trends in on-farm pressurized irrigation. Researchers can use such studies as a source for insight and to validate irrigation decision making models. On the other hand, irrigation engineers can use these analyses as to improve network and on-farm designs. As a consequence, assessing the factors guiding farmers' irrigation scheduling will lead to more water- and cost-effective future pressurized collective irrigation networks.

Remote surveillance and control systems (RSCS) are being installed in many irrigation networks in Spain built in this century. These systems can provide valuable information on individual farmers' irrigation schedules. As a consequence, RSCS can not only provide a service to the farmers, but also provide feedback to irrigation practitioners and analysts. This process is often limited by the database structure (not oriented to data analysis) and by the enormous amount of information often produced by these systems. These findings underline the fact that RSCS are rarely designed taking into consideration the long-term feedback value of the information they store. As a consequence, data mining techniques are required to produce useful information for the analysis of farmers’ irrigation scheduling. Data mining concerns the extraction of useful information from large amounts of data (Han and Kamber, 2006). In order to obtain knowledge from large databases the first step is data cleaning, followed by data integration if different sources of information are used. Once all information sources are located in the same platform, data selection and transformation will be required if only part of these data is useful or if data presentation is not adequate. Data mining will be followed by pattern evaluation and knowledge presentation.

In this work, the RSCS of an on-demand pressurized WUA located in northeastern Spain was analyzed. The research objectives were to: 1) Build a database on hydrant irrigation (30 min interval) for sprinkler and drip irrigation combining crop, year, hydrant, farmer, agrometeorology and irrigation system; 2) Classify the irrigation seasons recorded at the WUA hydrants according to their irrigation scheduling patterns; and 3) Identify and classify patterns in farmers’ behavior regarding relevant factors in irrigation decision making.

2. MATERIALS AND METHODS

2.1 Area description

The data analysed in this study were obtained at the Candasnos Water Users Association (WUA). The WUA makes part of the *Riegos del Alto Aragón* Project (Lecina et al., 2010). This irrigated area is located in North-eastern Spain, and can irrigate 6,937 ha. Irrigation systems have only been installed in 4,916 ha. The area presents a semi-arid climate, with very hot summers and long, cold winters. The local meteorological characterization in the years of study (2004-2008) was based on the data obtained at the agrometeorological station of Candasnos, belonging to the SIAR network (Ministerio de Medio Ambiente y Medio Rural y Marino, 2011). A summary of the agrometeorological characterization is presented in Table 1. Annual daily temperature (T) fluctuated between -3.9 and 27.7 ºC, with an average of 13.8 ºC. Annual average reference evapotranspiration (ET_0) and precipitation (P) in this period were 1,232 mm and 324 mm, respectively. The average wind speed (WS) was 2.3 m s^{-1}, a value that often separates adequate and low solid-set sprinkler irrigation performance (Playán and Mateos, 2006).

Among the study years, 2005 was characterized by severe drought induced by low storage at the main *Riegos del Alto Aragón* reservoirs. As a consequence, farmers' irrigation water use was limited to 4,500 m^3 ha^{-1}. In fact, 2005 showed the lowest storage at the beginning of the irrigation season, 51% of full capacity. This value should be compared with the average of the study years (77%), and maximum storage in the series (96% in 2007). Regarding storage in August, 2005 was characterized by 29%, while the average for the study years was 49%.

Differences in water application along the study years could also be observed for major crops. In corn, the average crop water requirements (CWR) during the study period was 519 mm, while the average water use was 665 mm. In the case of alfalfa, CWR and water use averaged 635 and 744 mm, respectively. In 2005, water use in both corn and alfalfa were lower than CWR, with average differences of 8 mm for corn and 215 mm for alfalfa. Farmers made an effort to avoid water stress in corn, since this crop is more sensitive to water stress than alfalfa.

WUA irrigation water is stored at a local reservoir located at the head of the pressurized collective network. The difference in elevation between the reservoir and the WUA hydrants provides the network with natural pressure. Furthermore, the reservoir is gravity fed by the Monegros supply channel. As a consequence, the WUA faces irrelevant energy costs. Flow limiting valves were installed in all WUA hydrants, with discharge limits ranging from 8 to 80 L s^{-1}. The most common discharge limits are 8, 10 and 12 L s^{-1}. These discharges derive from a hydrant design criterion of 1.2 - 1.3 L s^{-1} ha^{-1}. There are exceptions to this rule, represented by maximum values of 4.1 L s^{-1} ha^{-1} (additional discharge for small plots) and occasional minimum values of 0.5 L s^{-1} ha^{-1}.

A cable-based remote surveillance and control system (RSCS) was installed at the Candasnos WUA in 1998. The system was set to record hydrant discharge every ten minutes (approximately). The RSCS software and computers were upgraded just before this research was performed. This fact made the exploration of the four old hard drives easy: they could be taken to the laboratory for complete analysis. This RSCS contains the oldest data of this nature in the Ebro basin, and therefore represents a very interesting opportunity for the analysis of irrigation patterns. Unfortunately, the RSCS system does not record irrigation management variables. This problem was solved in 2004, when Candasnos started making full use of the Ador software for the management of WUAs (Playán et al., 2007). As a consequence, the data series concerning plots, hydrants, irrigation systems, water users, water uses (crops) and time evolution of hydrant discharge is available from 2004 to 2008. This period corresponds to the time frame of this study.

The WUA showed an average of 276 landowners and 131 irrigators in the years of study. The difference between the number of landowners and irrigators derives from the need to cultivate large extensions of irrigated land (irrigators lease landowners' farms) in order to obtain adequate economic return. The average area was 17.43 ha for landowners and 36.85 ha for irrigators. Some of the irrigators do part-time farming in the area.

The irrigation system information was individually collated by observing WUA orthophotographs (Ministerio de Medio Ambiente y Medio Rural y Marino, 2011). The most common irrigation system in Candasnos is solid-set, present in 53 % of the WUA area, followed by pivot (40 %) and drip irrigation (7 %). In some plots, pivot(s) and solid-sets are found in combination. In these cases the central part of the plot is pivot irrigated, while the corners are irrigated by solid-sets. The spatial distribution of Irrigation systems was also available from the Ador database.

Crop distribution in the WUA changed each year of study (from 2004 to 2008). Summer field crops prevail in the study area: Averaging the study years, alfalfa and corn occupy 20 % and 40 % of the WUA area, respectively. Other relevant crops in the area are the sequence barley/corn and drip irrigated peach, with respective percentage areas of 15 and 7 %.

Water management in the study area is based on previous water orders. The WUA is located at the downstream end of a 223 km canal system (Lecina et al., 2010). As a consequence, water used in Candasnos needs to be ordered to the Project office two days in advance. This time is an approximation of the travel time from the main project reservoirs to the local WUA reservoir. Farmers file individual water orders at the WUA office. Confirmation of these orders by WUA officers ensures the supply of the agreed volume of water, except in the case of accidents in the supply network. Orders are stored in the Ador database. Every day, the water orders filed for the day after tomorrow are summarized and sent to the project office *via* Internet. Water orders permit to document water use in parallel of the RSCS system, providing a means for the validation of water use information. However, the need for previous water orders reduces farmers' freedom to use irrigation water: once water is ordered farmers must use it, since the capacity of the WUA reservoir (218,000 m^3) only represents 4.4 mm when distributed to the whole irrigated area.

2.2 Data mining: Extraction of knowledge

An exploratory data analysis was performed on the contents of the RSCS hard drives. The tabular information contained in the system only detailed daily water deliveries per hydrant. However, a graphic utility presented daily evolution of discharge per hydrant. As a consequence, a binary search was started in the RSCS system files in order to locate time-discharge records per hydrant. The original records were found in binary Flow Files (FF) and decrypted. Discharge registers were recorded with time intervals ranging between 11 and 18 min. Decryption did not permit to assess the hydrant code in the system used for tabular reports (corresponding to the project hydrant code).

The association between decrypted information and hydrant codes was obtained by comparison of the tabulated and computed daily water delivery per hydrant. The first step was to integrate the FF discharge values into daily delivery volume and standardized semi hourly values (FFst). A specific software application compared the water application patterns and performed the association. Manual supervision was used to provide additional certainty. A total of 256 hydrants were associated to FFst discharge files, creating HFFst files. Additionally, the annual water delivery derived from HFFst files was compared to annual water billed to the irrigators through the Ador software. In cases where differences between the two data sources exceeded 8 %, a case by case analysis was performed to detect anomalies, which were often located at the HFFst files (periods without RSCS data).

In a further step, a file was produced for each hydrant summarizing the yearly irrigation events. For each identified event, the date and time of irrigation start and end were recorded, as well as the percent daytime and nighttime irrigation, the average discharge and the irrigation volume. Daytime irrigation was assigned between 8.00 and 20:00 (local civil time). This file contained information about 75,546 irrigation events corresponding to 1,216 hydrant-year combinations.

2.3 Data mining. Selection of valid information

A relational database was created containing all data sources used for this research: HFFst, irrigation events, daily delivery volume per hydrant, agrometeorological data and a number of tables copied from the Ador database: crops, irrigation network, hydrants, irrigation system, landowners, irrigators and plot areas.

A series of queries to the relational database were used to obtain specialized information. In a first step, graphics of daily delivery volume were produced for the available combinations of crop, hydrant and year. Individual visual inspection of these graphs was used to discard cases of hydrant-year combinations revealing failed crops or clear errors in crop declaration by farmers. In a second step, a table was created containing hydrant name, cadastral identification, plot area and irrigation system. Since two sources of information were available for plot irrigation systems, plots showing discrepancies were discarded from the database. Finally, hydrants shared among various plots were eliminated because it was not possible to distinguish from the RSCS the plot receiving a given irrigation event. As a consequence of this process, a final database was established containing 39,909 irrigation events resulting from 585 hydrant-year combinations.

2.4 Statistical analyses

The file containing irrigation events was used to elaborate basic statistics about frequencies and general trends of the irrigators' behaviour. The number of hydrants simultaneously irrigating in each semi-hourly period was used for comparison with agrometeorological data. This permitted to analyse the influence of meteorology on sprinkler irrigation decision making. The meteorological factors used in this study included wind velocity, daily precipitation, temperature and relative humidity.

The irrigation events file was used for more involved analyses. In a first step, a hierarchical cluster analysis was used on the three variables: weekly number of irrigation events, standard deviation of weekly irrigation events and statistical mode of the starting hour of the irrigation events. This classification was performed to identify homogeneous groups of irrigation decision making in the WUA. Three additional variables were discarded from the analysis at an early stage: the weekly average irrigation duration, the standard deviation of weekly average irrigation duration, and the percentage of irrigations in which irrigation started during the modal range.

Differences among these homogeneous groups were analysed using ANOVA and Duncan tests. In a second step, the influence of the year, crop, irrigator, plot area, hydrant characteristics and irrigation system on irrigation decision making was assessed analysing frequencies and using categorical regression. These analyses were performed using the SPSS v.19 statistical software (Statistical Package for the Social Sciences, version 19 for Windows, SPSS Inc, Chicago, USA). Finally, semi hourly hydrant discharge data were transformed into binary semi hourly files with the objective of plotting the identified irrigation patterns.

3. RESULTS AND DISCUSSION

3.1 Exploratory statistics: irrigators, plot size and operation time

The data selection process focused on selecting combinations of year-hydrant presenting high data quality. As a consequence, both the number of hydrants and the area under study differed from year to year. The study areas were 2,736, 2,083, 1,919, 2,788 and 861 ha for 2004, 2005, 2006, 2007 and 2008, respectively (Table 2). The irrigation systems installed in the analysed plots included solid-set, drip, pivot and combinations of pivot and solid-set. Considering the area irrigated in each of the study years, the average of area occupied by solid-set was 54 %. Combinations of pivot and solid-set occupied an average 34 % of the area. Pivot irrigation occupied an average 4 % of the area, and the remaining 8 % was occupied by drip irrigation.

Summer field crops were very important in the WUA. Corn and alfalfa occupied an average of 46 and 24 % of the studied area, respectively. A certain association could be observed between crops and irrigation systems. This was particularly true in corn, alfalfa and peach trees. Solid-set was installed in 61 % of the corn plots, while 54 % of the area cropped to alfalfa was irrigated by pivots or combinations of pivots and solid-sets. All the area cultivated to peach trees used drip irrigation.

The number of irrigators analysed in each study year averaged 71, ranging from 44 in 2008 to 88 in 2004. The average irrigated area (all study years) was 28.1 ha per irrigator, with a maximum of 32.8 ha per irrigator in 2007 and a minimum of 19.6 ha per irrigator in 2008. The average duration of the irrigation events was 23 hours. This is the time the hydrant is open in each irrigation event. This time is typically very different from the actual irrigation application time in the field, due to the division of the field area into sequentially-irrigated sets or to the passage time of the pivot. Relevant differences were found in the average irrigation time between irrigation systems: 50 hours for pivots, 36 hours for pivot + solid-set, 23 hours for solid-sets and 11 hours for drip systems.

The starting time of the irrigation events presented two periods of high frequency, located around 8 and 20 hours (Fig. 1). 24 % of the irrigation events started between 07:00 and 09:00, while 30 % started between 19:00 and 21:00. The least frequent times for irrigation start were in the ranges between 13:00 and 15:00 and between 02:00 and 05:00. These periods represent central hours of the day and night, respectively.

Irrigation hours were grouped in three-hour blocks and separated by months (Table 3). In this Table, the two peaks presented in Fig. 1 can be identified. Further, the effect of the season can be observed: during the irrigation season (May to September), the most frequent range of irrigation start time was 18:00 to 21:00. Irrigators are thus aware of the advantages of night-time irrigation. The second frequent range of irrigation start during the irrigation season was 6:00 to 9:00. During the off-season months, the most common starting irrigation time range was 09:00 to 12:00, although a different pattern could be observed in April and November.

35,152 out of the 39,909 analysed irrigation events were applied during the irrigation season. This represents 88 % of the total, and a monthly average of 7,030 irrigations. In the rest of months, irrigation was much less frequent, with an average of 680 irrigations per month, and a total of 4,757 irrigations.

Regarding the percentage of irrigation hours in daytime and nighttime, all months within the irrigation season exceeded 50 % of nighttime irrigation. The month with the highest percentage of nighttime irrigation hours was July, with 58.3 %. During the months falling outside the irrigation season, the percentage of daytime irrigation hours was about 70 %.

Figure 2 presents the number of hydrants simultaneously irrigating during each semi hourly value and for each year of study. Since differences among study years in the number of considered hydrants were high, data were standardized dividing by the yearly average of hydrants simultaneously irrigating. A clear decrease in hydrant operation could be observed at the central hours of the day, reaching minimum values between 16:00 and 17:00. Hydrant operation increased along the evening, typically reaching a peak in the early night hours (21:00 - 2:00). These results differ from previous findings by Khadra and Lamaddalena (2010) in southern Italy, where peak irrigation flows were recorded at the central hours of the day (from 9:00 to 17:00). In that study, crops included olive trees and vegetable crops, generally under drip irrigation. Differences in the irrigation system explain the opposite daily water use patterns in both areas, since drip irrigation performance is largely independent of meteorology.

Irrigation water was limited in 2005 due to water shortage at the main system reservoirs. Irrigators were more careful about water application, giving preference to the nighttime hours (Fig. 2). Irrigator behavior in this year resulted in the largest differences between the number of hydrants irrigating in daytime hours and nighttime hours. This pattern cannot be explained by differences in evapotranspiration and precipitation at the WUA during the irrigation season. In fact, 2005 was an intermediate meteorological year in comparison with the rest of analysed irrigation seasons. In 2006, a similar situation was announced at the beginning of the season, although water restrictions were finally not applied. Irrigators' behaviour during these years proved that sufficient information about best irrigation management practices was known by the irrigators. However, this information was only put into practice during critical moments. Drought years also illustrate the complexity of water use in the WUA, where a large number of factors determine water application patterns.

Figure 3 presents scatter plots between the plot area and the average yearly hydrant irrigation hours. Data are presented for different irrigation systems. In the case of solid-sets, a weak but significant relationship (R^2=0.15) was found. For a given plot size, the variability in irrigation hours is influenced by the variability in crops, hydrant discharge and on-farm design. However, this variability basically reveals differences in individual irrigation management practices. It is interesting to note that the variability is severely reduced with increasing plot size. In the case of pivot and pivot + solid-set, a better relationship was found. This seems to be due to the fact that irrigation management in pivots is easier than in solid-sets. Similarities could be appreciated between both irrigation systems: the regression intercept is about 1,300 hours and the slope is 19 in solid-set and 13 in pivot(s) + solid-set. Finally, a significant relationship between plot area and irrigation hours could not be established for drip irrigation. Dechmi et al. (2003), in a study about a WUA in northeast of Spain, reported a significant and negative relationship between the plot area and the applied irrigation water depth. The differences between that study and the present results can be attributed to different water costs and agricultural systems.

3.2 Meteorology and irrigation

In order to assess the influence of meteorology on irrigation scheduling, semi-hourly and daily values were analysed in conjunction with the number of simultaneously operating hydrants at a given time. As an example, Figure 4 presents daily precipitation and daily number of hydrants in operation during 2005 and 2006. A decrease in hydrant operation was detected in both years following medium to large precipitation events (exceeding about 10 mm). Despite the oscillations in hydrant operation introduced by a number of additional factors, the effect of precipitation on irrigation scheduling is clear, although moderate: precipitation only occasionally reduced irrigation operation to less than half.

The effect of wind speed, temperature and relative humidity on sprinkler irrigation scheduling was analysed using semi-hourly values and only for hydrants with solid-set or pivot + solid-set. Non-parametric correlations were used, determining Spearman's Rho (r_S). Regarding wind speed, monthly correlation analyses were performed from May to September (25 analyses in total). 84 % of these analyses were significant ($P<0.01$) and showed a negative correlation coefficient. The average value of significant coefficients was -0.285, ranging between -0.113 and -0.552. When similar analyses were performed for temperature and relative humidity, results were more variable. Significant, negative correlations were found in 60 % of the analysed months for air temperature (average r_s of -0.469). Regarding relative humidity, 84 % of r_s coefficients were significant and positive (average of 0.418). The influence of wind speed, relative humidity and air temperature on sprinkler irrigation has been analysed in a number of research works. In the local conditions, Playán et al. (2005) reported a clear relationship between these variables and wind drift and evaporation water losses. Ortiz et al. (2009) experimenting in a different area of semiarid Spain, reported similar results, emphasizing the influence of wind speed. Finally, Tarjuelo et al. (1999) reported on the influence of wind speed on sprinkler irrigation uniformity.

Similar correlations were performed in drip irrigation. Opposite results were found, with the correlation between operating hydrants and temperature being significant ($P<0.01$) and positive in 100 % of the combinations of years and months of the irrigation season. Negative and significant correlations were also detected in 100 % of analyses performed for relative humidity. Finally, 92 % of the correlations with wind speed were significant and positive. These results indicate that drip irrigators effectively searched for "windows of opportunity", in which the irrigation network was not saturated. These periods corresponded to the hours of the day showing worst agrometeorological conditions for sprinkler irrigation.

A certain trend could be observed in the global data set to schedule irrigation during times when meteorology is adequate for sprinkler irrigation performance. However, in detailed hydrant analyses, this trend could not be identified. The lack of immediate reaction to meteorology is determined by the fact that farmers order their irrigation water two days in advance, and can not cancel their water orders following a sudden change in meteorology.

3.3 Classification of irrigation patterns

Cluster hierarchical analyses resulted in a total of ten groups of irrigation patterns (labelled A to I). Each of them contained a different number of elements (hydrant-years). Groups were differentiated when separated by more than 6 re-scaled units. Identified groups belong to two hierarchical families. The first one includes groups A to D, while the second includes groups E to I. The distance between both families is 25 re-scaled units. Distances within groups in a given family are variable, ranging between the 5 units separating groups E and F, and the 18 points separating group I from the rest of the second family. Figure 5 presents a scheme of the characteristics of each group in terms of irrigation starting time and number of weekly irrigations. Table 4 presents the number of hydrant-year combinations in each cluster group.

In the first family, groups A and D shared a range of morning starting irrigation time (6:00 - 12:00), the difference between these groups being the average number of irrigations per week (1.9 and 5.2 irrigations/week for groups A and D, respectively). Standard deviation is also higher in group D than in group A. Similar differences were found between groups B and C, starting irrigation events in the 0:00 – 3:00 range and with averages of 2.3 and 5.2 irrigations/week, for groups B and C, respectively.

In the second family, group E shows the lowest number of weekly irrigations (on average, 1.4 irrigations/week, SD = 0.6 irrigations/week). This is the only group starting in the afternoon-evening (15:00 - 18:00). Groups F, H and I start irrigating a bit later (18:00 - 21:00), but show relevant differences in irrigation frequency. Group F is characterized by 2.6 irrigations/week, while groups H and I reach 4.6 and 7.6 irrigations/week, respectively. Regarding the standard deviations, the resulting values were 1.6, 2.2 and 3.2 irrigations/week for groups F, H and I, respectively. Finally, group G is similar to H in terms of number of weekly irrigations, but shows a larger variability (SD = 3.0 irrigations/week), and starts irrigating from 18:00 to 0.00.

Categorical regression was performed to assess the influence of additional variables in the definition of irrigation pattern groups. Significant variables included the irrigator, with an importance of 56.4 %, the irrigation system (32.9 %), and the crop (10.7 %). The adjusted regression coefficient was 0.736. The irrigation year, the plot size and the maximum hydrant discharge per unit plot area were not statistically significant. Cluster hierarchical analyses have been applied before to agricultural irrigation studies (Karami, 2006). However, this author used the technique for a different purpose: identifying the adequacy of a given irrigation system.

Table 4 shows the distribution of cluster groups by crop and by irrigation system. Clear associations could be observed between irrigation systems and cluster groups. This is particularly true for pivot(s)+solid-set with group A (54 % of records) and for drip with group D (89 % of records). Groups H and A are common in solid-sets, with a 42 and 23 % of records, respectively. Group F is quite uniformly distributed across most irrigation systems. Some of these associations stem from the characteristics of the irrigation systems. For instance, long irrigation events are required in pivot irrigation. Some associations could also be observed between crops and groups. Group A (long, low-frequency irrigations) represented 56 and 41 % of records in alfalfa and barley, respectively. Group H (frequent irrigations starting at sunset) led the classification in corn, barley/corn and snap/bean. Finally, cluster D (frequent irrigations starting during the morning) capitalized peach trees. Again, group F was populated by different crops.

3.4 Irrigation patterns, irrigators, irrigation systems and crops

Six examples of irrigation patterns are presented in Figure 6 to illustrate the variability in irrigators' behavior. Subfigures a) and b) present the same hydrant (and irrigator) in different crops and years. Despite the fact that the crops (alfalfa and corn) differ in cropping techniques and irrigation management, group A was assigned to both cases. The main difference between them was the duration of the irrigation events, which in corn were uninterrupted along the peak of the irrigation season. In alfalfa, irrigation was interrupted during hay harvest operations. Subfigures c) and d) present similar traits as subfigures a) and b) (same irrigator, same irrigation system, different crops). However, the irrigation patterns were different: B for subfigure c) and H for subfigure d). The irrigator applied different irrigation scheduling patterns to both crops, giving long irrigations to alfalfa and short, frequent irrigations to corn. These differences cannot be explained by differences in crop water requirements, and derive from the individual preferences of the irrigator. Finally, the last pair of subfigures (e and f) corresponds to two different irrigators. The crop (peach trees) and the irrigation system (drip) are the same in both graphs. Irrigation scheduling patterns were classified in groups D and I for graphs e) and f), respectively. Two management strategies are presented for fruit trees, both with frequent irrigations starting during the daytime. Lamacq (1997) presented a similar effort of graphing irrigation scheduling. Her purpose was to validate a simulation model for irrigation scheduling, not to classify irrigation behavioral patterns.

Combinations of the same significant variables (irrigator, irrigation system and crop) were selected to study the distribution of irrigation scheduling pattern groups. A total of 132 combinations of these three variables were identified. Each combination included between 2 and 12 elements. 40 % of the combinations showed the same irrigation pattern group in all elements;

18 % of the combinations showed different groups in the elements, but the groups belonged to the same cluster family. Finally, 42 % of the combinations included elements belonging to different groups and families.

An analysis was run on the inter-year variability of irrigator's behavior for all the plots with the same irrigation system. Figure 7 – illustrating this analysis – is again divided in six subfigures. Subfigure a) typifies the irrigator who gets all hydrants classified in the same group. This is the case of 34 % of irrigators, although only half of them (17 %) irrigated more than one hydrant-year. Most drip irrigation farmers showed this behavior, since group D is clearly prevalent in this irrigation system. Subfigure (b) typifies an irrigator that generally followed a given irrigation pattern, but showed an atypical pattern in a given year. No trend in the irrigation schedule pattern can be appreciated in this case. This trait could only be observed in 5 % of the analyzed irrigators. Subfigures c), d) and e) show a certain time trend. Subfigures c) and d) belong to the same irrigator, but differ in the irrigation system. A certain pattern is observed in the first years of the study, with evolution along the years. In fact, in 2008 (subfigure c) or 2007 and 2008 (subfigures d and e), the group(s) stabilized. 22 % of the analyzed irrigators presented a certain evolution in their irrigation patterns along the irrigation system. Finally, subfigure f) presents the most common type of irrigators' behavior, with 39 % of the analyzed population. Changes in the group of irrigation pattern are common and do not follow appreciable trends.

In the last group analysis, the goal was to assess the irrigation pattern groups applied by each farmer to his crops. All hydrant-years for each farmer were analyzed per group and crop (Figure 8). Subfigure a) uses different groups for the same crop (four, in this case) along the study years. 20 % of the irrigators followed this behavior. Subfigure b) presents a case typifying an opposite behavior: The irrigation pattern used by a certain irrigator is classified in the same group in all occurrences of the same crop. This behavior could be observed in 21 % of the irrigators, but only 4 % of the irrigators in this group had more than one occurrence of the same crop. Subfigure c) typifies crop specialization, with each crop being classified in the same group. Only 14 % of the analyzed irrigators belonged to this category. Subfigure d) shows an opposite behavior to c): all crops are classified in the same group. 8 % of the farmers showed this low-profile irrigation pattern. The remaining 37 % of irrigators were typified in the last category, illustrated by subfigures e) and f). In this case, at least 50 % of the hydrant-year-crops are classified in the same group, while the rest populates other irrigation pattern groups. The prevalence of groups D, E and

F (45 % in total) underline the relevance of the irrigator in the irrigation pattern, as announced by the categorical regression analysis.

The results above can be connected to the findings of Zapata et al. (2009). These authors analysed sprinkler irrigation scheduling in a WUA located next to *Candasnos* and showing similar traits. Those authors focused on irrigation adequacy, and concluded that the farmers' irrigation scheduling practices limited the yield of field crops. They proposed a collective irrigation controller as a means to better adapt irrigation water application to crop water requirements and to the changing environment. The results of this research point at the same direction. In fact, a wide array of different irrigation scheduling patterns has been identified. Farmers use these patterns in a non-specialized way, and show inconsistencies in their application in time and different crops and irrigation systems. Since the RSCS has long been installed in the analysed WUA, the opportunity arises to use it to distribute centrally elaborated irrigation schedules focusing on water conservation and on farmers' economic return. The research reported in this paper has not addressed any of these issues, but has revealed widespread lack of consistency and specialization in the irrigation scheduling patterns.

4. CONCLUSIONS

The fact that WUA water orders need to be filed two days in advance of water use makes it difficult to analyze the effect of meteorology on irrigation management. However, the total number of open hydrants was influenced by precipitation and (in sprinkler irrigation) by wind speed (r_s = 0.285), relative humidity (r_s = 0.418) and air temperature (r_s = -0.469). Drip irrigation hydrants took advantage of the periods with worst agrometeorological conditions for sprinkler irrigation. Both irrigation systems showed complementarity in irrigation scheduling. The starting irrigation time presented two periods of high frequency, located around 8:00 and 20:00 hours. The least frequent times for irrigation start were between 02:00 and 05:00 and between 13:00 and 15:00, representing central hours of the day and night periods. Irrigation scheduling patterns could be classified in ten groups according to the average number of weekly irrigations, the SD of the number of weekly irrigations and the modal range of the irrigation starting time. The variables explaining these classifications were the irrigator (56.4 %), the irrigation system (32.9 %), and the crop (10.7 %). The human factor, as an integrator of knowledge and experience, stands as the key variable to explain how irrigation events are programmed in an area. In 22 % of the irrigator–irrigation system combinations, changes in irrigation scheduling patterns seemed to respond to a time trend, a structured change in the abovementioned classification variables. However, in 39 % of the cases, changes in time were relevant but appeared to follow a random distribution. Regarding the irrigators' behavior in different crops, 45 % of the irrigators used the same irrigation pattern in at least half of their hydrant-years, independently of the crop. Only 14 % of the irrigators showed specialization, applying different irrigation scheduling patterns to different crops. Irrigation decision making in this WUA seems to be limited by shortages in water storage. However, our results suggest that irrigators do not find value or do not have the capacity to develop irrigation patterns more consistent and adapted to the local environment, the crops and the irrigation systems. The complexity in the irrigator behaviour makes it necessary to compile additional data about the response of water users to factors (economic, social and environmental) determining irrigation water use and irrigation performance. These data will contribute to the future development of advanced irrigation controllers and, therefore, to the optimization of water use in on-demand pressurized irrigation networks. Future research should also assess the trade-off between irrigators' behaviour and water productivity. Detail information on water productivity could either explain the observed behavioural traits or justify the need for the adoption of more specialized behavioural rules.

5. ACKNOLEDGEMENT

This research was funded by grants 2006 CSD2006-00067 and AGL2010-21681-C03-01. Thanks are due to the board and technicians of the Candasnos WUA of the *Riegos del Alto Aragón* irrigation project.

6. REFERENCES

Brown, P. D., Cochrane, T. A. and Krom, T. D., 2010. Optimal on-farm irrigation scheduling with a seasonal water limit using simulated annealing. Agricultural Water Management, 97, 892-900.

Cancela, J. J., Cuesta, T. S., Neira, X. X. and Pereira, L. S., 2006. Modelling for Improved Irrigation Water Management in a Temperate Region of Northern Spain. Biosystems Engineering, 94(1), 151-163.

Chopart, J. L., Mezino, M., Aure, F., Le Mézo, L., Mété, M. and Vauclin, M., 2007. OSIRI: A simple decision-making tool for monitoring irrigation of small farms in heterogeneous environments. Agricultural Water Management, 87, 128-138.

Clemmens, A. J., 1987. Arranged delivery schedules, in: Planning, operation, rehabilitation and automation of irrigation water delivery systems. D. D. Zimbelman (Ed.), Proceedings of a Symposium, July 28-30, 1987, Portland, OR, USA. Irrigation and Drainage Division, American Society of Civil Engineers. pp. 57-80.

Clemmens, A. J. and Dedrick, R., 1992. Identifying factors that influence farm water use. Technical papers, volume II. Conferencia regional panamericana. Mazatlán, Sinaloa, México.

Cortignani, R. and Severini, S., 2009. Modeling farm-level adoption of deficit irrigation using Positive Mathematical Programming. Agricultural Water Management, 96, 1785-1791.

Dechmi, F., Playán, E., Faci, J.M., Tejero, M. and Bercero, A., 2003. Analysis of an irrigation district in northeastern Spain II. Irrigation evaluation, simulation and scheduling. Agricultural Water Management, 61, 93-109.

Department of Water Resources. Office of water use efficiency., 2011. California irrigation management information system. Retrieved from http://wwwcimis.water.ca.gov/cimis/welcome.jsp.

Faysse, N., 2003. Allocating irrigation water : the impact of strategic interactions on the efficiency of rules. European Review of Agricultural Economics, 30(3), 305-332.

Government of Aragón., 2011. Necesidades hídricas de los cultivos (Irrigation requirements of crops). Retrieved from http://servicios.aragon.es/oresa/necesidadHidrica.inicioPublico.do?sm=5. [in Spanish].

Han, J. and Kamber, M., 2006. Data Mining: Concepts and Techniques. (Elsevier, Eds.). Morgan Kaufmann Publishers.

Karami, E., 2006. Appropriateness of farmers' adoption of irrigation methods: The application of the AHP model. Agricultural Systems, 87, 101-119.

Khadra, R. and Lamaddalena, N., 2010. Development of a Decision Support System for Irrigation Systems Analysis. Water Resources Management, 24, 3279-3297.

Lamacq, S., 1997. Coordination entre l'offre et la demande en eau sur un périmètre irrigué : des scénarios, des systèmes, et des hommes... Unpublished Doctorate Thesis, CEMAGREF-ENGREF, 134p.

Lamaddalena, N. and Sagardoy, J.A., 2000. Performance analysis of on-demand pressurized irrigation systems. FAO irrigation and drainage paper, 59. Land and Water Development Div., 148 p.

Lecina, S., Isidoro, D., Playán, E. and Aragüés, R., 2010. Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón. Agricultural Water Management, 97, 1663-1675.

Liyuan, X., Liping, C., Tianen, C. and Gao, Y., 2010. SOA-based precision irrigation decision support system. Mathematical and Computer Modelling. Mathematical and Computer Modelling, 54 (3-4), 944-949.

Merot, A., Bergez, J.E., Capillon, A. and Wery, J., 2008. Analysing farming practices to develop a numerical, operational model of farmers' decision-making processes: An irrigated hay cropping system in France. Agricultural Systems, 98, 108-118.

Ministerio de Medio Ambiente y Medio Rural y Marino, Gobierno de España, 2011. Estaciones Agroclimáticas. Red SIAR. (Agrometeorological stations. SIAR network) Retrieved from http://www.mapa.es/siar/Informacion.asp [in Spanish].

Ortíz, J. N., Tarjuelo, J. M. and De Juan, J. A., 2009. Characterisation of evaporation and drift losses with centre pivots. Agricultural Water Management, 96(11), 1541-1546.

Playan, E., Salvador, R., Faci, J.M., Zapata, N. and Martínez-Cob, A., 2005. Day and night wind drift and evaporation losses in sprinkler solid-sets and moving laterals. Agric. Water Manage., 76: 139-159.

Playán, E. and Mateos, L., 2006. Modernization and optimization of irrigation systems to increase water productivity. Agricultural Water Management, 80(1-3), 100-116.

Playán, E., Cavero, J., Mantero, I., Salvador, R., Lecina, S., Faci, J.M., Andrés, J., Salvador, V., Cardeña, G., Ramón, S., Lacueva, J.L., Tejero, M., Ferri, J. and Martínez-Cob, A., 2007. A Database Program for Enhancing Irrigation District Management in the Ebro Valley (Spain). Agricultural Water Management, 87 (2): 209-216.

Sanchez, I., Zapata, N. and Faci, J M., 2010. Combined effect of technical, meteorological and agronomical factors on solid-set sprinkler irrigation: I. Irrigation performance and soil water recharge in alfalfa and maize. Agricultural Water Management, 97(10), 1571-1581.

Styczen, M., Poulsen, R. N., Falk, a K. and Jørgensen, G. H., 2010. Management model for decision support when applying low quality water in irrigation. Agricultural Water Management, 98(3), 472-481.

Tarjuelo, J. M., Montero, J., Honrubia, F. T., Ortiz, J. J. and Ortega, J. F., 1999. Analysis of uniformity of sprinkle irrigation in a semi-arid area. Agricultural Water Management, 40(2-3), 315-331.

Zapata, N., Playán, E, Martinez-Cob, A., Sánchez, I., Faci, J.M. and Lecina, S., 2007. From on-farm solid-set sprinkler irrigation design to collective irrigation network design in windy areas. Agricultural Water Management, 87, 187-199.

Zapata, N., Playán, E., Skhiri, A. and Burguete, J. 2009. A collective solid-set sprinkler irrigation controller for optimum water productivity. J. Irrig. and Drain. Engrg., ASCE, 135 (1): 13-24.

Zapata, N., Nerilli, E., Martínez-Cob, A., Chalghaf, B., Fliman, D. and Playán, E., 201Xa. Water use in an orchard in a semiarid climate (Ebro basin, Spain): I. Sources of spatial variability. Agricultural Water Management. Submitted.

Zapata, N., Nerilli, E., Martínez-Cob, A., Chalghaf, I., Fliman, D. and Playán, E., 201Xb. Water use in an orchard in a semiarid climate (Ebro basin, Spain): II. Irrigation performance. Agricultural Water Management. Submitted.

LIST OF FIGURES

Figure 1. Histogram of starting irrigation time (hour) for all irrigation events in 2004-2008.

Figure 2. Standardized number of operating hydrants (divided by the average number of operating hydrants of each year) vs. time within the day (hour). Data are presented for 2004-2008.

Figure 3. Number of yearly irrigation hours *vs*. irrigated area for the hydrants irrigating three types of irrigation systems: solid-.set, pivot + solid-set and drip.

Figure 4. Yearly evolution of the number of hydrants operating in a given day and daily precipitation. Results are presented for 2005 and 2006.

Figure 5. Graphical representation of the attributes of the different irrigation scheduling groups: number of weekly irrigations and irrigation starting time.

Figure 6. Representation of six irrigation schedules involving different irrigation scheduling groups, crops and irrigation systems. The black line indicates hydrant in operation.

Figure 7. Irrigator adoption of different irrigation scheduling groups along the years of study. Subfigures correspond to combinations of irrigator and irrigation system. Different crops can be considered within each subplot.

Figure 8. Irrigator attitude towards the different irrigation scheduling groups. Subfigures present how a given irrigator distributes his crops among the different groups. All hydrants, irrigation systems and years are considered in this analysis.

YEAR	2004		2005		2006		2007		2008		Average
	Value	Month	Value	Month	Value	Month	Value	Month	Value	Month	Value
Average Daily T (ºC)	13.6	-	13.5	-	14.6	-	13.7	-	13.5	-	13.8
Maximum Daily T (ºC)	27.8	JUL	27.9	JUL	28.1	JUL	27.5	AUG	27.1	AUG	27.7
Minimum Daily T (ºC)	-0.6	JAN	-4.3	DEC	-2.9	DEC	-2.1	JAN	-9.6	DEC	-3.9
Average Daily WS (m s^{-1})	2.17	-	2.53	-	2.18	-	2.43	-	2.11	-	2.3
Maximum Daily WS (m s^{-1})	9.37	JAN	10.68	FEB	8.97	MAR	9.26	JAN	9.60	MAR	9.6
Maximum Daily P (mm)	29.6	APR	49.2	JUN	27	SEP	14.2	APR	41.8	MAY	32.4
Total P (mm)	359.4	-	335.6	-	262.2	-	194.4	-	470.6	-	324.4
Total ET_0 (mm)	1141	-	1319	-	1292	-	1261	-	1147	-	1232

Table 1. Agrometeorological characterization of the Candasnos Water Users Association in the years of study (2004-2008). Values of Temperature (T), Wind Speed (WS), Precipitation (P) and Reference Evapotranspiration (ET_0) are presented, along with the month of maximum and minimum values.

		Year				
Irrigation system	**Crop**	**2004**	**2005**	**2006**	**2007**	**2008**
Solid set	Alfalfa	368	287	242	211	68
	Barley/Wheat	10	43	200	132	40
	Barley/Corn	140	7	126	214	27
	Corn	819	698	406	744	297
	Snap/Beans	53	39	61	39	52
	Other	59	0	90	99	7
	TOTAL	**1449**	**1074**	**1124**	**1439**	**491**
Drip	Peach trees	176	99	98	221	110
	TOTAL	**176**	**99**	**98**	**221**	**110**
Pivot	Alfalfa	50	50	0	50	0
	Barley	0	0	0	0	65
	Corn	0	27	65	65	0
	TOTAL	**50**	**77**	**65**	**115**	**65**
Pivot(s) + Solid set	Alfalfa	345	342	332	202	53
	Barley	0	27	23	0	0
	Barley/Corn	92	40	83	164	0
	Corn	422	425	193	589	142
	Snap/Bean	179	0	0	58	0
	Other	23	0	0	0	0
	TOTAL	**1061**	**834**	**632**	**1013**	**195**

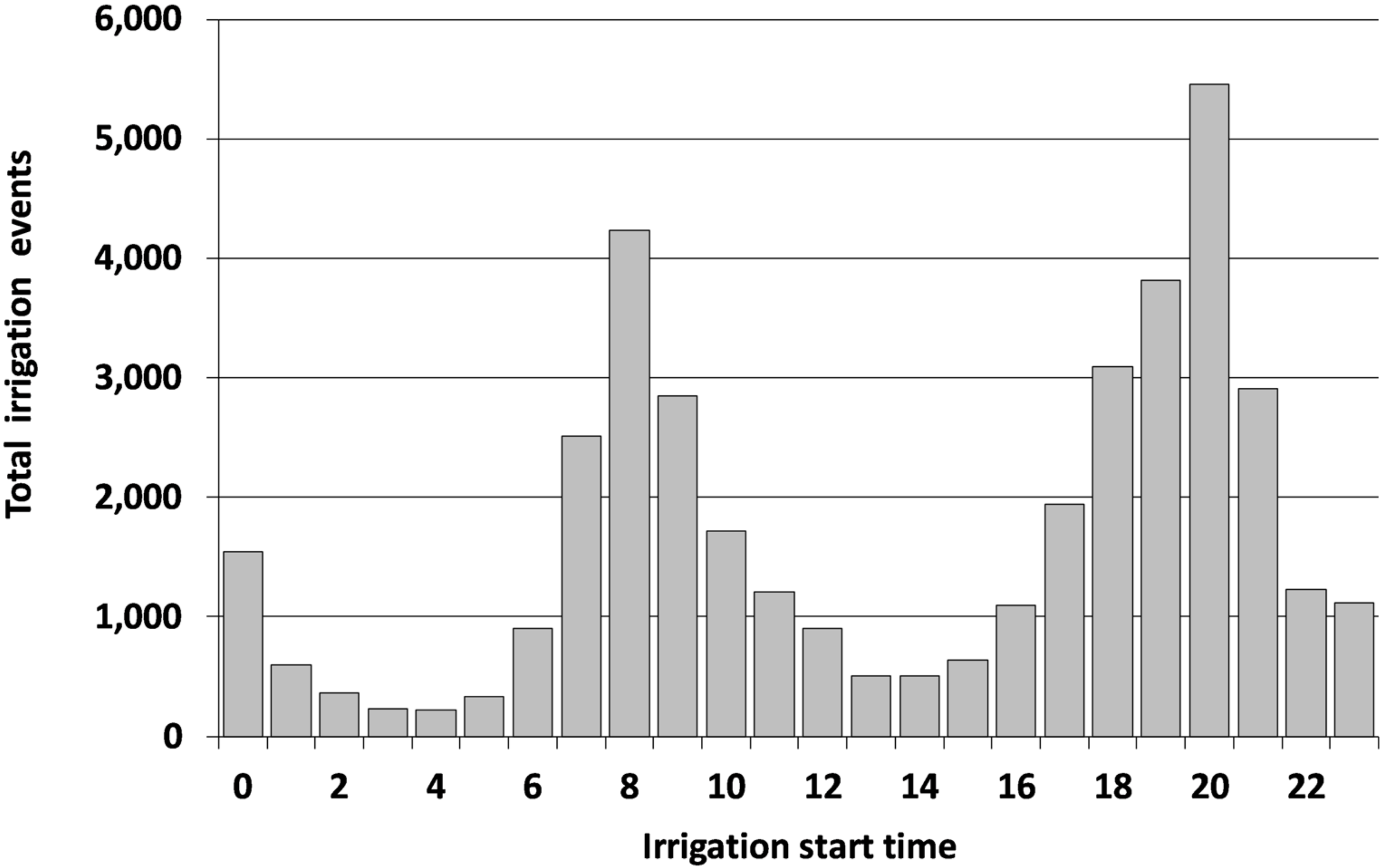
Table 2. Distribution of main crops and irrigation systems in the Candasnos Water Users Association during the study years. Two crops are often grown in rotation in one year.

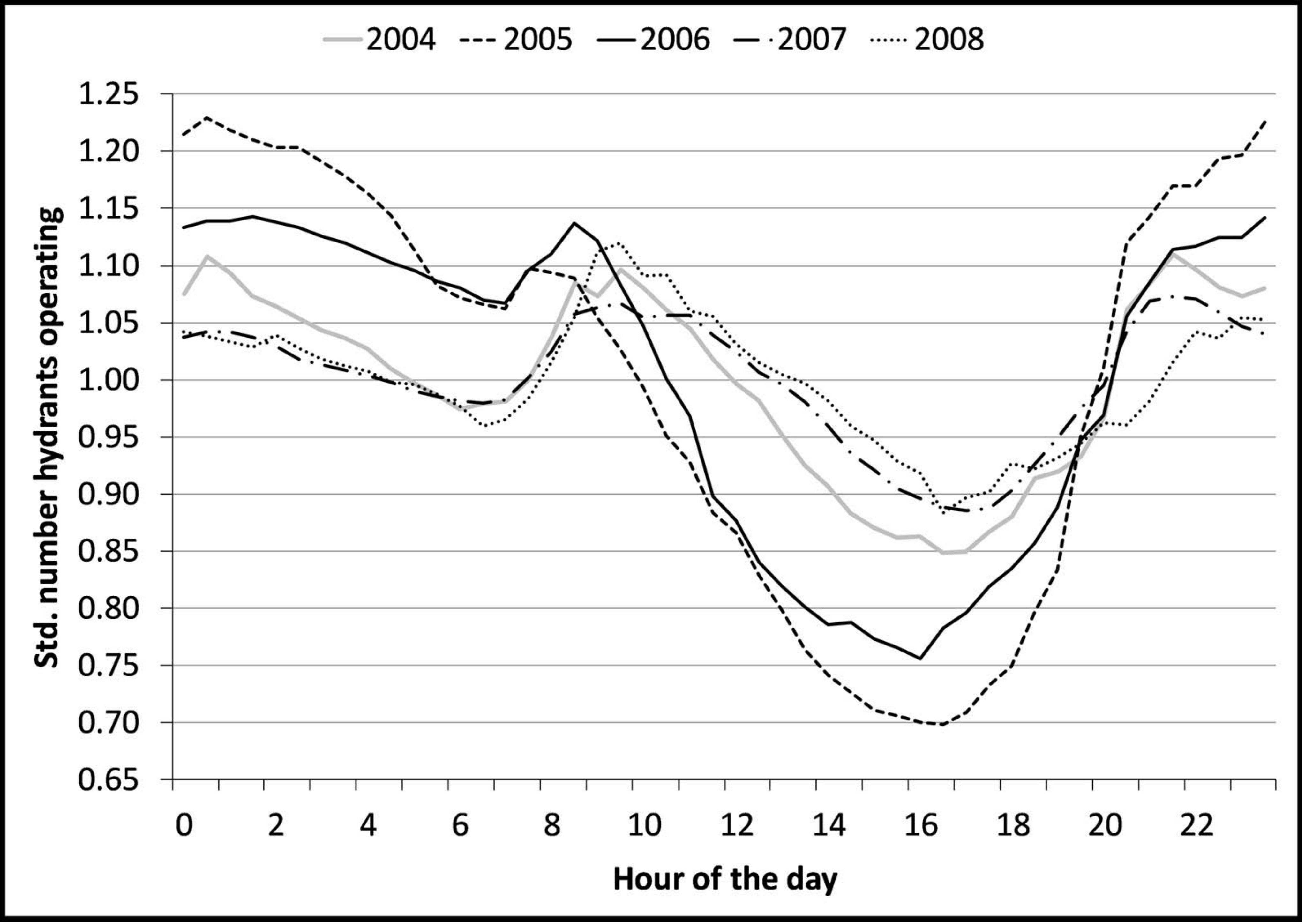
	Month											
Start time range	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0 - 3	0.7	1.0	2.9	7.3	6.6	8.2	6.8	5.2	4.5	4.4	0.0	7.7
3 - 6	1.5	2.5	1.8	1.7	1.3	2.2	2.6	1.6	1.8	2.2	0.0	0.0
6 - 9	9.0	15.8	20.9	**24.4**	21.0	19.9	16.5	17.6	20.9	19.2	0.0	10.8
9 - 12	**53.0**	**36.9**	**32.8**	23.6	13.3	12.3	10.8	11.6	17.2	**27.2**	0.0	**49.2**
12 - 15	11.2	20.7	13.2	5.8	4.9	4.0	4.0	4.5	3.6	6.4	**60.0**	18.5
15 - 18	14.2	16.7	16.2	11.6	10.0	8.5	9.2	8.3	7.3	7.1	20.0	9.2
18 - 21	6.0	5.4	10.2	17.2	**27.1**	**29.6**	**35.9**	**37.4**	**33.7**	26.3	20.0	4.6
21 - 0	4.5	1.0	2.0	8.4	16.0	15.2	14.2	13.7	10.9	7.3	0.0	0.0

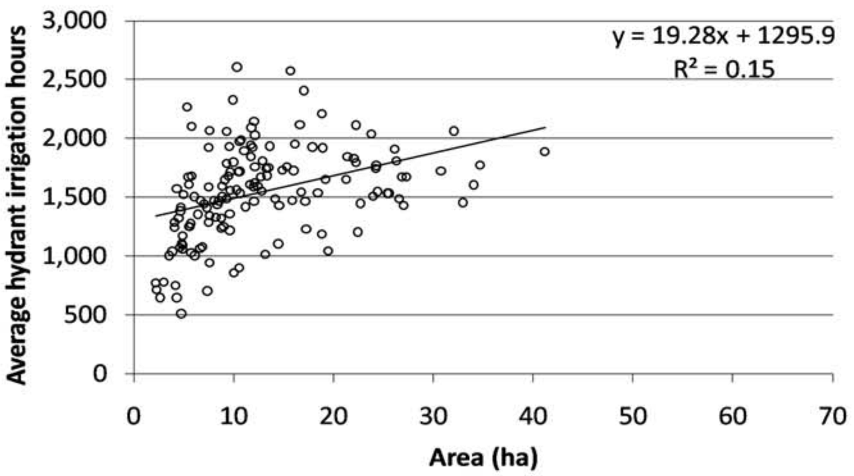
Table 3. Monthly percentage of irrigation events starting at different time ranges. The most frequent monthly time range is presented in bold type.

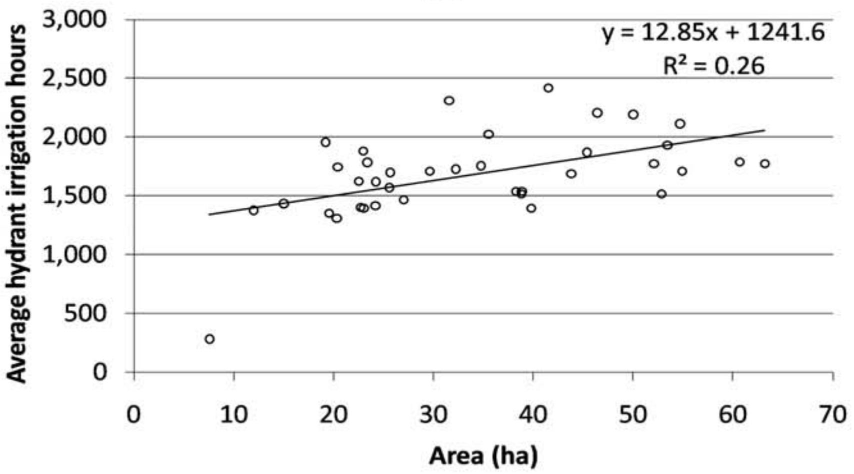
Nº Elements	163	36	10	57	9	95	7	194	5
GROUP	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
CROP									
Alfalfa	**56**	9	0	4	4	15	1	10	1
Barley	**41**	12	0	2	0	**27**	0	17	0
Barley/Corn	11	2	4	2	0	**24**	2	**54**	0
Corn	18	5	3	6	0	17	2	**48**	1
Peach tree	0	0	0	**89**	0	0	0	5	5
Snap/Bean	**22**	6	0	6	0	**28**	0	**39**	0
IRRIGATION SYSTEM									
Solid-set	**23**	7	2	4	2	17	1	**42**	1
Drip	0	0	0	**89**	0	0	0	5	5
Pívot	**83**	0	0	0	0	17	0	0	0
Pívot(s) + Solid-set	**50**	3	0	5	1	22	1	17	0

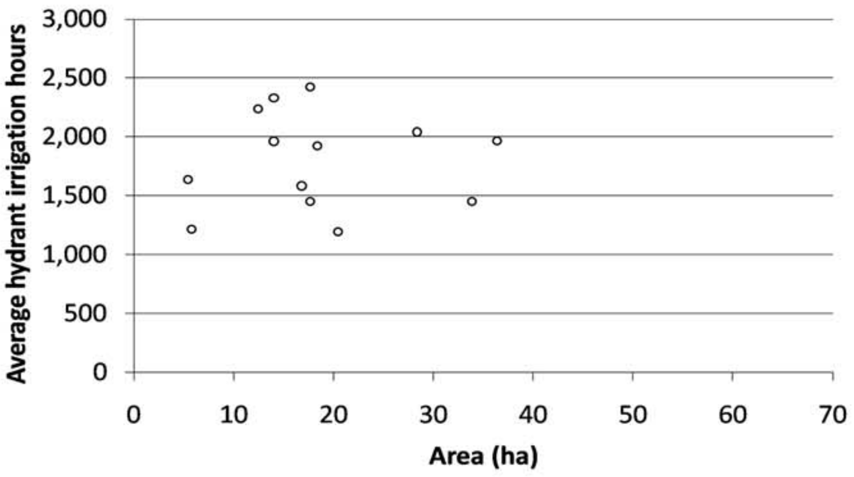
Table 4. Frequency of the different irrigation scheduling groups in the main crops and in the different irrigation systems. Frequencies over 20 % are presented in bold type.

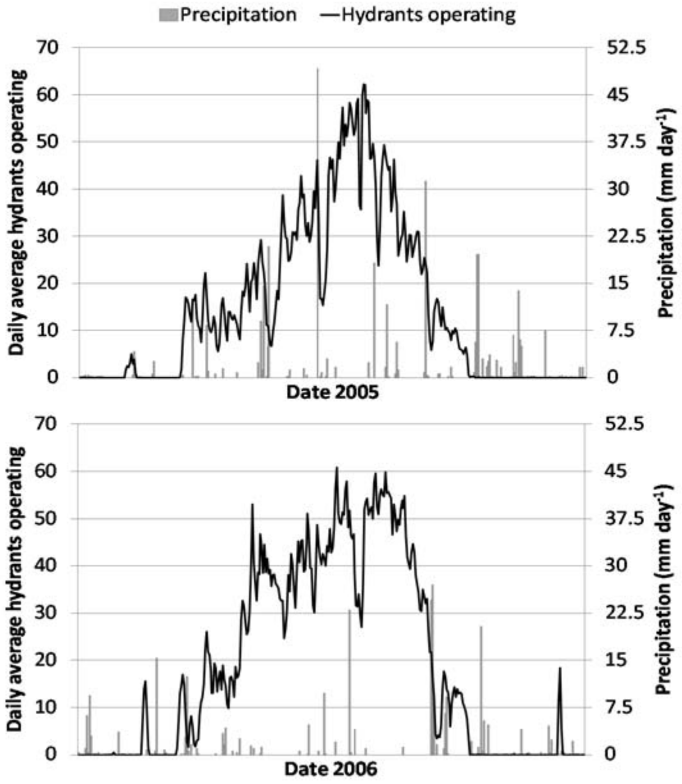

Total irrigation events
6,000
5,000
4,000
3,000
2,000
1,000
0
0
2
4
6
8
10
12
14
16
18
20
22
Irrigation start time

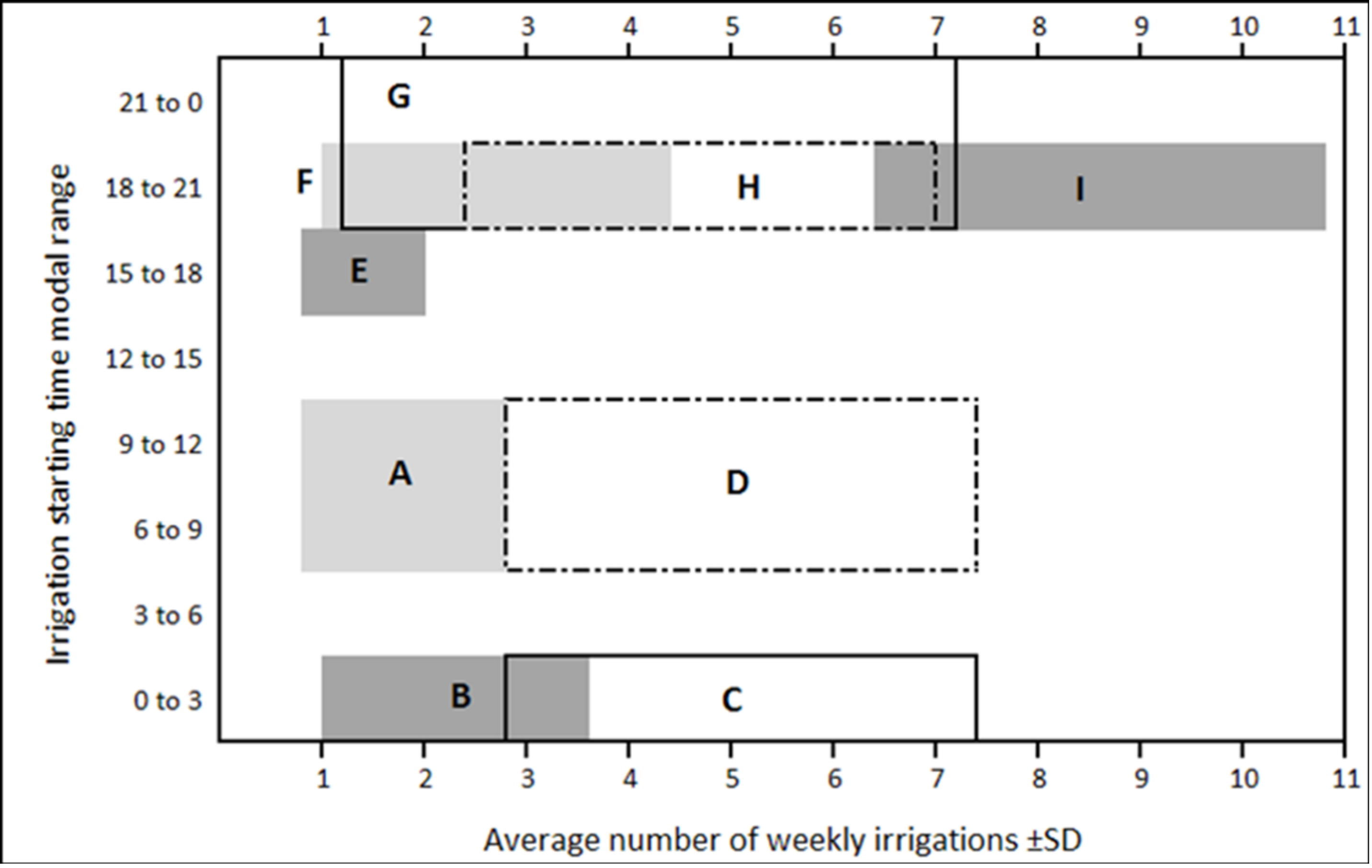

2004
2005
2006
2007
2008
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
Std. number hydrants operating
0
2
4
6
8
10
12
14
16
18
20
22
Hour of the day


Solid-set

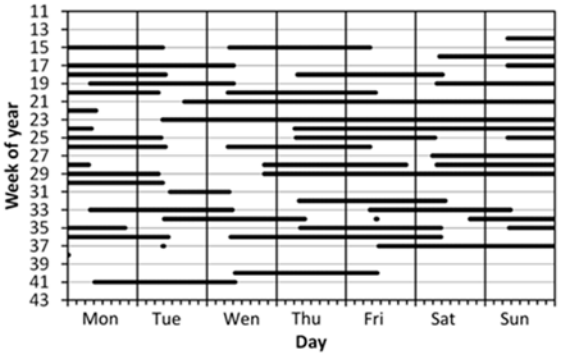

Pivot(s)+Solid-set


Drip

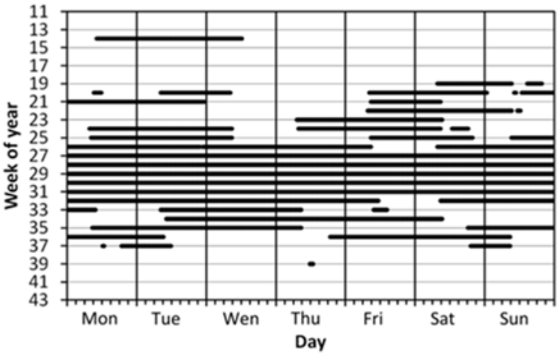

Precipitation
Hydrants operating
Daily average hydrants operating
0
10
20
30
40
50
60
70
Precipitation (mm day^{-1})
0
7.5
15
22.5
30
37.5
45
52.5
Date 2005
Daily average hydrants operating
0
10
20
30
40
50
60
70
Precipitation (mm day^{-1})
0
7.5
15
22.5
30
37.5
45
52.5
Date 2006


Irrigation starting time modal range
21 to 0
18 to 21
15 to 18
12 to 15
9 to 12
6 to 9
3 to 6
0 to 3
Average number of weekly irrigations ±SD
1
2
3
4
5
6
7
8
9
10
11
A
B
C
D
E
F
G
H
I

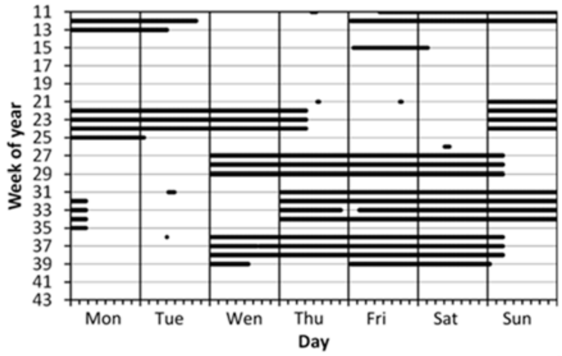
a) Group A - Alfalfa - Pivot+Solid-set



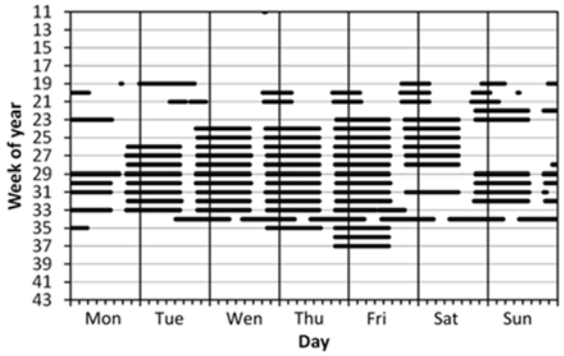
b) Group A - Corn - Pivot+Solid-set



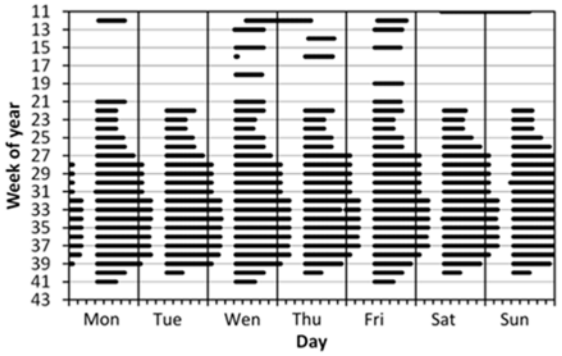
c) Group B - Alfalfa - Solid-set



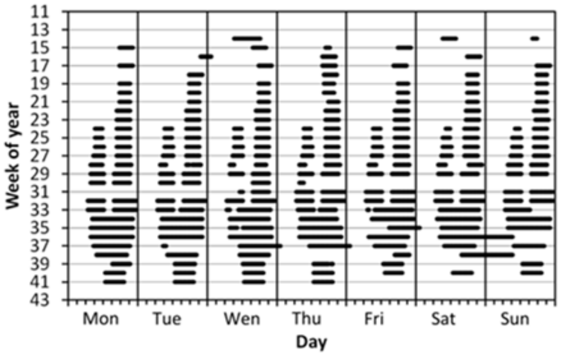
d) Group H - Corn - Solid-set

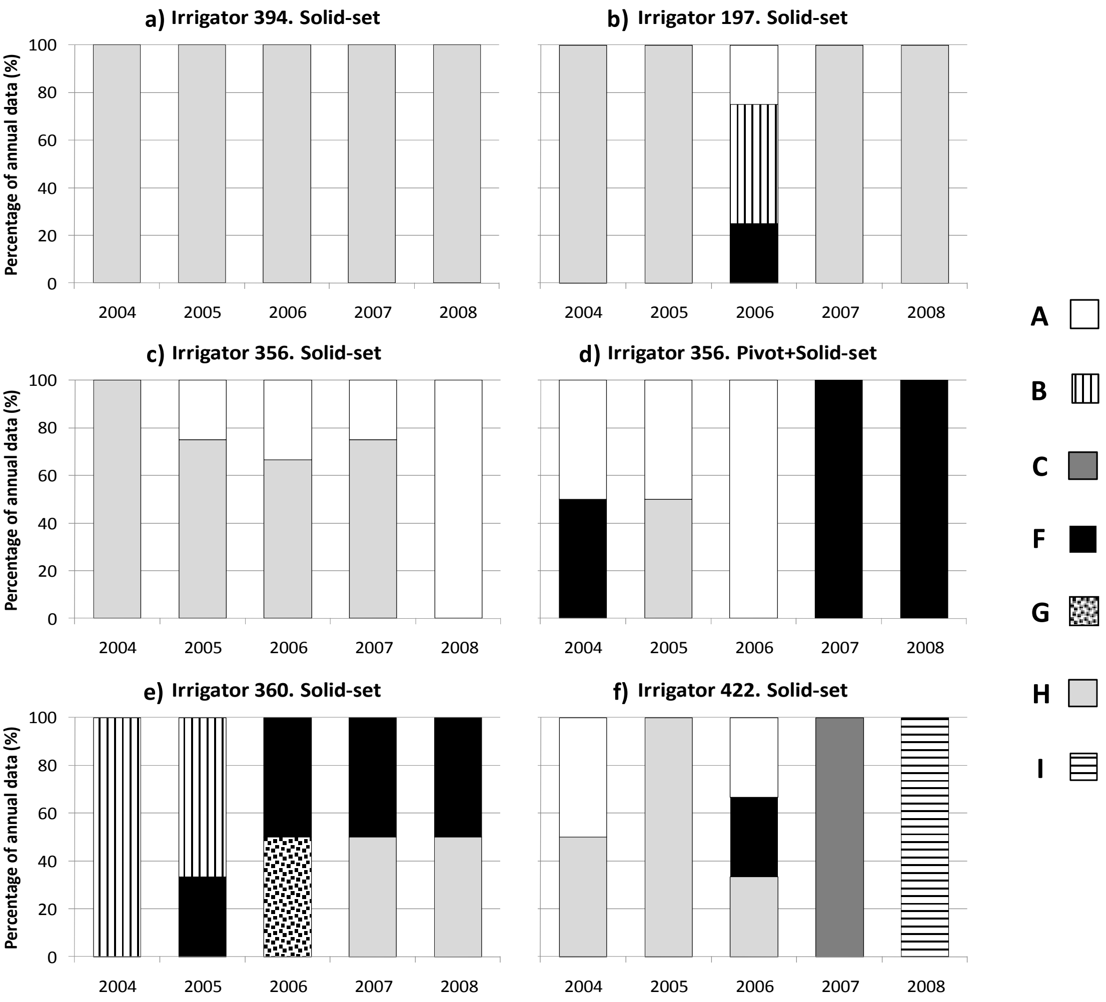


e) Group D - Peach tree - Drip



f) Group I - Peach tree - Drip




a) Irrigator 394. Solid-set

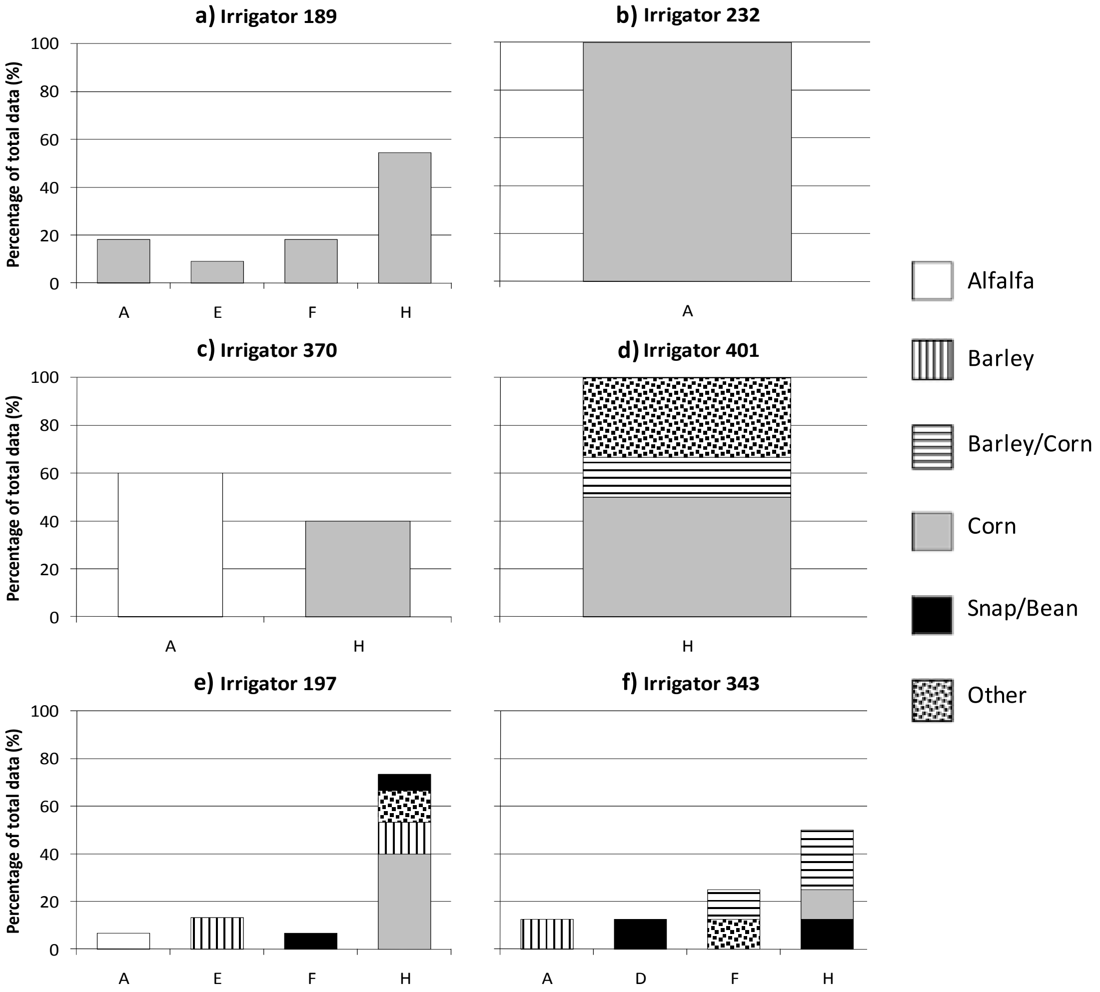
b) Irrigator 197. Solid-set

c) Irrigator 356. Solid-set

d) Irrigator 356. Pivot+Solid-set

e) Irrigator 360. Solid-set

f) Irrigator 422. Solid-set


a) Irrigator 189
b) Irrigator 232
c) Irrigator 370
d) Irrigator 401
e) Irrigator 197
f) Irrigator 343
Percentage of total data (%)
0
20
40
60
80
100
A
D
E
F
H
Alfalfa
Barley
Barley/Corn
Corn
Snap/Bean
Other