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Projection of harvestable water from air humidity using artificial neural network (Case study: Chabahar Port)

Previsione della acqua raccoglibile dall'umidità dell'aria attraverso l'uso della Rete Neurale Artificiale (Caso di studio: Chabahar Port)

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Abstract. The optimum use of existing water resources as well as the efforts to achieve new water resources have been considered as two major solutions to the relative resolution of water scarcity. Through utilization of the information and meteorological data, it is possible to identify areas with potentials for water harvesting from air humidity. It also allows for collecting and converting them into fresh water using simple physical laws. Due to lack of atmospheric precipitations or inappropriate distribution of precipitations in Chabahar, located in the south of Sistan and Baluchistan province, Iran, water is a limiting factor for agricultural activities and even for the entire life. In this study, water was harvested from air humidity using a screen collector with dimensions of 1×1 m. The magnitude of water harvesting was monitored daily for a period of 365 days. The results revealed that approximately 20% of the water available in the air could be extracted in this area. Then, monthly meteorological data from Chabahar synoptic station between 1990 and 2011 was used to predict the harvestable water for the upcoming year using an artificial neural network. After determining the effective input variables in predicting the amount of harvestable water, the modeling was performed using Multi-Layer Perceptron Network (MLP) and General Feed Forward Network. The results indicated that the MLP network had a higher ability to predict the amount of harvestable water when compared to the GFF network (at the R^2 test stage it was 0.86 versus 0.44). The most suitable structure to predict harvestable water from the fog in Chabahar was the MLP Artificial Neural Network with the array of 12-1-25 and the Hyperbolic Tangent Stimulus Function with the Lewenburg Marquette Training Law. Also, the values of the RMSE and MAE error rates were 2.19 and 1.81, respectively. Therefore, it is possible to predict the amount of harvestable water in the next 12 months which can be used in water resources management and productivity.

Keywords. Chabahar, air humidity, water extraction, prediction, neural network.

Abstract. L'uso ottimale delle risorse idriche esistenti e gli sforzi per ottenerne nuove, sono stati considerate due delle più importanti soluzioni al problema della scarsità di acqua. Attraverso l'uso delle informazioni e dati meteorologici è possibile identificare aree che abbiano potenzialità per la raccolta di acqua dall'umidità dell'aria. Oltretutto, ciò permette di raccogliere e convertire queste (riserve) in acqua potabile usando semplici leggi fisiche. A causa della mancanza di precipitazioni atmosferiche o di una loro distribuzione temporale non corrispondente alle necessità delle colture, nel Chabahar, posizionato nel sud della provincia di Sistan e Baluchistan, Iran, l'acqua risulta un fattore limitante per le attività agricole. In questo studio, l'acqua è stata raccolta dall'umidità dell'aria usando uno schermo raccoglitore con dimensioni di 1 X 1 metro. La capacità di raccoglimento dell'acqua è stata controllata giornalmente per un periodo di 365 giorni. I risultati hanno rilevato che in quest'area potrebbe essere estratto approssimativamente il 20% dell'acqua libera nell'aria. Successivamente, i dati meteorologici mensili dalla stazione sinoptica Chabahar tra il 1990 e il 2011 sono stati usati per predire l'acqua raccoglibile per l'anno successivo usando una Rete Neurale Artificiale. Dopo aver determinato le effettive variabili in entrata nel predire la quantità di acqua raccoglibile, il modello è stato applicato usando la Rete Multi-Layer Perceptron (MLP) e la Rete General Feed Forward. I risultati hanno evidenziato che la rete MLP aveva una maggiore abilità nel predire la quantità di acqua raccoglibile quando confrontata con la rete GFF (in fase di test nella prima l'R^2 era 0.86 contro 0.44 dell'altra). La migliore rete adatta a predire l'acqua raccoglibile dalla nebbia in Chabahar era Rete Neurale Artificiale MLP con il Sistema di 12-1-25 e la Funzione di impulso tangente iperbolica con la Legge di Formazione Lewenburg Marquette. Inoltre, i valori di RMSE e i tassi di errore MAE erano rispettivamente 2.19 e 1.81. Infine, è possibile prevedere la quantità di acqua raccoglibile nei successivi 12 mesi, così che possa essere usata nella gestione delle risorse idriche e ai fini produttivi.

Parole chiave. Chabahar, umidità dell'aria, estrazione di acqua, previsione, rete neurale.

INTRODUCTION

Today, with the growth of population especially in developing countries, which are mostly located in arid and semi-arid regions, the need for water increased considerably. Iran is a country which is located in the arid belt zone of the world. Chabahar is the southernmost part of Sistan and Baluchistan province, where weather warming is its most significant climatic phenomenon due to its climatic characteristics and location in the ultra-tropical region. This region is one of the hottest and most humid regions of Iran, and its atmospheric precipitation is extremely little or it does not have good dispersal. There are no significant precipitations in this area for more than two thirds of the year, where most precipitations occur once or twice which is often as flood spring rains causing a considerable damage. However, given that this city is located near the Oman Sea, its relative humidity is largely high and even exceeds 85% (IRIMO).

Therefore, due to the scarcity and inconsistency of the spatial and temporal distributions of precipitation, harvesting water from air humidity can be considered as a modern technology in the field of water resources. Large amounts of water can be collected via collectors for local and domestic uses, agriculture, or forestry (Davtalab *et al.*, 2013). The lower cost of water harvesting from the fog compared to other water supply methods, as well as its simple and accessible technology and the high quality of harvested water and sustainability of water resources for many years are main advantages of this new technology.

Given the general understanding of meteorological conditions across the globe along with recognition of site topograhy, many parts of the world such as North America, the Middle East, North Africa, China and India can have the potential to utilize water harvesting program from the fog (Sekar and Randhir, 2007). To the best of our knowledge, only few studies have been conducted to evaluate water harvesting from the fog in Iran. Mousavi-Baigi and Shabanzadeh (2008) reported that up to 40 L of water per day was harvested from four different collectors in highlands of Khorasan-Razavi province of Iran.

The prediction of water demand for urban, agricultural, and industrial uses is the main factor in planning and managing water resources. Today, the use of computer models and software has become commonplace for prediction, and managers can easily make decisions by entering available data and analyzing outputs. One of the software commonly used is artificial neural networks (ANNs). The rapid expansion of the use of these networks as an empirical and effective model in various sciences including meteorology and climatology, sugegsts the need to these valuable models. ANNs are an effective tool for modeling nonlinear systems. since these networks do not require a mathematical equation for complex phenomena of interest (Kumar *et al.*, 2002).

Accordingly, due to water scarcity in Chabahar on the one hand and the presence of heat and humidity on the other hand, and for optimal use of new water resources, the purpose of this study was to assess the potential use of harvesting water from the air humidity and also predict the amount of harvestable water using an ANN in the Chabahar region for 12 months.

MATERIALS AND METHODS

Area of study

Sistan and Baluchestan province is the largest province of Iran. The Oman Sea in south of Sistan and Baluchestan covers all southern borders of the province. This huge moisture source can affect most part of the province's southern regions, especially Chabahar coastal area. Chabahar is located at 60°37' E longitude and 25° 17'N latitude, with a height of 8 meters from the free water level of the southernmost city of Sistan and Baluchestan province. The location of the Chabahar station is shown in (Fig. 1). The long-term study (2010-1991) of Chabahar climate parameters showed average annual temperature of 26 °C, average minimum temperature of 23.1°C, average maximum temperature of 29.4°C, average annual precipitation of 125.4 mm, average annual evaporation of 6.9 mm and average annual humidity of 74%.

Data

In order to predict the amount of harvestable water from air humidity in Chabahar, the required meteorological data and statistics including monthly data of absolute maximum temperature, absolute minimum temperature, average maximum temperature, average minimum temperature, average air temperature, absolute maximum relative humidity, absolute minimum relative humidity, average maximum relative humidity, average minimum relative humidity, average relative humidity, total precipitation, total evaporation, average evaporation, average sunshine, and average QFF pressure were obtained from the Chabahar synoptic station during the years 1990 to 2011.

Nonparametric tests were performed on the weather data of Chabahar synoptic station using HYFRAN-PLUS software (2008) and the results showed that the data were 95% homogeneous, random and independent and do not have trend.

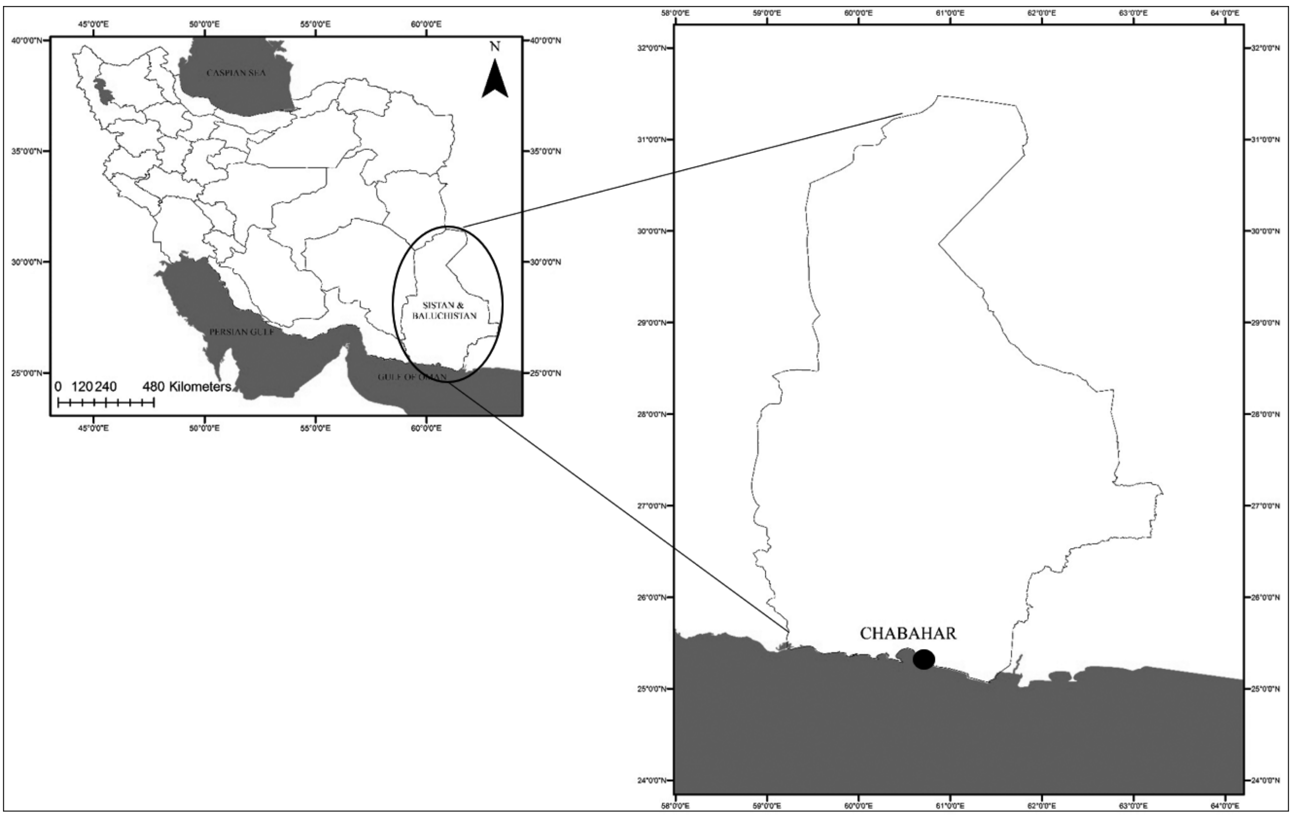

Fig. 1. Geographical situation of Chabahar station.
Fig. 1. Collocazione geografica della stazione di Chabahar.

The feasibility of water harvesting from air humidity in the area using statistical data

The results of theoretical calculations in the Chabahar area (Fig. 2) showed that because of average relative humidity of above 70%, except for the 3 cold months of the year (December, January, and February) and the relatively low temperature range, prone to any water harvesting design from humidity.

Calculation of the amount of harvestable water using statistical data

In order to investigate the existent water potential of the Chabahar station air, the absolute humidity parameter with unit of g / m^3 should be used. This parameter is calculated according to equation 1:

$$m = \frac{216.98}{T} \times e \qquad (1)$$

Where T is the temperature in degrees Kelvin and e is the vapor pressure in hPa. The results of this equation represent the amount of water vapor contained in one cubic meter of air.

As the meteorological data was read and recorded for periods of 3 hours, then the calculation unit of harvestable water must be calculated for 3 hours and with specific wind speed. The maximum amount of harvestable water was calculated by using equation 2:

(Humidity index) × (wind speed) × (one hour) × (time index) × (harvesting index) = amount of harvestable water (2)

Water harvesting

For the practical calculations of the amount of water harvesting from air humidity, a screen collector with dimensions of 1×1 m was designed and implemented (Fig. 3) (Mahmoudi *et al.*, 2016). The amount of water harvesting from this collector was daily monitored for a period of 365 days (from September 2011 to September 2012).

Prediction of the amount of harvestable water using artificial neural network

The traditional statistical methods for modeling complex and nonlinear systems are often unmanageable, especially if the relationship between output and meas-

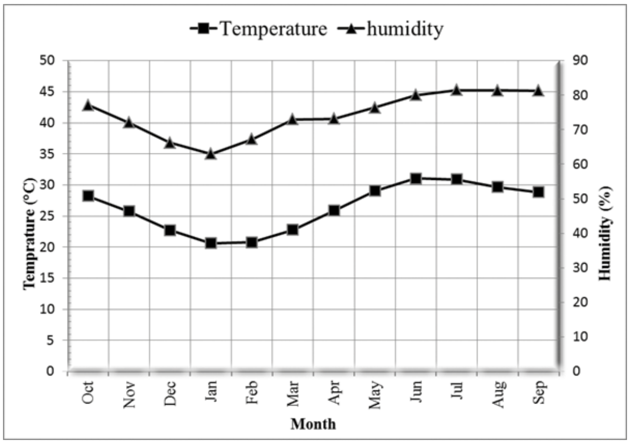

Fig. 2. Diagram of long-term monthly average of relative humidity and temperature in Chabahar station (statistical period of 20 years).
Fig. 2. Diagramma della media mensile di lungo periodo di umidità relativa e temperatura nella stazione di Chabahar (periodo statistico di 20 anni).

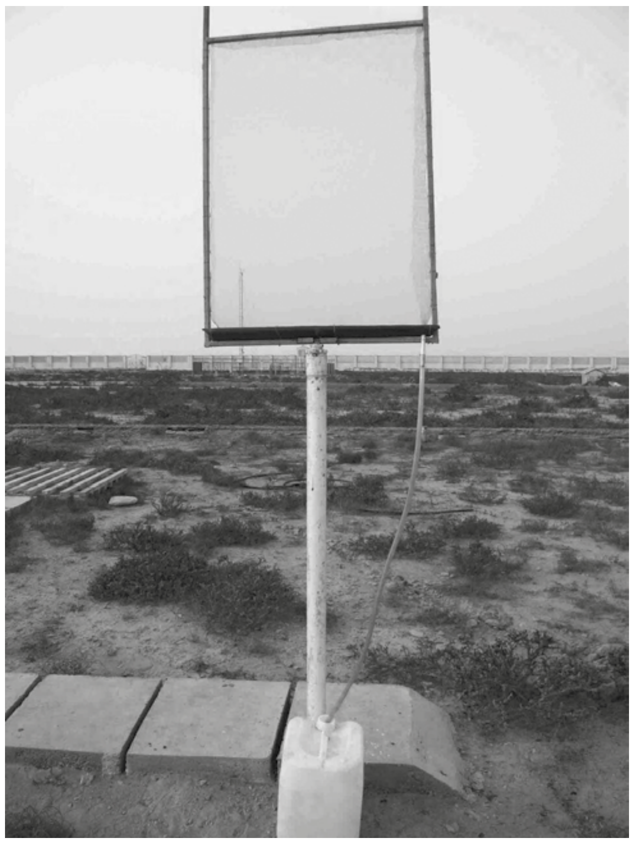

Fig. 3. Picture from designed screen collector.
Fig. 3. Foto dello schermo collettore progettato.

ured characteristics of the model is not clear (Namdar Khojasteh *et al.*, 2011). But today, with the advent of science and the invention of smart methods, the necessity of its substitution (traditional methods) is posed. One of these smart methods is artificial neural networks (ANN). The use of ANN technique in dissolving engineering issues began in the late 1980s (Flood and Kartam, 1994 a,b). The basic concepts of ANN and its application in hydrology are described in the report by the American Society of Civil Engineers (ASCE, 2003). High ability of ANN to predict and simulate water resource issues has been shown previously.

Artificial neural networks like the natural neural networks are composed of components called nerve cells. As in the natural neural network, a number of cells are responsible for receiving the stimulus effect, some for information processing, and a number for transmitting the response to the stimulus to the desired member. In ANN a number of cells also are responsible for receiving problem data, some for information processing, and some also for providing the answer to the problem. In all ANN, there is an input layer, an output layer, and some hidden layers. In the mathematical modeling of the neuron, a set of data is used as the input of the neuron (which may be the outputs of the other neurons) (Noori *et al.*, 2013).

The calculation method in the neural networks is that the inputs to the neurons (x1 to x2) are multiplied by weights (w1 to w2), and the sum of the results of each input after applying in a function which is called the transfer function, is applied and the output of the neuron is determined. Equation (3) represents its mathematical model:

$$net_j = \sum_{i=1}^{n} w_{ij} x_j \tag{3}$$

In some cases, the steady-state value in each neuron namely Biase weight is also added to the above-mentioned equation and the equation 3 is given by the equation 4 (Fattahi *et al.*, 2008):

$$net_j = \sum_{i=1}^{n} w_{ij} x_j + b \tag{4}$$

In this research, Hyperbolic Tangent Transfer Functions was used in the hidden layer. This function is most commonly used in simulations. Neural networks include various types of structures that are divided into different types based on direction of data entry and process (ASCE, 2003). For this reason, after review, two conventional types of artificial neural networks were used. These models included the Multi-Layer Perceptron-MLP model and the Generalized Feed Forward-GFF, which have high ability in predicting different climatic parameters (Azadeh *et al.*, 2009; Behrang *et al.*, 2010; Hung *et al.*, 2008; Senthil Kumar *et al.*, 2005).

In this research, to predict the amount of harvestable water among different training methods, the method of back propagation error with the Leungberg-Marquard algorithm was used because of faster convergence in network training. The basis of the method of back propagation error is based on the law of error-correction learning, which consists of two main paths of forward and backward. In the forward path, the input vector is applied to the network and its effects propagate through the middle layers to the output layer, and the output vector produces the real network response. (Ghabaei Sough *et al.*, 2010).

NeuroSolution software, version 6, was used to investigate the possibility of predicting the amount of harvestable water using ANN. This software has the potential of designing, learning and evaluating ANN, and includes different networks with different learning rules due to using various stimulus functions among the existent stimulus functions in the software box. Also, in order to increase the accuracy and speed of the implementation of ANN, normalized data in the range of [0, 1] should be used. Since NeuroSolution software has the ability to normalize the data, the implementation of this step was done automatically by software.

Neural network architecture and its performance evaluation criteria

The choice of architecture in neural network calculations is a trial and error method in which the optimal network can be determined using different varieties of hidden layers and related neurons.

In order to evaluate the performance of the neural networks, the three factors namely the coefficient of explanation (R^2), the root mean square error (RMSE) and the mean absolute magnitude error (MAE) were used. R^2 is a dimensionless criterion and its best value is equal to one. It is calculated based on the following equation (5):

$$R^2 = \frac{\sum_{k=1}^{k} X_k Y_k}{\sqrt{\sum_{k=1}^{k} X_k^2 \sum Y_k^2}} \tag{5}$$

The root mean square error (RMSE) and mean absolute magnitude error (MAE) also represent the error rate of the model. The best values for RMSE and MAE are zero and are calculated according to equations 6 and 7, respectively

$$RMSE = \sqrt{\frac{\sum_{k=1}^{k}\left(X_k - Y_k\right)^2}{k}} \quad (6)$$

$$MAE = \frac{\sum_{k=1}^{k}\left|X_k - Y_k\right|}{k} \quad (7)$$

Where X_k=the observed values, Y_k=estimated values, and K= the number of data. Whatever RMSE and MAE are closer to zero and R^2 is closer to one, indicates that the outputs are more accurate and the observed and predicted values are closer to each other (Fattahi *et al.*, 2008).

Model inputs and training courses and verification

Selection of model inputs is an important step in designing ANN. The most important factor in choosing the inputs of the model is the physics dominating the process of the research. Therefore, various inputs included maximum absolute temperature $T_{\max_{abs}}(°C)$, absolute minimum temperature $T_{\min_{abs}}(°C)$, average maximum temperature $T_{\max_{mean}}(°C)$, average minimum temperature $T_{\min_{mean}}(°C)$, average air temperature $T_{\mathrm{mean}}(°C)$, absolute maximum relative humidity $H_{\max_{abs}}(\%)$, absolute minimum relative humidity $H_{\min_{mean}}(\%)$, average relative humidity $H_{\mathrm{mean}}(\%)$. Total precipitation $R(mm)$, total evaporation $E(mm)$, mean evaporation $E_{mean}(mm)$, mean sunlight hour H_{sun}(s), average pressure $P_{\mathrm{QFF}}(Hpa)$ and the amount of harvestable water $P(m^3/day)$ were considered monthly. The data set given to the network is divided into two general categories: a training set and a test set. This monthly data was generated between 1990 and 2011 and was introduced to the neural network model.

Finally, all available data were randomly divided into two groups as training (70%) and calibration (30%) groups. This categorization is based on the usual practice and there is no specific rule in this regard. However, various studies have shown that for training a better ANN, the number of training data should be more than the test stage (Diamantopoulou *et al.*, 2005).

RESULTS AND DISCUSSION

The results of the field experiment (collecting water using screen collector) indicated that the amount of water available was 0.0086 m^3/day in June and 0.0011 m^3/day in February (Fig. 4). This indicated that the maximum amount of water was harvested in the warm season with highest relative humidity. On the other hand, the minimum amount of water was collected in the cold season with lowest relative humidity.

Since the whole water in the atmosphere cannot be harvested, harvesting indices of 10%, 20%, and 50% were used in Eq. 2. The comparison of the harvestable water from the screen collector with the values obtained from the theoretical indicators indicated no significant difference between the theoretical data of 20% and the real collector values (Fig. 5). Therefore, it can be concluded that only 20% of the existent atmospheric humidity can be harvested in southeastern Iran, and conse-

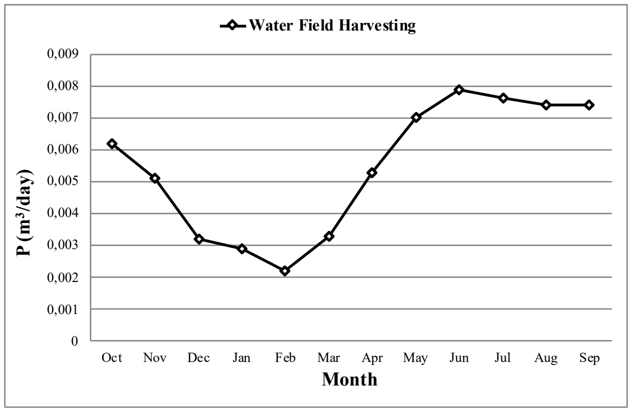

Fig. 4. Diagram of monthly harvested water from screen collector device (m^3/ day).
Fig. 4. Diagramma dell'acqua raccolta mensilmente dall'apparecchio a schermo collettore (m^3/ giorno).

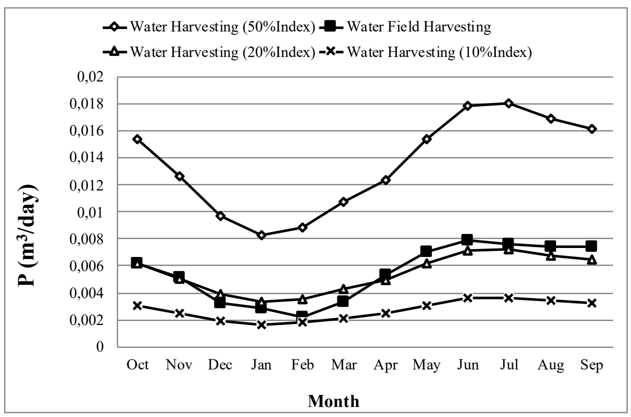

Fig. 5. Comparison diagram of monthly harvested water in the field method with theoretical indices (m^3/day)
Fig. 5. Diagramma di confronto dell'acqua raccolta mensilmente tra il metodo di campo e gli indici teorici (m^3/giorno)

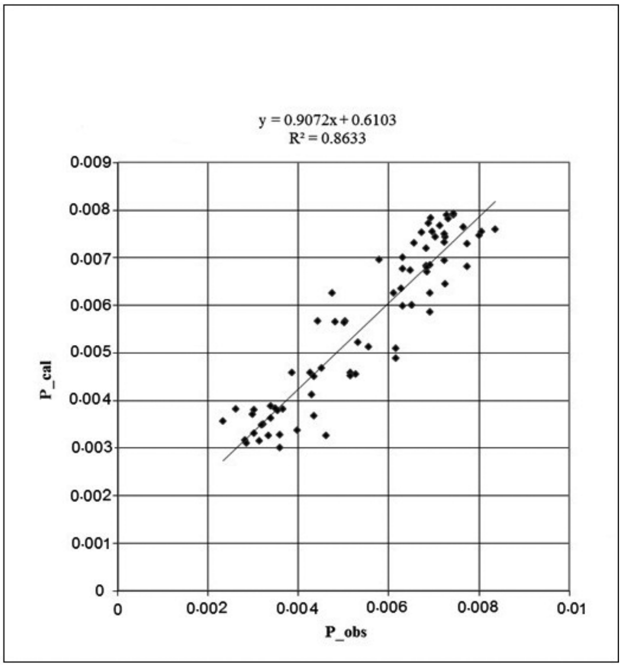

Fig. 6. The relationship between the calculated values of the neural network (P_ cal) and the actual amounts of harvestable water (P_ obs)

Fig. 6. Rapporto tra i valori calcolati dalla rete neurale (P_ cal) e la quantità attuale di acqua raccoglibile (P_ obs)

quently 20% of theoretical data was used to predict the harvestable water using ANN.

The results of using the proposed neural structures in predicting the amount of harvestable water were calculated based on Eqs. 5 to 7 and compared with each

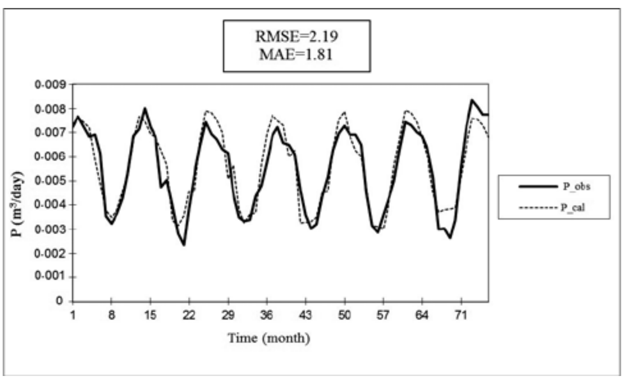

Fig. 7. Comparison of observed (P_ obs) and calculated values of 12-month prediction (P_ cal) of the amount of harvestable water using artificial neural network

Fig. 7. Confronto tra valori osservati (P_ obs) e calcolati (P_ cal) della quantità di acqua raccoglibile in 12 mesi usando la rete neurale artificiale.

other. Table 1 presents some of the best results from the 12-month forecast, at the testing stage using the MLP and GFF ANN model, with different inputs and in different states of the number of hidden layers and hidden layer neurons.

The investigation of performance of the models indicated that in the test phase, the MLP had $R^2 = 0.86$ while RMSE and MAE were 2.19 and 1.81, respectively which was ideally able to predict the amount of harvestable water for 12 months (Table 1, Figs. 6 and 7).

According to Table 1, the selected model with the lowest standard error and the highest coefficient of determination has been MLP ANN with 12 neurons in the input layer, 1 hidden layer, 25 neurons for the hidden layer (12-1-25 array), whose stimulus function has been the Hyperbolic Tangent by Lewenburg Marquette Training Law.

On the other hand, the best result obtained from the GFF network at the test stage was $R^2 = 0.64$ whose RMSE and MAE values were 4.41 and 4.38, respectively.

Also, the best data for the 12-month prediction of the amount of harvestable water were as follows:

$$P = F(T_{\max_{abs}}, T_{\min_{abs}}, T_{\max_{mean}}, T_{\min_{mean}}, T_{mean}, H_{\max_{abs}}, H_{\min_{abs}}, H_{\max_{mean}}, H_{\min_{mean}}, H_{mean}, R, P_{QFF})$$

The performance of this network in the 12-month prediction of absolute humidity in Chabahar is represented in Fig. 6 indicating the predicted data and observed data relative to the line. Fig. 6 displays the relationship between the output of the neural network and the actual values of the harvestable water in the form of first-order equation and the standard deviation of the first-order bisector line. Note that the closer the data are to the one to one graph, the greater the model's ability to estimate the harvestable water will be. Fig. 6 also revealed that the results of ANN had a small dispersion.

The simulated and observed values of the 12-month prediction of the best structure of the ANN are demonstrated in Fig. 7. The graphical results of this figure indicated no significant difference between the observed and simulated values during the study period. This result was already confirmed based on the error scaling criteria (Table 1).

CONCLUSION

Since the study area suffers from a lack of adequate water, especially in rural areas, which sometimes even have difficulty with drinking water, some solutions should be developed to manage the existing resources

Tab. 1. Confronto in fase di prova di diverse reti per la previsione della quantità di acqua raccoglibile in 12 mesi.
Tab. 1. Comparison of different networks for 12-month prediction of the amount of harvestable water at the testing stage.

Model	Network types	number of input	number of hidden layers	Hidden layers neurons	RMSE	MAE	R^2
$P=F(T_{\min_{abs}},T_{\min_{mean}},H_{\max_{abs}},H_{mean},R,E,E_{mean},H_{sun})$	FF	8	3	15	4.43	4.23	0.14
$P=F(T_{\max_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},R,P_{QFF},E,E_{mean},H_{sun})$	FF	13	2	24	4.5	4.52	0.58
$P=F(T_{\max_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},R,P_{QFF},E,H_{sun})$	FF	12	2	28	4.65	4.36	0.59
$P=F(T_{\max_{abs}},T_{\min_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},H_{mean},R,P_{QFF},E,E_{mean},H_{sun})$	FF	15	2	14	4.51	4.25	0.62
$P=F(T_{\max_{abs}},T_{\min_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},R,P_{QFF},E,H_{sun})$	FF	13	1	24	4.41	4.38	0.64
$P=F(T_{\max_{abs}},T_{\min_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},H_{mean},R,P_{QFF},E,E_{mean},H_{sun})$	MLP	15	1	16	4.02	4.01	0.67
$P=F(T_{\max_{abs}},T_{\min_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},H_{mean},R,P_{QFF},E,E_{mean},H_{sun})$	MLP	15	1	22	3.47	2.65	0.72
$P=F(T_{\max_{abs}},T_{\min_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},H_{mean},R,P_{QFF},E)$	MLP	13	1	23	2.69	1.84	0.79
$P=F(T_{\max_{abs}},T_{\min_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},R,P_{QFF})$	MLP	11	1	30	2.73	1.95	0.81
$P=F(T_{\max_{abs}},T_{\min_{abs}},T_{\max_{mean}},T_{\min_{mean}},T_{mean},H_{\max_{abs}},H_{\min_{abs}},H_{\max_{mean}},H_{\min_{mean}},H_{mean},R,P_{QFF})$	MLP	12	1	25	2.19	1.81	0.86

efficiently. Predicting and calculating available water (precipitation, air humidity, etc.) in the future, can help the agricultural sector as well as optimal water management by regional managers by determining appropriate crop patterns.

In this study, the results of field experiment suggested that approximately 20% of the water available in the air can be extracted in Chabahar region. After determining the effective input variables in predicting the amount of harvestable water using ANN, the modeling was performed using MLP and GFF. Between the two MLP and GFF networks, the MLP network presented greater ability than the GFF network to predict the amount of harvestable water.

The most suitable structure for predicting the harvestable water from fog in the Chabahar area was MLP ANN with 12 neurons in the input layer, 1 hidden layer, 25 neurons for the hidden layer, (12-1-25 array) and the Hyperbolic Tangent Stimulus Function with the Lewenburg Marquette Training Law. In general, it can be stated that ANN is a powerful model with high capability which can be viewed positively in predicting hydraulic problems especially when this network is able to extract the rule dominating data.

Since the amount of harvestable water is a nonlinear and complex phenomenon and many meteorological parameters are involved in its estimation, this research was conducted to predict it and to introduce an accurate estimate of the amount of harvestable water with the highest accuracy and lowest error. Notably, the prediction of harvestable water for 12 months, especially in warm and humid areas such as Chabahar, can be very valuable.

REFERENCES

Azadeh A., Maghsoudi A., Sohrabkhani S., 2009. An integrated artificial neural networks approach for predicting global radiation. Energy Conversion and Management, 50(6): 1497-1505.

ASCE Task Committee on Application of Artificial Neural Networks in hydrology. 2000. Artificial Neural network in Hydrology. I. preliminary concepts. Journal of Hydrologic Engineering, 5(2): 124-137.

Behrang M.A., Assareh E., Ghanbarzadeh A., Noghrehabadi A.R., 2010. The potential of different artificial neural network (ANN) techniques in daily global solar radiation modeling based on meteorological data. Solar Energhy, 84: 1468-1480.

Davtalab R., Salamat A., Oji R., 2013. Water harvesting from fog and air humidity in the warm and coastal regions in the south of Iran. Irrigation and Drainage, 62(3): 281-288.

Diamantopoulou M.J., Antonopoulos V.Z., Papamichail D.M., 2005. The use of a neural network technique for the prediction of water quality parameters of Axios River in Northern Greece. European Water, 5(1): 115-125.

Fattahi E., Sedaghatkerdar A., Delavar M., 2008. Long-range precipitation prediction using artificial neural networks. Pajouhesh & Sazandegi, 80: 44-50.

Flood I., Kartam N., 1994a. Neural networks in civil engineering, I: principles and understanding. Journal of Computing in Civil Engineering, ASCE, 8(2): 131-148.

Flood I., Kartam N., 1994b. Neural networks in civil engineering II: systems and applications. Journal of Computing in Civil Engineering, ASCE, 8(2): 149-162.

Ghabaei Sough M., Mosaedi A., Hesam M., Hezarjaribi A., 2010. Evaluation effect of input parameters preprocessing in Artificial Neural Networks (ANNs) by using stepwise regression and gamma test techniques for fast estimation of daily evapotranspiration, Journal of Water and Soil, 24 (3): 610-624 (In Persian).

Hung N.Q., Babel M.S., Weesakul S., Tripathi N.K., 2008. An artificial neural network model for rainfall forecasting in Bangkok, Thailand. Hydrology and Earth System Sciences Discussions, European Geosciences Union, 5 (1): 183-218.

Iran Meteorological Organization. Available online at: http://www.irimo.ir.

Kumar M., Raghuwanshi N.S., Singh R., Wallender W.W., Pruitt W.O., 2002. Estimating evapotranspiration using artificial neural network. Journal of Irrigation and Drainage Engineering. 128: 4. 224-233.

Mahmoudi P., Khajeh Amiri Khaledi Ch., Salari Fanodi M.R., 2016. Examining the feasibility of water harvesting from air humidity in the Southern province of Sistan and Baluchestan. Journal of Water and Soil Conservation, 23(2): 253-265.

Mousavi-Baygi M., Shabanzadeh S., 2008. Design and construction of an apparatus for fog and cap cloud collection (A new method of water harvesting). Agricultural Sciences and Technology (Special Issue in Water and Soil), 1: 2-11. (In Persian)

Namdar Khojasteh D., Shorafa M., Omid M., 2011. Estimation of soil moisture content using artificial neural network. Iranian Journal Of Watershed Management Science And Engineering. 5(14):53-60

Noori S., Fallah-Ghalhary Gh.A., Sanaei-Nejad S.H., 2013. Modeling of potential evapotranspiration by Artificial Neural Network from minimum climatic variables in Mashhad synoptic station. Journal of Water and Soil Conservation, 20(5): 163-178 (In persian)

Sekar I., Randhir T.O., 2007. Spatial assessment of conjunctive water harvesting potential in watershed systems. Journal of Hydrology, 334: 39-52.

Senthil Kumar A.R., Sudheer K.P., Jain S.K., Agarwal P.K., 2005. Rainfall-runoff modelling using artificial neural networks: comparison of network types. Hydrological Processes, 19(6): 1277-1291.

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Wheat productivity and water use efficiency responses to irrigation, cobalt and weed management

Produttività del frumento e efficienza di utilizzo dell'acqua a diverse gestioni del livello di irrigazione, cobalto e gestione delle infestanti

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Abstract. The effect of three irrigation levels (100%, 75% and 50% of crop water requirement), five weed control treatments (pyroxsulam, mesosulfuron-methyl, isoproturon+diflufenican, hand weeding and unweeded check control treatment), five cobalt concentrations (0, 5, 10, 15 and 20 ppm) and their interaction on wheat productivity, weed growth and water use efficiency, were examined in two field experiments in sandy soil at the Agricultural Experimental Station of the National Research Centre, Egypt. The results indicated that pyroxsulam recorded the greatest weed control efficiency. Application of 100% of crop water requirement showed the largest values of flag-leaf area, chlorophyll content, plant height, spikes number/m^2, grains number/spike, 1,000 grain weight, straw and grain yield of wheat plants, compared with all other irrigation treatments. Isoproturon+diflufenican followed by pyroxsulam and mesosulfuron-methyl treatments gave the largest grain yield. Application of cobalt resulted in recovery from the negative effects of insufficient water on wheat yield in low fertility soils and using cobalt at a rate of 15 ppm resulted in increased wheat grain yield. The maximum grain yield with largest protein and carbohydrates percentages in grains was obtained by application of 100% of crop water requirement with pyroxsulam and using 15 ppm cobalt, followed by 75% of crop water requirement combined with isoproturon+diflufenican treatment, with insignificant difference between both two interaction treatments.

Keywords. Wheat, herbicides, water requirement, weeds, cobalt, yield.

Abstract. L'effetto di 3 livelli d'irrigazione (100%, 75% e 50% del fabbisogno idrico della coltura), 5 trattamenti di controllo delle infestanti (pyroxsulam, mesosulfuron-methyl, isoproturon+diflufenican, diserbo manuale e un trattamento di controllo non diserbato), 5 concentrazioni di cobalto (0, 5, 10, 15 and 20 ppm) e la loro influenza sulla produttività del frumento, sulla crescita delle infestanti e sull'efficienza d'utilizzo dell'acqua, sono stati esaminati in due campi sperimentali su suolo sabbioso nella Stazione Sperimentale Agricola del Centro di Ricerca Nazionale, Egitto. I risultati hanno indicato che pyroxsulam ha riportato la migliore efficienza per il controllo delle infestanti. L'applicazione del 100% del fabbisogno idrico ha avuto come effetto maggiori valori di superficie fogliare, contenuto di clorofilla, altezza della pianta, numero di spighe per m^2, numero di semi per spiga, peso di 1000 semi, resa di granella e paglia per le piante di frumento, in confronto agli altri trattamenti di irrigazione. Isoproturon+diflufenican seguito dai trattamenti con pyroxsulam e mesosulfuron-methyl hanno dato i migliori risultati in termini di resa in granella. L'aggiunta di cobalto è risultata in un recupero dall'effetto negativo dovuto all'insufficienza idrica sulla resa del frumento nei suoli a bassa fertilità e usando cobalto con una dose di 15 ppm è risultato un aumento di resa della granella. La massima resa in granella è stata ottenuta dall'applicazione di 100% del fabbisogno idrico con pyroxsulam e usando cobalto a 15 ppm, seguito da 75% di fabbisogno idrico combinato con il trattamento di isoproturon+diflufenican, con una differenza non significativa per le interazioni tra entrambi i trattamenti.

Parole chiave. Frumento, Erbicidi, Fabbisogno idrico, Infestanti, Cobalto, Resa.

INTRODUCTION

Increasing wheat production under biotic (weeds, etc.) and abiotic (drought, salinity, etc.) stress conditions has become an important focus over the last decades in the world and particularly in Egypt, with the aim of decreasing the gap between production and consumption. Increasing wheat yield could be achieved by maximizing the production through vertical and horizontal expansion by desert reclamation (Mahgoub and Sayed, 2001). Growing wheat in the typical desert sandy soils would require different specific cultural practices to those applied in the old cultivated fertile soils.

Irrigation water and weed control are the most limiting factors for wheat production in the newly reclaimed desert areas. Water deficit is the major obstacle for crop production, especially in arid and semi-arid regions (Hussain *et al.*, 2004). Decreasing the irrigation requirements from 100% to 50% significantly decreased most growth characteristics such as yield, yield attributes and protein content while water use efficiency increased significantly (Abdelraouf *et al.*, 2013).

Weeds limit wheat yield potential in arid regions because they increase evapotranspiration and compete with wheat plants for limited soil moisture, nutrients and light resulting in reported grain yield reductions of 41% (Abouziena *et al.*, 2008), 92% (Tiwari and Parihar, 1997) and in serious cases, leading to complete crop failure (Abdul-Khaliq and Imran, 2003). Weeds may inhibit wheat growth through the release of allelopathic chemicals that are toxic to wheat plants (Ortega *et al.*, 2002). Using chemical weed management significantly decreased the weed population and increased wheat grain yield over weedy check control plots (El-Metwally *et al.*, 2015a; Abd Elsalam *et al.*, 2016).

Cobalt (Co) could promote growth, especially under abiotic stress, as it plays an important role in the drought tolerance of plants and may be essential for some plants (Pilon-Smits *et al.*, 2009). Cobalt plays a major role in the water balance of plants cultivated under water deficit conditions and is an essential element for the synthesis of vitamin B_{12} which is required for human and animal nutrition (Smith, 1991). Application of cobalt at 12.5 ppm significantly increased growth, yield and yield parameters as well as nutritional status of the wheat grain (Gad and El-Metwally, 2015). Therefore, the objective of this investigation was to study the effects of irrigation requirements, weed management and Co concentration on wheat productivity.

MATERIALS AND METHODS

Experimental procedures

A two-year field experiment was conducted during two successive seasons (2012/13 and 2013/14) at the Agricultural Experimental Station of the National Research Centre, Nubaria, Beheira Governorate, Egypt. The site is classified as arid with cool winters and hot dry summers. Tab. 1 illustrates the monthly mean weather data for the two growing seasons studied, as obtained from the Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation, Egypt. Little rainfall was observed during the two growing seasons. The soil texture of the experimental site is sandy.

Most relevant physical and chemical properties of the experimental soil are shown in Tab. 2. Irrigation water had pH 7.35, and EC was 0.41 dS/m. The experiment was established as a split-spilt plot design with four replicates.

The main plots included three irrigation water requirements (100%, 75% and 50% of the crop water requirements, CWR) while the sub-plots comprised weed management treatments including: three herbicides each of them applied 25 days after sowing (DAS), (1) Pyroxsulam, Pallas 4.5% OD, at the rate of 400 ml ha^{-1}; (2) Isoproturon+diflufenican, Panther 55% SC, at the rate of

Tab. 1. Monthly weather data of the experimental site.
Tab. 1. Dati meteo mensili del sito sperimentale.

Month	Solar radiation [W/m²]	Precipitation [mm]	Wind speed [m/sec]	Air temperature [°C]			Relative humidity [%]
				Min.	Max.	Average	
2012/13							
December	49.4	0.2	1.8	8.9	22.2	15.6	63.3
January	49.7	0.0	2.3	8.3	21.4	14.9	61.0
February	67.5	0.1	2.1	9.3	24.5	16.9	57.7
March	93.5	3.6	2.2	11.0	26.2	18.6	60.0
April	111.0	0.0	2.3	12.8	28.8	20.8	52.3
May	130.0	0.0	1.4	12.7	27.6	20.2	49.0
2013/14							
December	49.5	0.0	2.0	9.1	22.6	15.8	63.4
January	50.0	1.2	2.5	7.3	24.1	15.7	66.0
February	68.0	2.6	2.3	7.2	26.4	16.8	56.0
March	95.0	0.0	2.5	8.2	28.3	18.2	56.0
April	113.0	0.0	2.4	10.9	30.6	20.7	50.0
May	135.0	0.0	1.6	14.3	33.8	24.0	47.0

Tab. 2. Physical and chemical properties and water status of experimental soil.
Tab. 2. Proprietà fisiche e chimiche e condizioni idriche del suolo nel sito sperimentale.

Soil depth [cm]	Particle size distribution [%]				Chemical properties				Moisture status [%]	
	Coarse sand	Fine sand	Clay + Silt	Texture class	OM [%]	pH	EC [dS/m]	$CaCO_3$ [%]	FC	WP
20	47.76	49.75	2.49	Sandy	0.65	8.7	0.35	7.02	10.1	4.7
40	56.72	39.56	3.72	Sandy	0.40	8.8	0.32	2.34	13.5	5.6
60	59.40	59.40	3.84	Sandy	0.25	9.3	0.44	4.68	12.5	4.6

FC: field capacity; WP: wilting point, OM: Organic matter; pH: acidity or alkalinity in soils; EC: electrical conductivity.

1500 ml ha^{-1} and (3) Mesosulfuron-methyl, Atlantis 1.2 % OD, at the rate of 1500 ml ha^{-1} in addition to hand weeding twice at 30 and 50 DAS, and unweeded check (control). Five Co levels (0, 5, 10, 15 and 20 ppm in the form of cobalt sulphate) were distributed in the sub-sub plots and sprayed once at the third true leaf seedling stage (22 DAS). The experimental unit size was 10.5 m^2.

Based on weather data recorded from an adjacent weather station, reference evapotranspiration (ET_0) was calculated using the Penman-Monteith equation given by Allen *et al.* (1998). Crop evapotranspiration (ET_c) was then calculated as follows:

$$ET_c = ET_o \times K_c \tag{1}$$

where:
ET_c = Crop evapotranspiration [mm/day]
ET_o = Reference crop evapotranspiration [mm/day]
K_c = Crop coefficient

The amount of irrigation water was computed according to the following equation for the sprinkler irrigation systems:

$$AW = \frac{Etc}{Ea \times (1 - LR)} \tag{2}$$

where:
AW = applied irrigation water depth [mm/day]
E_a = application efficiency equals 75% for sprinkler irrigation system
LR = leaching requirements equals 10% for sprinkler irrigation system.

The seasonal irrigation water applied [m^3/ha] for each irrigation treatment in 2012/13 and 2013/14, respectively, are shown in Tab. 3.

Tab. 3. Seasonal irrigation water applied [m^3/ha] under different irrigation levels for 2012/1 and 2013/14 seasons.
Tab 3. Volumi di acqua stagionale applicati [m^3/ha] con differenti livelli di irrigazione per le stagioni 2012/1 e 2013/14.

Irrigation level	Growing season	
	2012/13	2013/14
100%	4284	4382
75%	3213	3287
50%	2142	2191

Grains of wheat variety Shaka 93 were planted at a rate of 167 kg/ha at 5-cm soil depth with 13.5-cm row spacing in the last week of November in both seasons.

All experimental units received the same fertilization rates. Ammonium nitrate was applied at 285 kg N/ha to the soil before planting and at tillering (10%), while the remaining was divided in six equal applications before each irrigation until the heading stage. Single super-phosphate was applied at a rate of 70 kg P_2O_5/ha to the soil in two equal rates before planting and at tillering stage. Potassium sulphate was applied once at 30 DAS at a rate of 60 kg K_2O/ha.

Measurements

Weeds

Weeds were hand pulled from one square meter of each experimental unit at 80 DAS, identified and classified into broadleaved and narrow-leaved weed groups. The collected weed biomass was first air-dried in the sun, then in an electric oven for 72 hours at a constant temperature of 70 °C before the dry weight was recorded. Macronutrients (N, P and K) in the weeds were determined according to Cottenie *et al.* (1982).

Wheat

Growth traits

At 90 DAS, flag-leaf area, SPAD chlorophyll values and plant heights were measured. Flag-leaf area was measured on 10 tillers chosen randomly from each plot. The chlorophyll content of the flag leaf was determined by chlorophyll meter (SPAD-502 plus) according to soil plant analysis department section, Minolta Camera Co., Osaka, Japan as reported by (Minolta Camera Co., 1989).

Yield and yield attributes

Harvesting was done in the first week of May in both seasons. Plant samples were collected from one square meter per plot to estimate the number of spikes. Subsequently, 10 tillers were chosen randomly to measure spike length, number of spikelet/spike, grains number/spike, grain weight/spike and 1000-grain weight. The whole plot was harvested to estimate the grain and straw yields per hectare.

Grain chemical analysis

Following to AOAC (1990) methods of analysis, samples of wheat grains were taken to estimate total carbohydrates, total soluble sugars percentage, fats % by extraction using Soxhlet Apparatus with hexane as an organic solvent. In addition, total nitrogen was determined by Kjeldahl method and total crude proteins calculated by multiplying total nitrogen by 5.8. Additionally, Co in wheat grains was determined as described by Cottenie *et al.* (1982).

Irrigation water use efficiency

Irrigation water use efficiency "IWUE" is an indicator of effectiveness use of irrigation to increase crop yield. IWUE of wheat yield was calculated according to James (1988) as follows:

IWUE wheat (kg m^{-3}) =Total yield (kg ha^{-1})/Total applied irrigation water (m^3 ha^{-1}).

Statistical Analyses

The combined analysis of variance for the data of the two seasons was performed after testing the error homogeneity. The data were then subjected to analysis of variance (ANOVA) according to Gomez and Gomez (1984). The differences among means were compared using Fisher's Least Significant Difference (LSD) test at 0.05 probability level.

RESULTS AND DISCUSSION

Weeds growth

The most commonly surveyed weeds in the experimental field through the two growing seasons were: grasses comprising wild oat (*Avena fatua* L.), green foxtail (*Setaria viridis* L) and ryegrass (*Lolium temulentum*

Tab. 4. Effect of water requirement, weed control and Co concentration on dry weight of wheat weeds and macronutrient uptake by weeds (combined analysis of two seasons).
Tab. 4. Effetto del trattamento irriguo, controllo delle infestanti e concentrazione di Co sul peso secco delle infestanti del grano e capacità di assunzione di macronutrienti da parte delle infestanti (analisi combinate di 2 stagioni).

Treatments	Dry weight of weeds (g/m^2)			Uptake of nutrients by weeds (g/m^2)		
	Broadleaved	Grasses	Total	N	P	K
Water requirement						
100%	49.63	26.31	75.94	1.34	0.121	2.18
75%	42.82	20.52	63.34	1.12	0.101	1.82
50%	33.38	13.33	46.71	0.82	0.075	1.34
LSD 0.05	3.17	2.23	4.82	0.14	0.17	0.24
Weed control						
Pyroxsulam	10.68	7.67	18.35	0.32	0.029	0.53
Mesosulfuron-methyl	15.15	11.55	26.70	0.47	0.042	0.77
Isoproturon+diflufenican	13.62	10.14	23.76	0.42	0.038	0.68
Hand weeding	35.86	24.16	60.02	1.06	0.096	1.72
Unweeded	134.57	46.75	181.32	3.20	0.291	5.25
LSD 0.05	5.11	4.71	9.15	0.19	0.022	0.35
Co concentration (ppm)						
0	36.33	15.73	52.06	0.92	0.083	1.49
5	40.30	18.47	58.77	1.04	0.094	1.69
10	43.35	20.88	64.23	1.13	0.103	1.84
15	44.77	22.19	66.96	1.18	0.107	1.92
20	45.12	22.29	67.41	1.19	0.108	1.93
LSD 0.05	2.07	1.39	3.17	0.11	0.013	0.24

L.) and broadleaved weeds comprising wild beet (*Beta vulgaris* L.), lambsquarters (*Chenopodium album* L.) and greater ammi (*Ammi majus* L.) .

The response of weed growth to irrigation levels differed among weed groups as reducing irrigation levels from 100% to 75% or 75% to 50% led to decreases in the dry weight of broadleaved, grasses and total weeds by 15.9 to 28.3%, 28.2 to 35.0%, and 19.9 to 35.6%, respectively (Tab. 4). Moreover, supplying wheat plants with 50% of crop water requirement caused decreases in N, P and K concentrations in weeds. In contrast, the application of 100% of crop water requirements gave the highest values of N, P and K. These results are in harmony with those obtained by Bhat *et al.* (2006); Chaudhary *et al.* (2011); El- Hag (2015).

All weed treatments reduced the dry weight of broadleaved, grasses and total weeds as well as nutrient uptake by weeds compared with weedy check control treatment (Tab. 4). Pyroxsulam was the most effective herbicide and reducing nutrient uptake by weeds, while isoproturon+diflufenican was the second most effective herbicide treatment. Pyroxsulam, isoproturon+diflufenican, mesosulfuron-methyl and hand weeding recorded the greatest efficiency and reduced the dry weight of weeds by 89.9, 86.9, 85.3 and 66.9%, respectively, compared with the unweeded control. The differences between the three herbicides tested were not statistically significant at the P=0.05 level.

The mode of action of the herbicides in this study differ. Isoproturon interferes with the photosynthetic process and diflufenican inhibits carotenoid synthesis in plants. The primary biochemical target site of mesosulfuron-methyl is the enzyme acetohydroxy acid synthase which acts via foliage and soil, to inhibit the development of new leaves. Pyroxsulam inhibits acetolactate synthase (metosulam), the key plant enzyme that inhibits the branched chain amino acids leucine, isoleucine and valine.

These results are in general agreement with those recorded by Shaban *et al.* (2009); Neijad *et al.* (2013); El-Metwally *et al.* (2015b); Abd Elsalam *et al.* (2016).

The results in Tab. 4 clearly indicate that Co levels caused a significant effect on weed growth as the application of 20 ppm Co markedly increased the dry weight and nutrient uptake of weeds after 80 DAS. The lowest values were the no Co treatment and there were insignificant differences between the 15 and 20 ppm Co treatments.

Sethi and Kaur (2016) reported that application of cobalt chloride at concentrations ≥ 0.1 mM caused significant reduction in the germination (%) and germination index and increased the mean germination time of littleseed canarygrass (Phalaris minor); whereas cobalt chloride at greater concentrations significantly reduced the seedling growth of littleseed canarygrass and wheat with a more pronounced effect on root length as compared to shoot length.

Significant interactions were found between irrigation levels and weed management on the dry weight of total weeds (Tab. 5). The application of 50% of crop water requirement resulted in the lowest values of weed dry weight when pyroxsulam herbicide was used. Similar trends were noticed by Chaudhary *et al.* (2011); Abd Elsalam *et al.* (2016).

With regard to the interactive effects between irrigation level and Co treatments on weeds, the data in Tab. 6 show that the plots which received 50% of crop water requirement and Co treatment produced the smallest dry weight of weeds. The maximum values were found with 100% irrigation level and Co applied at 15 ppm; this confirms the results cited by Gad and El-Metwally (2015) in corn. Moreover, Tab. 7 indicates that the maximum values of dry weight of total weeds were recorded with unweeded and spraying of 15 ppm Co. In contrast, the lowest value of dry weight of total weeds was obtained by pyroxsulam application without Co addition.

Wheat

Growth traits

The results in Tab. 8 reveal significant impacts of irrigation level on flag leaf area, flag leaf chlorophyll content (SPAD value) and plant height. Irrigation with 100% of crop water requirement significantly increased these growth traits compared with the 75 or 50% levels. No significant differences between 100 and 75% of crop water requirement were found. Accordingly, supplying wheat plants with adequate water requirement might help the plant to absorb greater amount of water and nutrients, enhancing internodes elongation, since nutrients encourage cell division and enlargement and meristematic activity. Besides, the beneficial effect of water for improving pigments and photosynthetic process. These results are in harmony with those obtained by El-Sherif *et al.* (2007); Ramadan and Awaad (2008); Abd Elsalam *et al.* (2016).

Pyroxsulam was the most effective treatment resulting in increasing wheat flag leaf area, flag leaf chlorophyll content and plant height (Tab. 8). Moreover,

Tab. 5 Effect of the interactions (weed control x water requirement) on total dry weight of weeds (g/m^2) in wheat (combined analysis of two seasons).
Tab. 5. Effetto delle interazioni (controllo delle infestanti X fabbisogno idrico) sul peso secco totale delle infestanti (g/ m^2) nel frumento (analisi combinate di 2 stagioni).

Weed control	Irrigation level		
	100%	75%	50%
Pyroxsulam	24.06	18.16	12.80
Mesosulfuron-methyl	32.94	24.04	23.14
Isoproturon+diflufenican	29.60	23.38	18.30
Hand weeding	77.60	61.20	39.26
Unweeded	216.00	187.92	138.02
LSD 0.05		9.82	

Tab. 6 Effect of the interactions (Co concentration x water requirement) on total dry weight of weeds (g/m^2) in wheat (combined analysis of two seasons).
Tab. 6. Effetto delle interazioni (concentrazione di Co X fabbisogno idrico) sul peso secco totale delle infestanti (g/ m^2) nel frumento (analisi combinato di due stagioni).

Irrigation level	Co concentration (ppm)				
	0	5	10	15	20
100%	62.60	71.30	78.92	82.80	84.58
75%	51.60	59.70	64.04	69.10	70.26
50%	42.00	45.28	47.74	49.00	49.50
LSD 0.05			4.34		

Tab. 7 Effect of the interactions (weed control x Co concentration) on total dry weight of weeds (g/m^2) in wheat (combined analysis of two seasons).
Tab. 7. Effetto delle interazioni (controllo delle infestanti X concentrazione di Co) sul peso secco totale delle infestanti (g/ m^2) nel frumento (analisi combinato di due stagioni).

Weed control	Co concentration (ppm)				
	0	5	10	15	20
Pyroxsulam	14.33	16.63	19.27	20.43	21.03
Mesosulfuron-methyl	21.33	23.83	28.23	29.80	30.33
Isoproturon+diflufenican	17.67	21.67	25.17	26.77	27.53
Hand weeding	46.67	54.00	59.33	67.33	69.43
Unweeded	160.33	177.67	185.83	190.50	192.23
LSD 0.05			10.12		

Tab. 8. Effect of water regime, weed control and Co concentration on growth and yield attributes of wheat (combined analysis of two seasons).
Tab. 8. Effetto del regime idrico, controllo delle infestanti e concentrazione di Co sulla crescita e resa del frumento (analisi combinate di 2 stagioni).

Treatments	Growth traits			Yield attributes					
	SPAD value	Flag leaf area (cm^2)	Plant height (cm)	Spikes number/ m^{-2}	Spike length (cm)	Spikelets number $spike^{-1}$	Grains number $spike^{-1}$	Grains weight $spike^{-1}$ (g)	1000- grain weight (g)
Irrigation level									
100%	46.02	44.40	93.9	408.8	12.46	18.70	58.22	2.45	37.18
75%	45.42	42.82	90.6	390.6	11.76	18.67	56.16	2.29	36.00
50%	42.96	38.01	78.8	312.8	9.88	16.96	46.66	1.61	31.43
LSD 0.05	2.03	2.11	4.2	20.2	1.53	0.93	2.51	0.29	2.01
Weed control									
Pyroxsulam	46.67	43.90	91.8	421.3	12.27	19.72	58.77	2.45	37.00
Mesosulfuron-methyl	46.00	42.61	87.7	380.3	11.60	18.33	56.27	2.34	35.97
Isoproturon+diflufenican	45.90	43.67	88.7	400.7	11.85	18.78	56.97	2.32	36.25
Hand weeding	44.27	40.22	85.8	337.3	10.70	17.55	52.53	1.89	34.10
Unweeded	41.17	38.42	84.9	314.0	10.20	16.30	47.20	1.57	31.11
LSD 0.05	1.21	2.13	3.2	23.1	0.78	0.93	3.25	0.18	2.11
Co concentration (ppm)									
0	40.70	37.73	83.7	328.0	9.87	16.60	50.50	1.70	30.90
5	43.47	39.62	87.9	353.1	10.66	18.00	52.60	2.00	33.20
10	45.80	42.95	89.8	386.5	11.99	18.90	55.50	2.31	36.50
15	47.40	44.40	88.9	396.3	12.16	18.60	56.70	2.40	37.15
20	46.23	43.84	88.5	389.4	12.10	18.40	55.90	2.17	36.60
LSD 0.05	1.53	1.77	3.2	19.2	1.21	NS	1.14	0.24	1.77

isoproturon+diflufenican treatment was statistically at par with pyroxsulam for improving these wheat growth characters. The enhancement of wheat growth in the weeded plots might be attributed to the efficiency in weed elimination (Table, 4) and the reduction of weed competition. Similar findings confirming these results were reported by (Chaudhary *et al.*, 2011; Neijad *et al.*, 2013; Singh *et al.*, 2013).

The results in Tab. 8 indicate that increasing Co up to 15 ppm gave the highest values of flag leaf area, flag leaf chlorophyll content and plant height. While increasing the Co level more than 15 ppm reduced these effects.

These observations are consistent with previous reports obtained by Gad and El-Metwally (2015) who reported that smaller doses of Co resulted in maximum growth and yield of corn plants as compared with the larger doses. They added that responses associated with low Co levels may be attributed to reduced catalase and peroxidase activities at smaller levels of Co (5, 10 and 15). These enzymes are known to induce plant respiration, increasing the consumption of products of photosynthesis reducing plant growth. Wheat seedlings treated with cobalt chloride at concentrations ≥0.1 mM exhibited significant increase in total soluble sugars (TSS) content with concomitant decrease in protein content (Sethi and Kaur (2016).

Moreover, smaller Co levels have positive effects due to several induced effects on hormonal synthesis and metabolic activity, while greater Co levels were found to increase the activity of some enzymes such as peroxidase and catalase in plant, thus increasing catabolism rather than anabolism. The same conclusion was mentioned by Gad *et al.* (2011); Korayem *et al.* (2014) and Gad and El-Metwally (2015).

Yield and yield attributes

Data presented in Tab. 8 and 9 reveal that the application of 100% of crop water requirements led to the maximum values of number of spikes/m^2, spike length, number of spikelets/spike, number of grain/spike grain, grain weight/spike, 1000- grain weight as well as grain and straw yields.

Tab. 9. Effect of water requirement, weed control and Co concentration on yield and chemical composition of grains wheat (combined analysis of two seasons).

Tab. 9. Effetto del fabbisogno idrico, controllo delle infestanti e concentrazione di Co sulla resa e composizione chimica della granella (analisi combinate di 2 stagioni).

Treatments	Yield		Chemical composition of grain					Water Use Efficiency
	Straw ton/ha	Grain ton/ha	Total carbohydrates %	Total soluble sugars %	Protein %	Fate %	Co ppm	
Irrigation level								
100%	9.42	4.30	70.74	4.95	11.60	2.64	5.30	0.92
75%	8.17	4.00	68.51	4.70	10.54	2.06	4.25	1.23
50%	6.84	2.81	65.60	3.60	9.62	1.71	3.97	1.30
LSD 0.05	0.71	0.53	2.11	0.49	0.51	0.33	0.27	0.12
Weed control								
Pyroxsulam	9.45	4.36	69.37	5.00	11.17	2.30	4.88	1.34
Mesosulfuron-methyl	8.13	3.73	68.86	4.70	10.95	2.18	4.72	1.15
Isoproturon+diflufenican	8.60	4.07	69.28	4.82	11.10	2.21	4.83	1.25
Hand weeding	7.67	3.35	67.24	4.10	10.00	1.94	4.16	1.03
Unweeded	6.87	3.00	66.65	3.55	9.64	1.75	3.89	0.92
LSD 0.05	0.82	0.42	1.14	0.63	0.42	0.28	0.30	0.11
Co concentration (ppm)								
0	7.20	3.12	67.20	3.80	10.11	1.70	3.31	0.96
5	7.85	3.52	67.80	4.00	10.50	2.02	4.56	1.08
10	8.50	3.89	68.50	4.80	10.77	2.20	4.83	1.20
15	8.90	4.08	69.30	4.85	10.99	2.31	5.02	1.25
20	8.20	3.92	68.60	4.70	10.60	2.13	4.75	1.21
LSD 0.05	0.47	0.34	0.72	0.35	NS	0.17	0.21	0.09

There was no significant difference between the addition of 100% and 75% watering requirement on most of the growth and yield traits. In contrast, using 50% of crop water requirements gave smaller values of these crop characters. Drought increases respiration which decreases assimilates for grain filling and investigator reported that drought stress reduces photosynthesis and translocation rates, decreasing grain yield (Mahgoub and Sayed, 2001; Badawi *et al.*, 2008). Thus, sufficient water of 100% or 75% of crop water requirement will help the plant to absorb greater amount of water and nutrients encouraging cell division and enlargement and meristematic activity (Fageria *et al.*, 2010). Besides, the beneficial effect of water for improving pigments and photosynthetic process and accumulation of metabolites lead to increases in yield and its components (El-Hag, 2015; Abd Elsalam *et al.*, 2016).

Concerning the effect of weeded practices on yield and its attributes, all weeded plots produced more yield over the weedy control treatment. Applying pyroxsulam resulted in increases in the number of spikes/m^2, straw and grain yields by 34.2, 37.6 and 45.3 % over the weedy control, respectively (Tab. 8 and 9). Such treatment minimized weed-crop competition (Tab. 4) and saved more of the available resources for improved crop growth (Tab. 8). Thus, this treatment increased plant height and resulted in greater straw and grain yields. The positive effect of weed control on wheat yield and its components have been confirmed by El-Metwally and El-Rokiek (2007); Tesfay (2014); Abd Elsalam *et al.* (2016) whereas weed competition causes a reduction in wheat grain yield;48.7% reduction was observed by Kamrozzaman *et al.*, (2015).

Data presented in Tab. 8 and 9 show significant increases of all the studied traits, (except protein %), with increasing Co levels from 0 to 15 ppm. Application of 15 ppm Co led to significant increase in the number of spikes/m^2, spike length, number of grains/spike, grain weight/spike, 1000- grain weight as well as grain and straw yields. On the other hand, the smallest values of these growth and yield parameters were recorded in untreated plots. Moreover, no significant differences between 15 and 20 ppm Co were found.

These data are in harmony with those obtained by Gad and El–Metwally (2015). They stated that smaller doses of Co resulted in maximum growth and yield of corn plants as compared with the larger doses. They also reported that the responses associated with small Co levels may be attributed to catalase and peroxidase activities which were found to decrease with low levels of Co and increase with the higher ones. These enzymes are known to induce plant respiration, so superior resulting in successive consumption for products of photosynthesis and consequently reduce the plant growth.

Data in Tab. 10 show that there was a significant effect due to the interaction between irrigation level and weed control on grain yield. Irrigation with 100% water requirement significantly increased grain yield when pyroxsulam was applied compared with the other treatments. Results also indicated that 100% irrigation and using Isoproturon+diflufenican was slightly less effective but not significantly so. The smallest grain yield was recorded with the unweeded treatment and irrigation of 50% of crop water requirement. These results are in harmony with those of El-Metwally *et al.* (2015b); Abd Elsalam *et al.* (2016).

There are significant interactions between irrigation level and Co addition rate on grain yield (Table 11). Irrigation with 100% crop demand recorded the largest grain yields when wheat plants were treated with 15 ppm Co.

The interaction effect of weed control treatments and Co level significantly affected grain yield as maximum values were obtained with combined treatment of pyroxsulam and 15 ppm Co (Tab. 11). The unweeded plots without Co application gave the smallest grain yield.

Grain chemical analysis

The concentrations of total carbohydrates, total soluble sugars, protein, fats and Co were appreciably influenced by irrigation level (Tab. 9), progressively increasing up to 100% irrigation demand. A similar trend was found by other authors (El-Sherif *et al.*, 2007; Singh *et al.*, 2013; El-Metwally *et al.*, 2015b; Abd Elsalam *et al.*, 2016).

As shown in Table 9 all of the weed control treatments significantly improved the concentrations of total carbohydrates, total soluble sugars, protein, fates and Co in wheat grain. The largest values were obtained from the pyroxsulam treatment followed by isoproturon+diflufenican and mesosulfuron-methyl treatments but these were no significantly different. These results may be due to the reduced weed competition for nutrients, water and light. Similar results were

Tab. 10. Effect of the interactions (weed control x water requirement) on grain yield of wheat ton/ha (combined analysis of two seasons).
Tab. 10. Effetto delle interazioni (controllo delle infestanti X fabbisogno idrico) sulla resa della granella ton/ha (analisi combinate di 2 stagioni).

Weed control	Irrigation level		
	100%	75%	50%
Pyroxsulam	5.08	4.80	3.20
Mesosulfuron-methyl	4.40	4.00	2.80
Isoproturon+diflufenican	4.80	4.40	3.00
Hand weeding	3.80	3.60	2.64
Unweeded	3.40	3.20	2.40
LSD 0.05		0.43	

Tab. 11. Effect of the interactions (Co concentration x water requirement) on grain yield of wheat ton /ha (combined analysis of two seasons).
Tab. 11. Effetto dell'interazione (concentrazione di Co X fabbisogno idrico) sulla resa della granella ton/ha (effetto combinato di 2 stagioni).

Irrigation level	Co concentration (ppm)				
	0	5	10	15	20
100%	3.64	4.10	4.48	4.86	4.60
75%	3.42	3.86	4.24	4.40	4.16
50%	2.30	2.60	2.95	3.18	3.01
LSD 0.05			0.37		

Tab. 12. Effect of the interactions (weed control x Co concentration) on grain yield of wheat ton /ha (combined analysis of two seasons).
Tab. 12. Effetto delle interazioni (controllo infestanti X concentrazione di Co) sulla resa del frumento ton/ha (effetto combinato di 2 stagioni).

Weed control	Co concentration (ppm)				
	0	5	10	15	20
Pyroxsulam	3.60	4.17	4.53	4.82	4.68
Mesosulfuron-methyl	3.33	3.60	3.87	4.07	3.87
Isoproturon+diflufenican	3.43	3.90	4.30	4.47	4.27
Hand weeding	2.75	3.15	3.57	3.73	3.60
Unweeded	2.48	2.78	3.18	3.25	3.20
LSD 0.05			0.52		

obtained by Shehzad *et al.*, 2012; Tesfay, 2014; Abd Elsalam *et al.*, 2016.

The concentrations of total carbohydrates, total soluble sugars, fats and Co in wheat grain were appreciably influenced by Co levels (Tab. 9). In this respect, with each increase in Co level, there was a progressive improvement in chemical composition.

Application of Co at 15 ppm led to the largest concentrations of total carbohydrates, total soluble sugars, protein, fats percent and Co. These results are in harmony with those obtained by Gad (2012) revealed that Co addition in plant media increased protein, total soluble solids, total carbohydrates and total soluble sugars in groundnut seeds. Similar findings were reported by Korayem *et al.* (2014) in rice, and Gad and El–Metwally (2015) in corn.

Water Use Efficiency

Water use efficiency (WUE) is expressed as grain yield (kg) divided by unit of water consumed (m^3). The data in Tab. 9 indicate that WUE progressively increased as water stress increased from 100% to 75% and 50%.

These results illustrate the significant impact of weed control treatments on water use efficiency. Pyroxsulam enhanced WUE more than the other weeded practices while the unweeded control has the poorest WUE value. The differences between the three herbicides tested were insignificant.

Co addition resulted in significant improvements in water WUE of wheat plants compared with the untreated plants with the best WUE value obtained by the addition of 15 ppm Co.

CONCLUSION

It may be concluded that the best approach to enhancing the yield of wheat is to apply at least 75% of crop water requirements and to control weeds by the application of pyroxsulam herbicide and 15 ppm Co. The results also indicated that Co significantly increases the ability of wheat plants to withstand water shortages, reducing the crop water requirement by 25%.

REFERENCES

1. Abd El-Salam M.S., El-Metwally I.M., Abd El Lateef E.M., Ahmed M.A., 2016. Effect of weed control and proline treatment on wheat productivity and weed nutrient removal under water stress conditions. Int. J. ChemTech Res., 9(7):18-31.
2. Abdelraouf R.E., El Habbasha S.F., Taha M.H., Refaie K.M., 2013. Effect of irrigation water requirements and fertigation levels on growth, yield and water use efficiency in wheat. Middle-East J. Sci. Res., 16(4):441-450.
3. Abdul-Khaliq K.A. and Imran M., 2003. Integrated weed management in wheat grown in irrigated areas. Int. J. Agric. Biol., 5(4):530-532.
4. Abouziena, H.F.; Sharara Faida A.A., El-desoki E.R., 2008. Efficacy of cultivar selectivity and weed control treatments on wheat yield and associated weeds in sandy soils. World J. of Agric. Sci., 4:384-389.
5. A.O.A.C., 1990. Official Methods of Analysis of the Association of Official Edition, Washington, D.C.
6. Allen R.G., Pereira L.S., Raes D., Smith M., 1998. Crop evapotranspiration - Guidelines for computing crop water requirements – FAO Irrigation and drainage paper 56. FAO – Food and Agriculture Organization of the United Nations, Rome.
7. Anter F., Gad N., 2001. Cobalt absorption in relation to plant water balance. Egypt. J. Soil Sci., 41(1-2):111-122.
8. Badawi M.A., El-Moursy S.A., El-Hindi M.H., Borham M.M.E., 2008. Productivity of wheat as affected by irrigation system, nitrogen levels and foliar application under newly reclaimed sandy soils. J. Agric. Sci., Mansoura Univ., 33(7):751-4760.
9. Bhat M.A., Mahal S.S., Hussain A., Mushki G.M., 2006. Effect of nitrogen levels, irrigation regimes and weed management in durum wheat (*Triticum durum* Desf.). Indian J. Crop Sci., 1(1-2):184-188.
10. Chaudhary S., Hussain M., Iqbal J., 2011. Chemical weed control in wheat under irrigated conditions. J. Agric. Res., 49 (3):253-261.
11. Cottenie A., Verloo M., Kiekens L., Velgh G., Camerlynck R., 1982. Chemical Analysis of Plant and Soil. Lab. Anal. Agrochem. State Univ Gthent, Belgium, 63.
12. El-Metwally I.M., El-Rokiek K.G., 2007. Response of wheat plants and accompanied weeds to some new herbicides alone or combined in sequence. Arab Univ. J. Agric. Sci., 15:513-525.
13. El_Metwally I.M., Abd El- Salam M.S., Osama A.M., 2015a. Effect of zinc application and weed control on wheat yield and its associated weeds grown in zinc-deficient soil. Int. J. ChemTech Res., 8(4):1588-1600.
14. El-Metwally I.M., Ramadan A.E., Ahmed M.A., Oussama M., Alarcon J.J., Abdelhamid M.T., 2015b. Response of wheat (*Triticum aestivum* L.) crop and broad-leaved weeds to different water require-

ments and weed management in sandy soils. Agric. (Poľnohospodárstvo), 61(1):22-32.

15. El-Hag W., 2015. Morphological studies on bread wheat under different regimes and planting method. Ph D. Thesis, Fac Agric, Kafer El-Shikh Univ, Egypt.
16. El-Sheref E.M., Omar A.M., El-Hag A.A., Shahen A.M., 2007. Effect of some agricultural treatments on barley yield and some technological characters. J. Agric. Sci., Mansoura Univ., 32:1671-1690.
17. Fageria N.K., Baligar V.C., Jones C.A., 2010. Growth and mineral nutrition of field crops. Third Edition. CRC Press, Taylor & Francis Group, 586 pp. ISBN 9781439816950.
18. Gomez K.A., Gomez A.A., 1984. Statistical Procedures for Agriculture Research. A Wiley – Inter Science Publication, John Wiley & Sons, Inc., New York, USA.
19. Hussein A., Ghaudhry M.R., Wajad A., Ahmed A., Rafiq M., Ibrahim M., Goheer A.R., 2004. Influence of water stress on growth, yield and radiation use efficiency of various wheat cultivars. Int. J. Agri. & Biol., 6:1074-1079.
20. Kamrozzaman, M. M., Khan M. A. H., Ahmed S. A., Ruhul Quddus F. M., 2015. On-farm evaluation of production potential and economics of Wheat-Jute-T. aman rice-based cropping system; J. Bangladesh Agril. Univ., 13(1):93–100.
21. Korayem A.M., Gad N., Mohamed M.M.M., 2014. Effect of cobalt on rice rlants infected with the rice-root nematode *Hirschmanniella oryzae* in irrigated rice. Middle-East J. App. Sci., 4(4):1150-1154.
22. Mahgoub H.S., Sayed M.A. 2001. Response of two wheat cultivars to irrigation amount and nitrogen level in sandy soils. J. Agri. Sci., Mansoura Univ., 26:1863-1873.
23. Minolta Camera Co. (1989) Manual for chlorophyll meter SPAD-502. Minolta Camera Co., Osaka, Japan.
24. Gad N., 2012. Role and Importance of Cobalt Nutrition on Groundnut (*Arachis hypogaea*) Production. World App. Sci. J., 20 (3):359-367.
25. Gad N., El–Metwally I.M., 2015. Chemical and physiological response of maize to salinity using cobalt supplement. Int. J. ChemTech Res., 8(10):45-52.
26. Gad N., Abd El-Moez M.R., Kandil H., 2011. Barley response to salt stress at varied levels of cobalt. II. Some physiological and chemical characteristics. J. App. Sci. Res., 7(11):1447-1453.
27. Neijad A.Y., Fazel M., Amani A., 2013. Evaluating the effects of atlantis, granstar and topic herbicides and split of nitrogen fertilizer on controlling weeds of D79-15 wheat conducted in Behbahan city. Int. J. Agric. and Crop Sci., 5(21):2584-2587.
28. James L.G., 1988. Principles of farm irrigation system design. John Willey & sons. Inc., Washington State University, pp. 73:152-153, 350-351.
29. Ortega R.C., Cordero G.A., Anaya A.L. 2002. Allelochemical stress produced by the aqueous leachate of *Callicarpa acuminata*: effects on roots of bean, maize, and tomato. Physiol. Plant, 116(1):20 -27.
30. Pilon-Smits E.A.H., Quinn C.F., Tapken W., Malagoli M., Schiavon M., 2009. Physiological functions of beneficial elements. Current Opinion in Plant Biology, 12:267-274.
31. Ramadan A.R., Awaad S.S. 2008. Response of yield and yield attributes of some bread wheat varieties to irrigation levels and seeding rate under old land conditions. J. Agric. Sci., Mansoura Univ., 33:4717-4737.
32. Sethi R., Kaur N., 2016. Role of ethylene in germination and seedling growth of littleseed canarygrass (*Phalaris minor* Retz.). Indian J. Plant Physiol., 21(3):345–349.
33. Shaban S.A., Soliman S., Yehia Z.R., El Attar M.H., 2009. Weed competition effects on some *Triticum aestivum* quality and quantity components. Egypt. J. Agron., 31(2):135-147.
34. Shehzad M.A., Nadeem M.A., Iqbal M., 2012. Weed control and yield attributes against postemergence herbicides application in wheat crop, Punjab, Pakistan. Global Adv. Res. J. Agric. Sci., 1(1):7-16.
35. Smith R.M. 1991. Trace elements in human and animal nutrition. Micronutrients News Information, 119.
36. Singh R.K., Singh S.R.K., Gautam U.S., 2013. Weed control efficiency of herbicides in irrigated wheat (*Triticum aestivum*). Indian Res. J. Ext. Edu., 13(1):126-128.
37. Tesfay A. 2014. Effect of weed management methods on weeds and wheat (*Triticum aestivum*) yield. African J. Agric. Res., 9(24):1914-1920.
38. Tiwari R.B. and Parihar (1997) Weed management in wheat (*Triticum aestivum*). Indian J. Agron., 42(4):726-728.

APPENDIX

Tab. 1. Source of variance, degree of freedom and mean square of the studied traits under irrigationlevels, weed control as well as cobalt concentrations.
Tab. 1. Fonte di varianza, grado di libertà e valore quadratic medio dei tratti studiati sotto diversi livelli di irrigazione, controllo delle infestanti e concentrazione di cobalto.

source	DF	Broad leaved	Narrow leaved	Total weeds	N-Uptake	P-Uptake	K-Uptake	SPAD value	Flag leaf area	Plant height	No. of spikes/ m^2	Spike length (cm)	Spikelets number $spike^{-1}$
Blocks	2	5.791 NS	0.2349 NS	276.15 NS	88.57 NS	0.00166 NS	0.0084 NS	148.61 NS	14.69 NS	2.40 NS	152.71 NS	0.624 NS	0.2672 NS
Irrigation	2	8476.26**	5115.36**	30179.22**	152.308**	1.051**	10.303**	64.98**	451.37**	83.52**	239788.3**	111.04*	128.383**
Main plot error	4	25.198	3.532	134.78	86.600	0.00134	0.01522	0.3741	6.5108	1.61	78.66	0.4225	1.5658
Weed	4	168427.37**	23182.62**	437782.98**	263.21*	2.007**	341.52**	275.42**	382.34**	2951**	184240.69**	73.088**	118.83**
Irr.×W.	8	2384.02**	749.02**	5407.10	94.35 NS	1.025**	5.081**	4.911 NS	1.505 NS	2.894 NS	4629.04**	1.289**	2.9116*
Sub plot Error	24	8.379	1.8849	117.74	87.44	0.0015	0.03059	3.771	5.91	2.714	172.93	0.6060	0.4083
Cobalt	4	1424.60**	725.41**	3840.70**	81.81 NS	0.0045**	0.6371**	23.44**	29.62**	30.94**	3651.41**	9.479*	21.016 NS
Irr.× Co.	8	65.879**	31.98**	188.89 NS	88.78 NS	0.00181 NS	0.01033 NS	0.4108 NS	0.2671 NS	0.328 NS	116.17 NS	0.34392 NS	0.25265 NS
W.×Co.	16	154.8984**	33.46**	436.35**	88.05 NS	0.0022 NS	0.0265*	0.5769 NS	0.2419 NS	0.6976 NS	107.08 NS	0.3548 NS	0.13967 NS
W.×. Irr×Co.	32	28.876 NS	18.334 NS	175.118 NS	88.32 NS	0.00181 NS	0.0048 NS	0.5016 NS	0.2281 NS	0.4077 NS	90.33 NS	0.36919 NS	0.10257 NS
Error	345	17.3197	6.133	126.49	89.99	0.00165	0.01348	4.292	2.996	3.387	173.11	0.48943	0.5137

Tab. 2 Source of variance, degree of freedom and mean square of the studied traits under irrigationlevels, weed control as well as cobalt concentrations.

source	DF	Grains number $spike^{-1}$	Grains weight $spike^{-1}$ (g)	1000-grain weight	Straw ton/ ha	Grain ton/ ha	Total carbohy-rates %	Total soluble sugar %	Protein %	Fate%	Cobalt ppm	Water use Efficiency
Blocks	2	14.90 NS	0.0279 NS	15.69 NS	0.3404 NS	0.0279 NS	13.98 NS	0.1201 NS	1.257 NS	1.016 NS	0.3879 NS	0.0187 NS
Irrigation	2	992.10*	6.3174**	399.17**	206.95**	6.3174**	852.10*	5.9994**	235.88**	11.664*	196.24**	4.2144**
Main plot error	4	1.0398	0.6444	5.2447	0.0761	0.6444	1.0277	0.6345	0.1446	0.837	0.0751	0.5342
Weed	4	1372.62*	14.993**	299.31**	94.366**	14.993**	128961*	13.981**	4.473**	7.842**	93.378**	11.248**
Irr.×W.	8	9.382**	0.038*	0.099 NS	5.0591**	0.038*	8.282**	0.101*	2.7699**	1.349 NS	4.0987**	0.029*
Sub plot Error	24	2.4553	0.0134	5.11	0.0878	0.0134	2.6553	0.0151	0.5865	1.297	0.0787	0.0112
Cobalt	4	41.7394**	0.5679**	28.12**	3.2476**	0.5679**	39.6292**	0.4987**	4.060 NS	1.181 NS	3.1422**	0.4214**
Irr.× Co.	8	0.5625 NS	0.0016 NS	0.2841 NS	0.0569 NS	0.0016 NS	0.6014 NS	0.0036 NS	0.035 NS	1.114 NS	0.0574 NS	0.0017 NS
W.×Co.	16	10.664 NS	0.0039 NS	0.2329 NS	0.0339 NS	0.0039 NS	11.321 NS	0.0041 NS	0.0671 NS	1.207 NS	0.0342 NS	0.0045 NS
W.×. Irr×Co.	32	0.3844 NS	0.00256 NS	0.2311 NS	0.0458 NS	0.00256 NS	0.3954 NS	0.01012 NS	0.0321 NS	1.163 NS	0.0464 NS	0.0114 NS
Error	345	2.773	0.0162	2.796	0.1494	0.0162	2.883	0.0148	0.32135	1.180	0.1399	0.0158

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How can policy influence innovation: An exploration of climate-smart activities in Emilia-Romagna

Il supporto politico verso l'innovazione: Le attività climate-smart dell'agricoltura dell'Emilia-Romagna

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Abstract. Climate change is one of the main issues in agriculture. Considering its involvement in the global anthropogenic emissions (GHG) it is no wonder that research is devising ways on how to reduce such effects. A solution to such problems is climate-smart agriculture (CSA). In this paper, we analysed which are the main opportunities granted by agricultural policies when aimed at sustaining innovative agricultural models. A review of the ongoing 93 Rural Development Projects (RDPs) uncovered potential climate-smart solutions for the identified potential threats. The Ministry of Agriculture, Hunting and Fishing of the Region of Emilia-Romagna in Italy has given importance to RDPs to innovate the agricultural sector through policy measures. We analysed an Operational Group (OG) project as an overview of the work. In the case of Emilia-Romagna, the amount of innovation and solutions that can be achieved if policies invest in CSA is very clear. Emilia-Romagna is on the forefront of technological and practical advancements in the EU by implementing CSA as one of the primary solutions to the aforementioned problems and will continuously work on transitioning its agricultural practices to fight climate change.

Keywords. Climate change, climate-smart agriculture, RDP, innovation, solution, technology.

Riassunto. L'adattamento al cambiamento e alla variabilità climatica sono tra le tematiche maggiormente rilevanti per la agricoltura di oggi. Considerando anche l'entità del contributo di numerose attività produttive agricole alle emissioni antropogeniche (GHG), sono ormai pressanti la ricerca e la applicazioni di strumenti che si indirizzino, in contemporanea e/o in alternativa, verso la mitigazione. Un approccio in questo senso è offerto dalla "Climate-Smart Agriculture" (CSA). Questo lavoro analizza alcune tra le opportunità che le politiche agricole offrano per sostenere e promuovere modelli agricoli innovativi di applicazioni CSA. Una revisione dei 93 Progetti di Sviluppo Rurale (PSR) finanziati in Emilia Romagna dal Ministero dell'Agricoltura, Caccia e Pesca della Regione Emilia-Romagna ha individuato la presenza di numerose soluzioni climate-smart in grado di fronteggiare potenziali minacce climatiche. In particolare, la ricerca si è indirizzata verso le attività dei Gruppi Operativi per l'Innovazione (GOI).

L'analisi ha evidenziato la portata dell'impatto che le politiche possano comportare verso la promozione di una agricoltura CSA. In questo senso, l'Emilia-Romagna si è dimostrata all'avanguardia all'interno dell'Unione Europea come regione promotrice di una attiva transizione delle pratiche agricole verso una sostenibilità in situazioni di cambiamento climatico.

Parole chiave. Cambiamento climatico, agricoltura climate-smart, PSR, innovazione, soluzione, tecnologia.

1. INTRODUCTION

One of the major issues plaguing agriculture that we are facing now is climate change. Considering that agriculture is co-responsible for the global anthropogenic emissions (GHG) it is no wonder that research is devising ways on how to reduce such effects. The world is producing enough food at the moment, yet the estimate of undernourished people has reached a staggering number of 870 million. Currently, FAO predicts that agricultural production will have to increase by approximately 60% by 2050 in order to satisfy the expected one-third increase in the world's population (FAO, 2013). When we consider everything, we realize that if we continue at this pace, agricultural emissions are projected to increase creating major issues for biodiversity and ecosystem services such as water quality and soil protection.

Agriculture must hence transform itself in order to maintain the current population growth and to reduce its overall global impact on climate change. During the 2010 Hague Conference on Agriculture, Food Security and Climate Change, a possible solution was proposed that could manage agriculture and food systems under climate change (FAO, 2013; Lipper *et al.*, 2014; Thornton *et al.*, 2017).

The solution in question is climate-smart agriculture (CSA) that is based on three main objectives: I) sustainable increase of agricultural productivity and income; II) adaptation and resilience to climate change; III) reduction and/or removal of greenhouse gases emissions, whenever possible. CSA tries to identify and operationalize sustainable agricultural development through climate-resilient pathways by increasing local institutional effectiveness, fostering coherence between climate and agricultural policies, and link climate and agricultural financing (Thornton *et al.*, 2017). The attainment of the three CSA objectives simultaneously proves to be difficult. Saj et.al, 2017 consider that research where all three CSA criteria are not taken into account, cannot effectively be considered climate smart. Even though research strives to produce results that try to embrace all of the key pillars, it remains unachievable on a global scale considering the differences in diverse regions and scenarios. CSA must derive locally acceptable solutions through potential synergies and trade-offs between the three pillars that will always be unique depending on the scenario (Lipper *et al.*, 2014). One of the most important policy processes launched, until now, dates in 2014 with the creation of the Global Alliance for Climate Smart Agriculture (GACSA; http://fao.org/gacsa/en/) constituting of many stakeholders including the World Bank, FAO and IFAD.

Research should be responsible for disseminating climate-friendly information that can be useful for policymakers at all levels from national governments and farmers alike, prioritizing climate-smart investment. By now we have gathered the notion that decision-making processes that plan for climate-smart activities are inherently multi-stakeholder, multi-scale and multi-objective (Notenbaert *et al.*, 2017). With that in mind, one of the most important policies on the European level dates back to 1962 as a partnership between agriculture and society, known as the Common Agricultural Policy (CAP). Since then, its objectives to support farmers and agricultural productivity, to ensure a stable income for European farmers, to help tackle climate change and to keep the rural economy alive, have steadily evolved to provide a central and connecting role between the farmer and policymakers (IFPRI, 2018; Recanati *et al.*, 2019). CAP has seen three major reforms that played a key part in its development over the decades. The first was in 1992 (Rio Earth Summit) which incentivized environmentally compatible farming practices through direct payments. The second was in 2003 (Fischler Reform) where the central roles of food quality, environmental protection, animal health and welfare, and rural development in the EU were acknowledged (Brady *et al.*, 2009; Recanati *et al.*, 2019). The last and most recent reform in 2013 saw the widening of CAP from modernizing agriculture, price stability and food accessibility (Erjavec and Erjavec, 2009) towards a multifunctional and sustainable agriculture and rural development (Solazzo *et al.*, 2016). It did so through the direct support to producers in order to achieve long-term objectives reflecting sustainability by way of viable food production, balanced rural development, and sustainable natural resources management and climate action (Policy and Brief, 2013). With the introduction of the CAP 2014-2020, the environmental concerns are tackled via two pillars tightening the gap between them in order to generate a more holistic and integrated approach to policy support.

The CAP is broken down into two pillars, Pillar I that introduced Single Payment Schemes (SPS) and Pillar II that supports the European Union's rural development policy. Pillar I marks a shift from decoupling to a targeting agricultural aid by means of direct payments and market measures for all EU farmers to respond to the 'Polluter-Pays-Principle', thus avoiding agricultural damage (Massot, 2018). Pillar II is created to support rural development policies under Agenda 2000. It is co-financed by the European Agricultural Food for Rural Development (EAFRD) to respond to the 'Provider-Gets-Principle' to remunerate farmers' voluntary choice in contributing to environmental objectives that go beyond legal requirements. The implementation of these policies comes through rural development programmes (RDPs) designed by the Member States. These multiannual programmes create a personalised strategy that coincides with specific needs of the Member States or Regions and relate to at least four of the six EU priorities for rural development policy (EP, 2018).

One of the most important Measures in the Rural Development Programmes (RDPs) is Measure 16 (M16). One of its Sub-Measures, 16.1, provides support for establishing and managing the European Innovation Partnership (EIP) Operational Groups (OGs) and the subsequent planning and realization of projects organized by the OGs. These groups have to consist of partnerships involving an array of stakeholders from farmers, researchers, advisors and businesses. OGs are expected to respond to challenges that require multidisciplinary solutions or to identify new opportunities for improvement by working on new techniques, processes, products, technologies etc. In the end, the dissemination of the results ensures that M16.1 implementation also achieves its objectives of knowledge and technology transfer (EIP, 2017).

Italian territory is largely dedicated to agriculture, with recognized excellence in the agri-food national sector, that poses itself as an engine for the national economy, labour and rural development. Emilia-Romagna, located in the North-East Po plane, is one of the regions in which noticeable high-quality crops are grown, and a traditional farming area due to climate and geographical local features (Fanfani and Pieri, 2017). Such an attitude has been progressively stimulating farmers to cope with climate, and local policymakers to support actions facilitating this. For example, a specific LIFE+ Project (ClimateChangER; http://agricoltura.regione.emilia-romagna.it/climatechanger) has been dedicated to the quantification of the GHG emissions by agricultural activities and a specific report has been produced on CSA (Borsetta *et al.*, 2018). In this paper, we have taken Emilia Romagna as a case study to investigate the potential for innovation through the implementation of RPD actions boosting climate-smart agriculture.

In this case study, we analysed which are the main issues that agriculture in Emilia-Romagna is facing and how the 2014-2020 Rural Development Plan has promoted CSA activities. The main climate-related threats have been categorized through extensive literature reviews and face-to-face meetings with farmers and landowner. A review of the ongoing 93 RDP projects uncovered potential climate-smart solutions for the identified potential threats. The selection criteria for worthy projects was done by reviewing the main issues that the OGs were tackling, the possible solutions to said issues and/or possible innovations from a technological and practical standpoint.

2. MATERIALS AND METHODS

As mentioned, the categorization for the main threats was done based on literature reviews that identified the main problems. In particular, papers from Constantin *et al.*, 2010; Dickie *et al.*, 2014; Iglesias and Garrote, 2015; Lindner *et al.*, 2010; Miraglia *et al.*, 2008; Rojas-Downing *et al.*, 2017; Smith *et al.*, 2011; Rana *et al.*, 2018 comprise a good overview of the general issues and solutions.

An outline of the main threats connected to climate variability and change was done thereafter. Threats identified were:

l) soil deterioration
II) water scarcity
lll) deterioration of water quality
V) shift in vegetative seasons
V) exasperation of pests and diseases
VI) extreme events
VII) GHG increase
VIII) deterioration of livestock conditions

Each category of threat exhibited specific solutions on how to tackle the threat in question. For instance, eight possible solutions have been identified to face soil degradation such as soil erosion control, desertification prevention, soil contamination prevention, improvement of organic matter in the soil etc. The same approach was established for all eight threats. With the categories outlined, the next step was the analysis of the 93 approved RDP projects. Firstly, we sought out to determine how many projects demonstrated climate-smart properties and/or applications in order to fully grasp the range of CSA integration in the RDP. Secondly, an in-depth analysis of the project proposals was completed to determine the quality of the proposal to understand the spectrum of innovation in Emilia-Romagna. With the termination of the analysis, we categorized the projects based on the solutions they provided to the aforementioned threats.

3. RESULTS

3.1 CSA in RDP

An example of an entity that has greatly invested in RDPs is the Ministry of Agriculture, Hunting and Fishing of the Region of Emilia-Romagna in Italy. The Emilia-Romagna RDP relies on an investment of 1 billion and 190 million Euros, which is by far the largest amount ever allocated to rural development in recent regional programming schemes and the largest amount among the northern Italian regions. Compared to previous RDPs, Emilia- Romagna resources have increased to 131 million Euros of total public spending with an additional 100 million Euros of regional co-financing. With such importance given to RDPs to innovate the agricultural sector, it comes to no surprise that Emilia-Romagna is on the forefront of technological and practical advancements in the EU by implementing CSA as one of the primary solutions to the aforementioned problems. For Sub-Measure 16.1, RER has financed 93 projects with nearly 20 million euros in investments. The investment was divided into different focus areas as can be seen in Fig. 1.

Of the 93 projects that have been approved under the Sub-Measure 16.1, 66 of them were oriented towards CSA. By going into detail, we identified that certain projects were offering multiple solutions for a single threat or even tackling multiple threats simultaneously. The project analysis found that the largest amount of funds and projects was financed for the threat of increased gas emissions, with soil deterioration and water scarcity and quality deterioration following closely (Fig. 2).

Another important result is that 14 of the projects are transversal by tackling multiple threats. Projects that were considered transversal had the characteristic of being innovative by managing to offer solutions to multiple threats.

The threat of soil deterioration has seen 12 projects that proposed solutions, 50% of which was dedicated to improving organic matter content in the soil (7 projects) and 30% to controlling soil erosion (Tab. 1). The remaining percentage tackled contamination prevention, biodiversity improvement and carbon enrichment of the soil. A piece of noteworthy information is the lack of projects that provide solutions for desertification, soil salinization and landslides, all of which point to possible future research possibilities. Water scarcity was largely addressed through the modernization of soil irrigation systems (7 projects), water management innovation (5 projects) and reduction of water necessity that managed to obtain 46% of the total financing for the threat. The remaining solutions such as re-usage of wastewater and enhancing the water retention capability of the soil showed that there are potential models to estimate groundwater levels and runoff events, saw one project

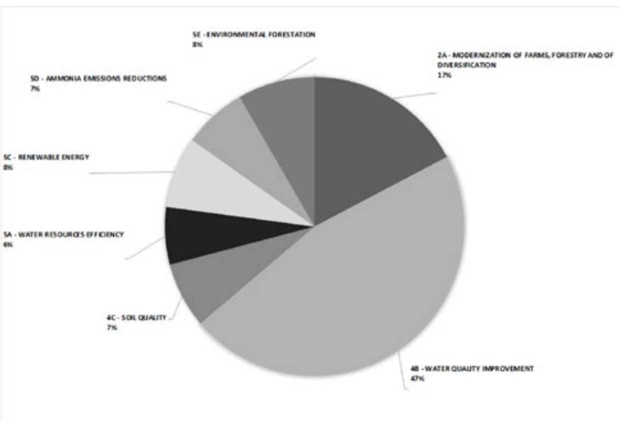

Fig. 1. Investment allocation for the different focus areas.
Fig. 1. Allocazione degli investimenti per le diverse focus area.

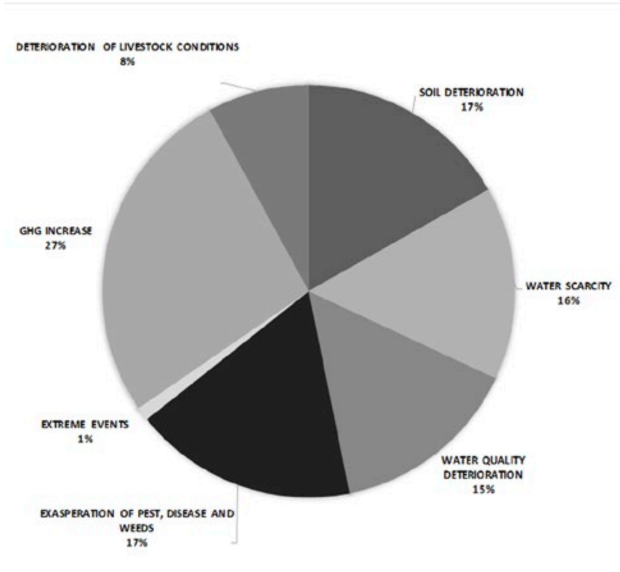

Fig. 2. Percentage of fund allocation.
Fig. 2. Percentuale dell'allocazione dei fondi.

Tab. 1. The analysis of the number of projects that contained solutions for specific threats.
Tab. 1. L'analisi del numero dei progetti che contengono soluzioni per specifiche minacce.

THREAT	SOLUTIONS
SOIL DEGRADATION	
Soil organic matter improvent	7
Soil erosion control	4
Soil contamination prevention	1
Soil biodiversity improvement	1
Carbon enrichment in soil	1
Desertification prevention	/
Decrease in soil salinization	/
Landslide prevention	/
WATER SCARCITY	
Modernization of irrigation system	7
Reduction of water necessity	4
Re-usage of wastewater	1
Enhancement of soil water retention	1
Water management innovation	5
Water harvesting equipment	/
New water efficient crops	/
WATER QUALITY DETERIORATION	
Fertilization efficiency improvement	5
Preservation of water quality	7
EXASPERATION OF PESTS, DISEASES AND WEEDS	
Increase in crop diversification/biodiversity	8
Increase in protection against pests and diseases	5
Promotion of new pest resistant varieties	2
EXTREME EVENTS	
Increased protection against disasters	1
Promotion of new resistant varieties	1
Income diversification	/
Strenghtening of weather forecasts and meteo stations	/
Strenghtening the micro meteorological applications	/
GHG INCREASE	
Increase of carbon sequestration	12
Reduction of GHG emissions	5
Reduction in ammonia (NH3), Nitrous oxide (N2O) and CH4 emission caused by manure storage	5
Reduction of CO2 emission by reducing fossil fuel consumption (e.g. : use renewable energy, improve energy efficiency, use alternative energy sources etc.)	4
Reduction of NH3 and N2O emission from manure and mineral fertilizer distribution	2
Reduction of CH4 from enteric fermentations	1
Reduction of CO2 emission by reducing chemicals (herbicides, pesticides, insecticides)	1
Reduction of CH4 from rice farming	1
DETERIORATION OF LIVESTOCK CONDITIONS	
Preservation of biosecurity	5
Preservation/improvement of quality of pastures	12

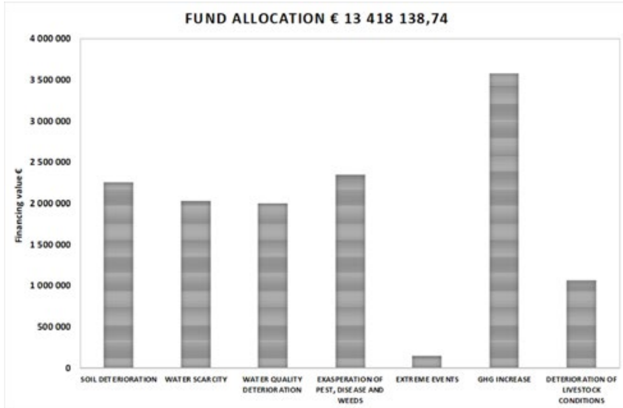

Fig. 3. RDP fund allocation for the different threat categories.
Fig. 3. Allocazione dei fondi del PSR per le diverse categorie di minacce.

each, whereas new water harvesting equipment and water efficient crops are still waiting for a viable idea. Water quality deterioration offered two types of solutions with 55% of the investment gone into improving fertilization efficiency and the remaining 45% towards preserving water quality. As far as exasperation of pests, diseases and weeds, Emilia-Romagna financed a total of 14 projects, 5 of which comprised 46% of the total investment, concentrated on protection against pests and diseases and crop diversification and biodiversity (8 projects). For new pest-resistant varieties, only two projects were discovered that offer a solution. In the extreme events category, two projects were identified each providing its own solution: protection against disasters and promotion of resistant varieties. No viable projects were evidenced for income diversification, strengthening of weather forecasts and meteo stations and micro-meteorological applications. The category of threats that saw the most amount of projects and investments was surely the GHG increase (Fig. 3) with 25 projects in total that offer mitigating solutions such as carbon sequestration in soils, reduction of emissions by reducing fossil fuels, reduction of CO_2, CH_4, NH_3, N_2O etc. Livestock is generally considered for preserving biosecurity (4 projects).

3.2 An example of CSA in RDP projects

As an example of how projects offer solutions to certain threats, we analysed an OG project approved by Emilia-Romagna as a case study of the work. '*Irrigation system optimization in fruit farming for adaptation to climate change*' is a project conducted in a pear and apple orchard of the Mazzoni Group at Medelana in the province of Ferrara. A multi-stakeholder project that saw the participation of the Department of Agricultural and Food Sciences of the University of Bologna (UNIBO-DISTAL), the Institute of Biometeorology (IBIMET) and the Consortium for the Emilia-Romagna Channel (CER) as partners. As Bianchi *et al.*, 2017 suggested to increase studies on field irrigation management, the aim of the project was to rationalize the use of irrigation systems by identifying the best practices for water use efficiency (WUE) improvement in drip irrigation and by developing sustainable protocols for orchard cooling irrigation. The activities were organized into four main actions: I) comparison of traditional drip irrigation with micro-sprinkler irrigation on four different scion/rootstock combinations of pear with three different volumes of water supply, II) study of the effects of ultra-low irrigation systems to reduce evaporative water losses, III) definition of specific guidelines for cooling irrigation, IV) establishment of the time for irrigation during the day. After the two-year experimentation, the evidence showed that besides the temperature reduction of the tree organs, the evaporative cooling influences the productivity performance. This type of irrigation could result interesting in case of recurrent heat waves since it has shown the possibility of reducing the temperature by 4°C. If we consider the temperature predictions in the future for northern and central Italy, it comes to no surprise that farmers need to have a backup solution in case of extreme temperatures that may damage tree productivity or even functionality. Cooling irrigation poses itself as a quality solution in order to manage heat stress in tree organs during the central hours of the day. For an even more successful orchard management in high heat, a viable option would be to install a sensor that could activate the cooling treatment as soon as the critical temperature threshold is reached. In that case, it generates small-calibrated intervals of water bursts throughout the day instead of having a continuous stream of water for a single fixed duration. By doing so, it is possible to use the short-term effect of thermic decrement due to the water's lower temperature and the long-term decrement due to water evaporation on the tree organs.

4. CONCLUSIONS

Our primary goal with this study was to give a general overview of how RDP and CSA can function in tune from a policy and a farmer's point of view. In the case of Emilia-Romagna, it is clear on the amount of innovation and solutions that can be achieved if policies invest in CSA. With research and policies collaborating towards a common goal, innovative solutions are much more easily obtainable. RER has financed 93 projects in the RDP, 70% of which are CSA oriented. The Sub-Measure 16.1 '*Operational Groups projects of the European Partnership for Agricultural Productivity and Sustainability*' had financed a total of 800 projects in the EU, which directly translates to Emilia-Romagna having invested the equivalent of 12% of the total European financing for the Sub-Measure. The GO project example is one of many financed by the Region in its struggle to adapt and mitigate climate change, showing the great interest it has into changing the overall image of agriculture as a polluter.

In addition to this, the regional development of climate-smart agriculture has financed further support with the Sub-Measure 16.2 '*Pilot projects and innovation development*' that consider supply chain projects. Of the 25 financed projects in animal production, eight are climate-smart and, of the 30 in plant production, nine are climate smart.

When all is considered, 35% of the projects in Emilia-Romagna have mitigating efforts, 21% are for adaptation, 11% are dealing with carbon sequestration and 33% of the projects have a potential for double action (mitigation and adaptation simultaneously).

We conclude that the RPD efforts of Emilia-Romagna are spearheading the promotion of new forms of resilient, low impact and sustainable agriculture by applying CS standards in their policies. With the newly created CSA Hub in Emilia-Romagna, operating at IBIMET, serving as an interface between research, policy and agriculture, Emilia-Romagna will continuously work on transitioning its agricultural practices to fight climate change.

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REFERENCES

Bianchi, A., Masseroni, D., Thalheimer, M., Medici, L. O. De, and Facchi, A. (2017). Field irrigation management through soil water potential measurements : a review. *Italian Journal of Agrometeorology*, (2), 24-38.

Borsetta, G., Chieco, C., Malavolta, C., Piacente, C., Marandola, D., Colaiacomo, E., Rossi, F., Ponti, F., Montanari, M., Dall'Olio, N., Georgiadis, T. (2018). Case Study: Italian synergies and innovations for scaling-up CSA.

Brady, M., Kellermann, K., Sahrbacher, C., and Jelinek, L. (2009). Impacts of decoupled agricultural support on farm structure, biodiversity and landscape mosaic: Some EU results. *Journal of Agricultural Economics*, *60*(3), 563–585.

Constantin, J., Mary, B., Laurent, F., Aubrion, G., Fontaine, A., Kerveillant, P., and Beaudoin, N. (2010). Effects of catch crops, no till and reduced nitrogen fertilization on nitrogen leaching and balance in three long-term experiments. *Agriculture, Ecosystems and Environment*, *135*(4), 268–278.

Dickie, A., Streck, C., Roe, S., Zurek, M., Haupt, F., Dolginow, A., West, P. (2014). Strategies for Mitigating Climate Change in Agriculture: Abridged report. CEA. California Environmental Associates.

EIP. (2017). EIP Operational Groups, 1–14.

EP. (2018). Second Pillar of the Cap: Rural Development Policy, 1–4.

Erjavec, K., and Erjavec, E. (2009). Changing EU agricultural policy discourses? The discourse analysis of Commissioner's speeches 2000-2007. *Food Policy*, *34* (2), 119-236.

Fanfani, R., and Pieri, R. (2017). *Il Sistema Agro-Alimentare Dell ' Emilia-Romagna*. Retrieved from https://www.ucer.camcom.it/osservatori-regionali/os-agroalimentare/pdf/2017-rapporto-osservatorio-agroalimentare-er.pdf

FAO. (2013). *Climate-Smart Agriculture Sourcebook. Food and Agriculture Organization of the United Nations. Sourcebook on Climate-Smart Agriculture, Forestry and Fisheries*.

IFPRI. (2018). *2018 Global Food Policy Report*.

Iglesias, A., and Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management*, *155*, 113–124.

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Marchetti, M. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management*, *259*(4), 698–709.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change* (4), 1068-1072.

Massot, A. (2018). First pillar of the Common Agricultural Policy (CAP): II — Direct payments to farmers. *Fact Sheets on the European Union*, (1307), 2–6. Retrieved from http://www.europarl.europa.eu/ftu/pdf/en/FTU_3.2.5.pdf

Miraglia, M., Marvin, H. J. P., Kleter, G. A., Battilani, P., Brera, C., Coni, E., Vespermann, A. (2008). Climate change and food safety: An emerging issue with special focus on Europe. *Proceedings of the Annual Conference of the International Speech Communication Association, INTERSPEECH*, *47*(5), 2743-2746.

Notenbaert, A., Pfeifer, C., Silvestri, S., and Herrero, M. (2017). Targeting, out-scaling and prioritising climate-smart interventions in agricultural systems: Lessons from applying a generic framework to the livestock sector in sub-Saharan Africa. *Agricultural Systems*, (151), 153-162.

Policy, A., and Brief, P. (2013). Overview of CAP REFORM, (December 2013).

Rana, G., Muschitiello, C., Ferrara, R. M., Verdiani, G., and Acutis, M. (2018). Modelling the groundwater level by water balance: A case study of a mediterranean karst aquifer of Apulia region (Italy). *Italian Journal of Agrometeorology*, *2018*(1), 35-48.

Recanati, F., Maughan, C., Pedrotti, M., Dembska, K., and Antonelli, M. (2019). Assessing the role of CAP for more sustainable and healthier food systems in Europe: A literature review. *Science of the Total Environment*, *653*, 908–919.

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., and Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, *16*, 145–163.

Saj, S., Torquebiau, E., Hainzelin, E., Pages, J., and Maraux, F. (2017). The way forward: An agroecological perspective for Climate-Smart Agriculture. *Agriculture, Ecosystems and Environment*, *250*(August), 20–24.

Smith, J., Smith, P., Wattenbach, M., Zaehle, S., Hiederer, R., Jones, R. J. A., Ewert, F. (2011). Projected changes in mineral soil carbon of European croplands and grasslands, 1990-2080. *12th International Conference on Indoor Air Quality and Climate 2011*, *2*(June), 2141–2152.

Solazzo, R., Donati, M., Tomasi, L., and Arfini, F. (2016). How effective is greening policy in reducing GHG emissions from agriculture? Evidence from Italy. *Science of the Total Environment*, *573*, 1115–1124.

Thornton, P., Aggarwal, P., and Parsons, D. (2017). Editorial: Prioritising climate-smart agricultural interventions at different scales. *Agricultural Systems*, *151*, 149–152.

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Effect of drought and nitrogen fertilisation on quinoa (*Chenopodium quinoa* Willd.) under field conditions in Burkina Faso

Effetto della siccità e della fertilizzazione azotata su quinoa (*Chenopodium quinoa* Willd.) in Burkina Faso

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Abstract. *Chenopodium quinoa* (Willd.) is an herbaceous C3 crop originating in the Andean Altiplano. Quinoa possesses a great deal of genetic variability, can adapt to diverse climatic conditions, besides of having seeds with high nutritional properties. An experiment conducted in Burkina Faso has determined the response of two quinoa varieties (Titicaca and Negra Collana) to different planting dates (November vs December), irrigation levels (Potential evapotranspiration-PET, 100, 80 and 60% PET), and N fertilization rates (100, 50 and 25 kg N ha^{-1}). Main research findings have shown that quinoa can be highly performant under drought stress conditions and low nitrogen inputs, besides of coping with high temperatures typically of the Sahel. The highest yields (1.9 t ha^{-1}) were achieved when sown in November at 60 % PET and 25 kg N ha^{-1}. For this location, short cycle varieties, such as Titicaca, were recommended in order to avoid thermic stress conditions occurring prior to the onset of the rainy season (May-October).

Keywords. Sahel, agro-meteorology, extreme climatic conditions, abiotic stress, water management.

Abstract. *Chenopodium quinoa* (Willd.) è una coltura erbacea C3 originaria dell'Altiplano andino. La quinoa, la cui granella è dotata di ottime proprietà nutrizionali, è caratterizzata da un'elevata variabilità genetica e ben si adatta a diverse condizioni climatiche. Lo scopo della ricerca, condotta in un sito sperimentale in Burkina Faso, è stato di valutare la risposta di due varietà di quinoa (Titicaca e Negra Collana) a diverse date di semina (novembre vs dicembre), diversi livelli di irrigazione (evapotraspirazione potenziale - PET, 100, 80 e 60% PET) e diverse dosi di concimazione azotata (100, 50 e 25 kg N ha^{-1}). I risultati hanno dimostrato che la quinoa può essere altamente performante anche in condizioni di stress idrico e bassi input di azoto, oltre a riuscire ad adattarsi alle alte temperature tipiche dell'area del Sahel. Le rese più elevate

(1,9 t ha^{-1}) sono state ottenute per la quinoa seminata a novembre, irrigata al 60% di PET e fertilizzata con 25 kg di N ha^{-1}. In base ai risultati ottenuti, per l'area considerata si raccomanda l'utilizzo di varietà a ciclo breve, come il Titicaca, per evitare condizioni di stress termico che si verificano prima dell'inizio della stagione delle piogge (maggio-ottobre).

Parole chiave. Sahel, agrometeorologia, condizioni climatiche estreme, stress abiotico, gestione irrigua.

1. INTRODUCTION

Climate change affects agricultural productivity that needs to adapt to satisfy food demand. Agricultural adaptation becomes crucial in hot-spot regions of climate change, especially affected by drought and water scarcity (Morsy *et al.*, 2018). These areas often match with those having highest undernourishment rates and greatest population growth, low use of external inputs such as improved seeds and fertilizers; absence of mechanization; and poor linkage to markets. This makes agriculture highly vulnerable to climate change (Eroula *et al.*, 2013). Among scientists, quinoa (*Chenopodium quinoa* Willd.) is considered a climate resilient and superfood crop, while being promoted in regions vulnerable to climate change. It is a highly nutritional and gluten free crop, having a balanced composition of essential amino-acids sometimes scarce in legumes and cereals (Repo-Carrasco *et al.*, 2003); as well as for been rich in Ca, Fe, and Mg, with high content of vitamins A, B2 and E (Adolf *et al.*, 2013).

Moreover, quinoa is well-known for its resilience to abiotic stresses being drought-tolerant, halophyte, pH versatile, and resistant to thermic variability. Most of the scientific research is focused on its adaptability to saline levels, being as high as those found in sea water (Jacobsen *et al.*, 2003; Razzaghi *et al.*, 2011; Hirich *et al.*, 2014a; Riccardi *et al.*, 2014; Fghire *et al.*, 2015). In fact, its salt tolerance is the result of osmotic adjustment, osmo-protection, sodium exclusion and xylem loading, potassium retention, gas exchange, stomatal control and water use efficiency (Adolf *et al.*, 2013). As a C3 crop, quinoa's crop water productivity (CWP), expressed in kg of biomass produced per m^3 of water applied, is generally low, lying between 0.3-0.6 kg m^{-3} in the Bolivian Altiplano while exceeding 1 kg m^{-3} in Morocco and Italy (Geerts *et al.,* 2009; Hirich *et al.*, 2014a; Riccardi *et al.*, 2014). Indeed, quinoa's transpiration rate is similar to that of reference evapotranspiration, hence having low water requirements, around 400 mm (Steduto *et al.*, 2012). Moreover, rapid stomata closure, restricting shoot growth and accelerated leaf senescence makes quinoa highly adaptable to drought stress conditions (Azurita-Silva *et al.,* 2015). In addition, it's capable of maintaining its turgidity with very low water potentials, while optimizing water use through minimum leaf gas exchange (Jensen *et al.*, 2000; Jacobsen *et al.*, 2003). It can also increase its assimilation efficiency by improving the ratio of photosynthetic rate over transpiration up to 2 (Vacher, 1998; Geerts *et al.*, 2008). Other morphological and anatomical responses are the presence of calcium oxalate crystals in leaf vesicles, reducing leaf-transpiration, besides of having a thick plant cuticle and sunken stomata (Azurita-Silva *et al.,* 2015).

Furthermore, the wide geographical distribution of quinoa has given the plant a great genetic variability, besides of increasing its coping-capacity under extreme climatic conditions (Ceccato *et al.*, 2015). Indeed, temperature is the environmental factor affecting the most crop's cycle duration, germination, development and seed formation (Hirich *et al.*, 2014b; Bertero, 2015; Hassan, 2015). Further research on nitrogen (N) suggests that greater N fertilisation can result in a significant yield increase, but having no effect on seed size or weight (Shams, 2012; Benlhabib *et al.*, 2013; Piva *et al.*, 2015). Soils with higher clay content are the most suitable for growing quinoa, as N-uptake, organic matter, soil's water holding capacity is highest (Razzaghi *et al.,* 2012).

To promote quinoa's consumption in West Africa, the Food and Agriculture Organization of the United Nations (FAO) has developed Technical Cooperation Programs (TCP/SFW/3404 and TCP/RAF/3602) together with the Ministries of Agriculture.

The aim of this research was to investigate the adaptability and performance of two quinoa varieties when sown at different dates, under decreasing levels of irrigation and different N fertilisation rates.

2. MATERIALS AND METHODS

The experiment was carried out during the dry season, from November 2017 to May 2018, at Institut de l'Environnement et Recherches Agricoles (INERA), Farako-Bâ's research station (11°05′N; 4°20′W). The area of study is within Burkina's Soudanian agro-climatic belt, with a tropical savanna-wet and hot climate. The onset of the wet season is in May and offset in October, with a total amount of rainfall exceeding 900 mm year^{-1}; where mean annual temperatures can attain 28 °C.

The experimental field was organized in a randomized split-split block design with a multiple factor analysis of variance (ANOVA): 3 levels of irrigation according to the potential evapotranspiration (PET) (Full irrigation-FI: 100 % PET; Progressive Drought-PD: 80 % PET; Deficit Irrigation-DI: 60 % PET), 3 levels of N fertilisation (100, 50 and 25 kg N ha^{-1}), two quinoa varieties (Titicaca-short cycle-85 days, and Negra Collana-long cycle-150 days), and 3 repetitions. Quinoa seeds were sown in 54 plots, each of 7.5 m^2, in 50 cm row distance and 10 cm space between plants (200000 plants ha^{-1}), at a rate of 10 kg seeds ha^{-1}. The ANOVA was done using IBM SPSS software and Tukey´s HSD test with Minitab 2018.

Sowing was carried out in two dates: 4/11/2017 (hereinafter November) and 8/12/2017 (hereinafter December). The harvesting of November´s sowing was done at the beginning of February for Titicaca (89 days after sowing-DAS) and end of March for Negra Collana (139 DAS). Whereas the harvesting for December´s sowing, it was carried out beginning March for Titicaca (82 DAS) and end of May for Negra Collana (159 DAS).

Prior to sowing the soil was amended with compost (50.2 % organic matter) at a rate of 5 t ha^{-1}, as well as with phosphate (26.7 % P_2O_5) at a rate of 400 kg P ha^{-1}. Nitrogen fertilisation, in the form of urea (46.2 % N), was split into two doses and was applied 25 and 40 DAS. Weed removal was carried out manually every 3/4 weeks to avoid weed interference with actual crop water requirements. Seeds were treated with fungicides/insecticides (Permethrin 25 g kg^{-1} + Thirame 250 g kg^{-1}) at a rate of 25 g per 10 kg of seeds, and through foliar application (Cypermethrin) at a rate of 1 litre ha^{-1}.

Prior to sowing and post-harvesting, soil samples were extracted at 0-20, 20-40 and 40-60 cm for the determination of its main physic-chemical characteristics. Leaf chlorophyll was recorded at 30 and 68 DAS using a Leaf Chlorophyll Meter SPAD 502 Plus with a total of 25 observations per plot. The canopy cover was measured at 40 DAS (sowing November) and 56 DAS (sowing December) using the Canopeo app. developed by the University of Oklahoma. The rest of the parameters, including plants height (10 per plot); biomass and seed yield (12 per plot); 1000 seeds weight (3 per plot); branching, panicle size, panicle width, stem diameter (5 per plot); root depth and root length (1 per plot), were done at physiological maturity.

Daily evapotranspiration was calculated using the following formula (Hargreaves and Samani, 1985):

$$ET_o = 0.023\ (T\ mean + 17.78)\ R_o\ (T\ max - T\ min)^{0.5}$$

Where: R_o = solar radiation at a given month and latitude (Allen *et al.*, 1998); T mean = mean daily temperature; T max = daily maximum temperature; T min = daily minimum temperature.

Moreover, crop evapotranspiration ($ETc = Kc*ET_0$) was calculated using the crop´s coefficient (*Kc*) for quinoa´s different phenological phases (Garcia *et al.*, 2003): 0.52 at emergence, 1.0 at maximum canopy cover and 0.70 at physiological maturity. Net irrigation requirements were estimated using ET_c daily data and adjusted according to the level of irrigation: ETc*1.0 (FI); ETc*0.80 (PD) and ETc*0.60 (DI). In fact, ETc was adapted according to the growing cycle of both quinoa varieties. A water-counter was placed at the entrance of each irrigation block to estimate the amount of water applied. The drip irrigation flow rate was of 1.05 l hour^{-1}, varying according to the water pressure, maximum 1 bar, and the frequency of water application, between 2 to 4 times a week depending on the growing stage of the plant.

3. RESULTS

The experimental field was characterised for having a sandy-loam texture in the first soil layer (0-20 cm) with high infiltration rate, low water holding capacity and very poor organic matter content, below 0.5 % (Table 1 and 2). Mineral nitrogen (ammonium and nitrate) was negligible (0.03 %), while soil pH was slightly acidic (pH 6.5). As a result of low soil carbon content and mineral nitrogen, the C/N ratio remained low (8.8

Tab. 1. Main soil physic-chemical characteristics before sowing (average of 5 samples).
Tab. 1. Principali caratteristiche fisico-chimiche del suolo prima della semina (media di 5 campioni).

Parameter	Units	Soil layer (cm)		
		0-20	20-40	40-60
Sand	%	67.2	54.6	41.3
Silt	%	17.6	16.5	15.7
Clay	%	15.2	28.9	43.0
Texture		Sandy-Loam	Sandy-Clay-Loam	Clay
pH (H_2O)		6.51	5.95	6.05
C	%	0.28	0.23	0.23
Organic matter	%	0.48	0.39	0.39
N	%	0.032	0.026	0.027
C/N		8.8	8.7	8.4
P available	mg/kg	4.0	1.70	1.02
K available	mg/kg	79.73	74.97	58.70

Tab. 2. Main soil physic-chemical characteristics post-harvesting (average of 3 samples).
Tab. 2. Principali caratteristiche fisico-chimiche del suolo dopo la raccolta (media di 3 campioni).

Parameter	Units	Soil horizon (cm) and Nitrogen fertilisation (kg N ha^{-1})								
		0-20cm			20-40cm			40-60cm		
		100kgN	50kgN	25kgN	100kgN	50kgN	25kgN	100kgN	50kgN	25kgN
Bulk density	g/cm^3	1.55	1.66	1.63	-	-	-	-	-	-
C	%	0.43	0.41	0.51	0.40	0.38	0.46	0.38	0.39	0.40
Org. Matter	%	0.75	0.71	0.89	0.68	0.66	0.79	0.66	0.66	0.69
N	%	0.035	0.038	0.051	0.032	0.034	0.044	0.029	0.033	0.037
C/N		12.5	10.8	10.0	12.4	11.2	10.5	13.4	11.7	10.9
P total	mg/kg	95.8	97.6	85.0	83.8	91.6	90.0	93.5	106.6	103.5
K total	mg/kg	711.9	879.6	993.4	1101.7	1123.5	1405.3	1535.5	1741.3	1881.7

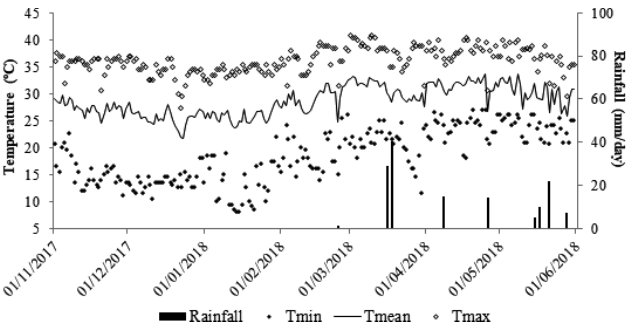

Fig. 1. Meteorological observations at INERA Farako-Bâ research station during the growing period.
Fig. 1. Dati meteorologici misurati nel sito sperimentale (INERA Farako-Bâ) durante il periodo di crescita.

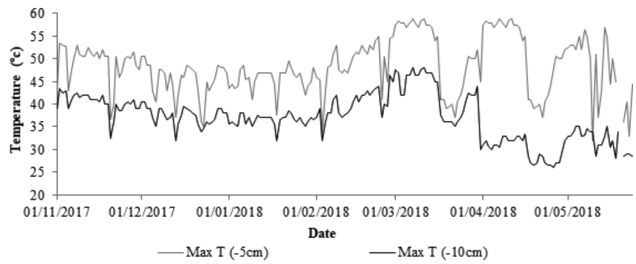

Fig. 2. Soil temperatures at 5 and 10cm depth during the growing period.
Fig. 2. Temperatura del suolo a 5 e 10 cm misurata durante il periodo di crescita.

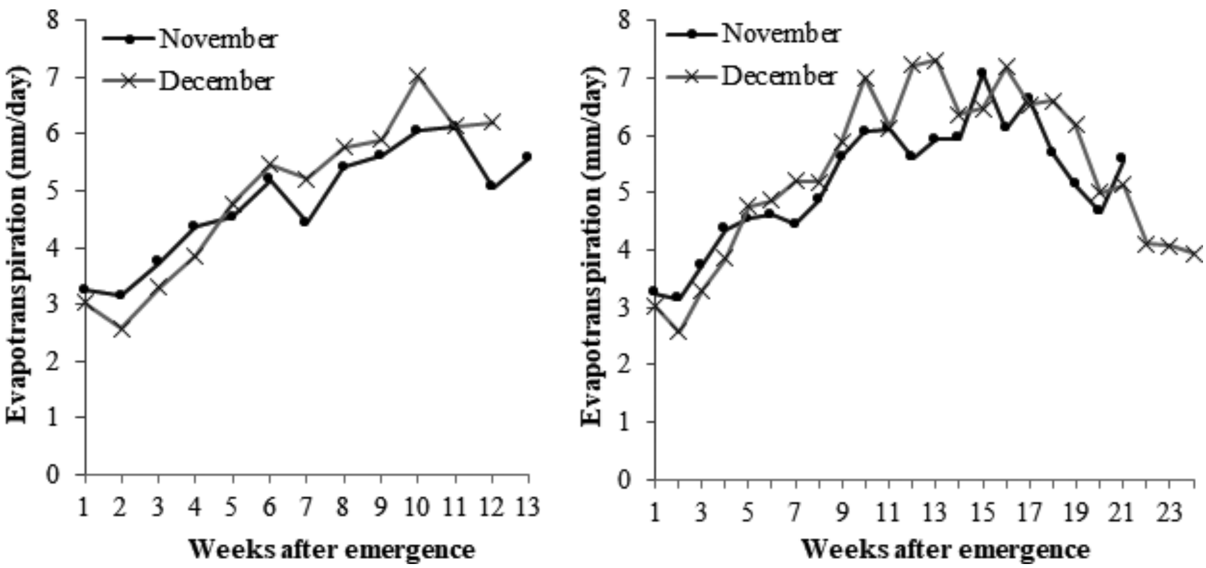

Fig. 3. Daily evapotranspiration for Titicaca (left) and Negra Collana (right).
Fig. 3. Evapotraspirazione giornaliera della vareità Titicaca (sinistra) e Negra Collana (destra).

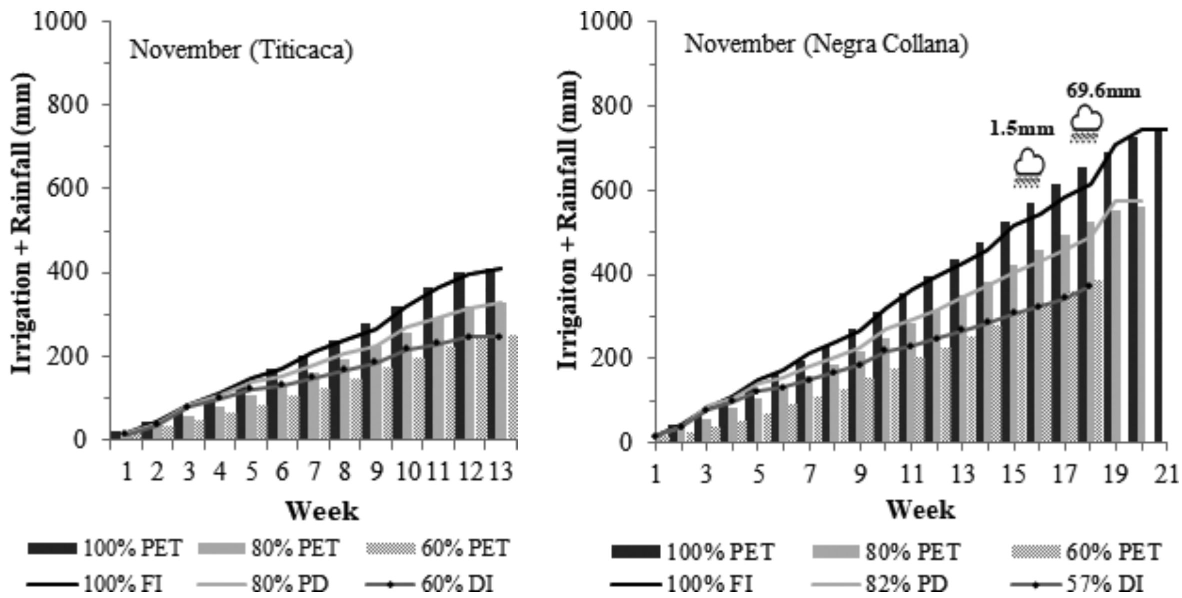

Fig. 4. Full Irrigation (FI-100% PET), Progressive Drought (PD-80% PET), and Deficit irrigation (DI-60% PET) for Titicaca (left) and Negra Collana (right) for first sowing date (November).

Fig. 4. Full Irrigation (FI-100% PET), Progressive Drought (PD-80% PET), Deficit irrigation (DI-60% PET) per le varietà Titicaca (sinistra) e Negra Collana (destra) alla la prima data di semina (novembre).

Note: bars showing Potential Evapotranspiration (PET); lines irrigation applied, and clouds week rainfall; total PET (columns) and irrigation applied (lines) do not always match at the end of the growing period.

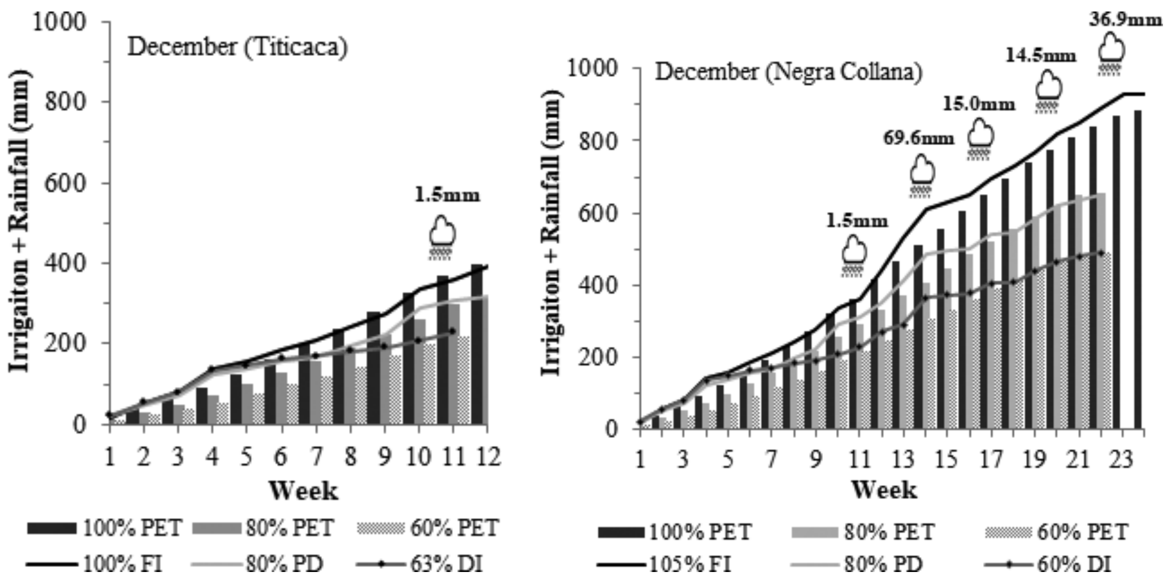

Fig. 5. Full Irrigation (FI-100% PET), Progressive Drought (PD-80% PET), and Deficit irrigation (DI-60% PET) for Titicaca (left) and Negra Collana (right) in the second sowing date (December).

Fig. 5. Full Irrigation (FI-100% PET), Progressive Drought (PD-80% PET), e Deficit irrigation (DI-60% PET) per le varietà Titicaca (sinistra) e Negra Collana (destra) alla la seconda data di semina (dicembre).

Note: bars showing Potential Evapotranspiration (PET); lines irrigation applied, and clouds week rainfall; total PET (columns) and irrigation applied (lines) do not always match at the end of the growing period.

Tab. 3. WUE (Water Use Efficiency in kg m^{-3}); GYP (Grain yield per plant in grams); HI (Harvest Index in yield/biomass); TGW (Thousand grain weight in grams); CL1-2 (Chlorophyll content); CC (Canopy Cover in %); PH (Plant Height in cm) of quinoa under the different treatments. Factors: a Variety (V) of Chenopodium quinoa Willd.; b Irrigation level (I) (100% PET; 80% PET; 60% PET); c Fertilisation (F) (100 kg N ha^{-1}; 50 kg N ha^{-1}; 25 kg N ha^{-1}). μ, σ, CV represents mean value, standard deviation and coefficient of variation of three repetitions, respectively.
Tab. 3. WUE (Efficienza d'uso dell'acqua in kg m^{-3}); GYP (resa per pianta in g); HI (Harvest Index in resa/biomassa); TGW (peso mille semi in g); CL1-2 (contenuto in clorofilla); CC (Canopy Cover in %); PH (altezza della pianta in cm) della quinoa nei diversi trattamenti. Fattori: a Vatrietà (V) di Chenopodium quinoa Willd.; b Livello irriguo (I) (100% PET; 80% PET; 60% PET); c Fertilizzazione (F) (100 kg N ha^{-1}; 50 kg N ha^{-1}; 25 kg N ha^{-1}). μ, σ, CV rappresentano rispettivamente la media, la deviazione standard e il coefficiente di variazione delle tre ripetizioni.

Factors			NOVEMBER								DECEMBER							
V[a]	I[b]	F[c]	WUE	GYP	HI	TGW	CL_1	CL_2	CC	PH	WUE	GYP	HI	TGW	CL_1	CL_2	CC	PH
Titicaca	60	25	1.69	9.56	0.48	2.40	55.3	21.9	6.26	59.4	0.50	1.27	0.32	1.91	47.9	37.7	7.44	33.5
	60	50	0.72	3.73	0.46	2.41	53.2	23.2	5.13	44.8	0.53	1.30	0.31	1.68	45.5	32.0	5.55	33.0
	60	100	0.21	0.85	0.25	2.01	50.3	21.1	1.39	28.7	0.23	1.29	0.29	1.78	41.6	30.6	6.06	32.4
	80	25	0.90	9.04	0.48	2.06	43.2	33.4	5.04	52.7	0.44	2.75	0.30	1.82	44.9	48.4	7.62	38.7
	80	50	0.68	5.47	0.45	1.87	45.4	31.4	2.33	45.1	0.81	4.05	0.36	1.87	41.6	54.6	8.66	44.8
	80	100	0.08	0.56	0.35	1.92	50.4	29.2	0.87	25.7	0.55	2.70	0.35	1.84	45.4	44.3	6.59	38.6
	100	25	0.29	4.29	0.41	2.02	39.1	45.7	1.97	34.7	0.44	2.98	0.43	1.83	46.7	31.8	6.14	39.8
	100	50	0.43	5.16	0.38	1.85	44.6	35.5	1.74	44.0	0.42	2.19	0.42	1.67	45.8	35.0	4.68	34.0
	100	100	0.17	2.42	0.38	1.75	40.6	25.4	1.36	36.4	0.35	1.42	0.32	1.68	46.1	30.4	6.56	36.3
μ	-	-	0.57	4.57	0.41	2.03	46.9	29.7	2.90	41.3	0.48	2.22	0.35	1.79	45.1	38.3	6.59	36.8
σ	-	-	0.57	3.61	0.08	0.28	6.35	9.46	2.58	13.1	0.30	1.71	0.07	0.22	4.75	10.3	3.33	10.1
CV	-	-	0.32	13.0	0.01	0.08	40.3	89.4	6.67	171.8	0.09	2.91	0.01	0.05	22.6	104.9	11.1	101.0
Negra Collana	60	25	1.43	2.32	0.12	0.87	42.6	33.3	2.29	54.2	0.08	0.04	0.02	0.77	37.1	41.9	2.06	26.8
	60	50	0.96	0.91	0.07	0.84	41.8	43.6	1.22	47.3	0.02	0.04	0.02	0.77	36.2	45.7	1.96	35.0
	60	100	0.24	0.20	0.03	0.88	43.0	42.8	0.35	26.4	0.10	0.05	0.02	0.71	31.6	51.3	2.18	33.4
	80	25	0.64	1.46	0.10	1.38	39.5	32.5	1.48	60.5	0.18	0.10	0.02	1.07	38.9	55.4	3.21	49.8
	80	50	0.47	0.69	0.09	1.38	39.9	39.4	0.95	44.0	0.22	0.05	0.01	0.99	44.5	50.7	2.78	49.3
	80	100	0.07	0.08	0.05	1.13	48.1	38.6	0.42	21.9	0.20	0.09	0.01	1.11	43.0	51.3	3.84	49.4
	100	25	0.37	1.11	0.05	1.32	30.5	44.9	0.64	54.9	0.24	0.68	0.06	1.02	41.1	47.0	2.42	52.3
	100	50	0.22	0.38	0.05	0.98	36.2	44.0	0.86	54.3	0.28	0.48	0.05	1.03	42.9	52.2	2.25	51.6
	100	100	0.05	0.13	0.04	0.85	42.8	41.5	0.22	30.8	0.29	0.51	0.05	0.99	41.4	47.0	4.11	48.2
μ	-	-	0.50	0.81	0.07	1.07	40.5	40.1	0.94	43.8	0.18	0.22	0.03	0.94	39.6	49.2	2.76	44.0
σ	-	-	0.49	0.82	0.04	0.26	5.78	5.47	0.85	15.7	0.11	0.28	0.02	0.27	4.85	7.75	1.49	12.7
CV	-	-	0.24	0.67	0.00	0.07	33.4	29.9	0.72	244.9	0.01	0.08	0.00	0.07	23.5	60.1	2.23	161.3
μ	-	-	0.54	2.69	0.24	1.58	43.7	34.9	1.92	42.5	0.33	1.22	0.19	1.36	42.3	43.7	4.67	40.4
σ	-	-	0.53	3.21	0.18	0.55	6.83	9.29	2.15	14.4	0.27	1.57	0.17	0.49	5.49	10.5	3.21	11.9
CV	-	-	0.28	10.3	0.03	0.31	46.6	86.2	4.61	206.1	0.07	2.48	0.03	0.24	30.1	111.1	10.3	141.8

units of C per 1 unit of N), but slightly increased after organic amendment up to 10-12 C units per 1 N unit at 0-20 cm depth. As a result of phosphate fertilisation, P within the first layer had boosted from 4 mg kg^{-1} prior to sowing, up to 84-106 mg kg^{-1} after harvesting. Finally, bulk densities were of 1.66 g cm^{-3}.

Mean daily temperature during the growing period was 28.6 °C (Figure 1). The 40 °C threshold was trespassed 14 times, especially in March and April. In addition, longer cycle varieties (Negra Collana) were affected to a larger extent than short cycle varieties (Titicaca) by maximum temperatures at flowering (> 39 °C). Finally, soil temperatures, at 5 and 10 cm depth, have shown that roots (average depth, 6.5 cm, for both varieties) were thermic-stressed throughout the whole growing period (Figure 2).

Estimated ETc (Figure 3) was lowest at plant emergence and two leaves stage (±3 mm day^{-1}), while steadily increasing at a rate of +0.5 mm week^{-1} during the vegetative stage up to 6-7 mm day^{-1}. The plateau phase of maximum water requirements for Titicaca was reached after 6 weeks (ETc = ±6 mm day^{-1}). Once leaf senescence took place, ETc started to decline, thus depleting during pasty seed formation and physiological maturity of the plant, 10-13 weeks (ETc = ±5.5 mm day^{-1}). For Negra Collana, with longer cycle, the ETc reached its maximum after

Tab. 4. Post-hoc Tukey´s pairwise comparison test for different crop parameters and factors of study (variety, irrigation and fertilisation).
Tab. 4. Post-hoc Tukey´s pairwise test per I diversi paretri e fattori analizzati (varietà, irrigazione e concimazione).

Factor	Level	WUE		GYP		HI		TGW		**CL1**		**CL2**		**CC**		**PH**	
		NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.
Variety	Titicaca	0.57	0.48**A**	4.57**A**	2.22**A**	0.40**A**	0.35**A**	2.03**A**	1.79**A**	46.9**A**	45.1**A**	29.6**B**	38.3**B**	2.90**A**	6.59**A**	41.3	36.8**B**
	Negra	0.50	0.18**B**	0.81**B**	0.22**B**	0.07**B**	0.03**B**	1.06**B**	0.94**B**	40.5**B**	39.6**B**	40.1**A**	49.2**A**	0.94**B**	2.75**B**	43.8	44.0**A**
Irrigation	60	0.89**A**	0.24	2.93	0.67	0.23**A**	0.16**B**	1.57	1.27	47.7**A**	40.0**B**	31.0**B**	39.8**B**	2.78**A**	4.21	43.5	32.4**B**
	80	0.47**B**	0.40	2.88	1.62	0.25**A**	0.18**B**	1.60	1.45	44.4**A**	43.0**AB**	34.1**AB**	50.8**A**	1.85**AB**	5.45	41.6	45.1**A**
	100	0.26**B**	0.34	2.25	1.37	0.22**A**	0.22**A**	1.46	1.37	39.0**B**	44.0**A**	39.5**A**	40.6**B**	1.31**B**	4.36	42.5	43.7**A**
Fertilisation	25	0.89**A**	0.31	4.63**A**	1.30	0.27**A**	0.19	1.67**A**	1.40	41.7**B**	42.8	35.3	43.7	2.95**A**	4.82	52.7**A**	40.2
	50	0.58**B**	0.38	2.72**B**	1.35	0.25**A**	0.20	1.55**AB**	1.33	43.5**AB**	42.7	36.2	45.0	2.04**AB**	4.31	46.6**A**	41.3
	100	0.15**C**	0.29	0.70**C**	1.01	0.19**B**	0.17	1.41**B**	1.35	45.8**A**	41.5	33.1	42.5	0.77**B**	4.89	28.3**B**	39.7

Note: capital letter (significant difference between set of groups); "A" is the group with highest value when compared to the other sets of groups "B" or "C" (in all cases statistically significant different); NOV. corresponds to the sowing in November and DEC. to the sowing in December.

Tab. 5. ANOVA for different crop parameters and interactions between factors (variety, irrigation and fertilisation).
Tab. 5. ANOVA per diversi parametri misurati e interazioni tra fattori.

Source	WUE		GYP		HI		TGW		CL1		CL2		CC		PH	
	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.	NOV.	DEC.
V	ns	***	***	***	***	***	***	***	***	***	***	***	***	***	ns	*
I	***	ns	ns	ns	*	**	ns	ns	***	*	***	***	*	ns	ns	**
F	***	ns	***	ns	***	ns	**	ns	*	ns	ns	ns	***	ns	***	ns
V x I	ns	ns	ns	ns	ns	ns	***	ns	*	*	**	*	ns	ns	ns	ns
V x F	ns	ns	***	ns	**	ns	ns	ns	*	ns	**	ns	ns	ns	ns	ns
I x F	**	ns	*	ns	***	ns	ns	ns	*	ns	*	ns	ns	ns	ns	ns
V x I x F	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
R^2	0.77	0.53	0.82	0.59	0.97	0.95	0.93	0.81	0.77	0.57	0.76	0.65	0.65	0.45	0.71	0.44

Abbreviations: WUE (Water Use Efficiency in kg m^{-3}); GYP (Grain yield per plant in grams); HI (Harvest Index in yield/biomass); TGW (Thousand grain weight in grams); CL_{1-2} (Chlorophyll content); CC (Canopy Cover in %); PH (Plant Height in cm); NOV. (November sowing); DEC. (December sowing).
Note: [a] Variety (V) of *Chenopodium quinoa* Willd. ; [b] Irrigation level (I) (100% PET; 80% PET; 60% PET); [c] Fertilisation (F) (100 kg N ha^{-1}; 50 kg N ha^{-1}; 25 kg N ha^{-1}); *** extremely significant ($p<0.001$); ** very significant ($p<0.01$); * significant ($p<0.05$); ns: not significant ($p>0.05$); R^2 is the proportion of variance in the dependent variable (crop parameter) which can be explained by the independent variables (V, I, F).

10 weeks, just after flowering. It remained on the plateau phase (ETc = ±6.5 mm day^{-1}) until 18 weeks, then decreased to ±4.5 mm day^{-1} during pasty seed formation and physiological maturity, 19-23 weeks.

Quinoa´s water requirements (Figures 4 and 5) under field conditions varied considerably depending on: cultivar, phenological phase, evapotranspiration rate, type of soil texture and efficiency of the irrigation system. Full irrigation (FI) results have shown that Titicaca´s water demand was 403 mm, whereas for Negra Collana 811 mm (average of both sowing dates). Under progressive drought (PD), the amount of water supplied to Titicaca was 323 mm, whereas for Negra Collana 614 mm. For deficit irrigation (DI), the amount of water supplied was 231 mm and 437 mm to Titicaca and Negra Collana, respectively.

The statistical analysis has shown that water use efficiency (WUE, expressed in kg biomass per m^3 of water applied) was higher under PD and DI, meaning that quinoa was performant under drought-stress conditions (except for Negra Collana sown in December). For the grain yield per plant (GYP), there was significant difference ($p<0.001$) between the two varieties and for both sowing dates, being up to 10 times higher for Titicaca than for Negra Collana. Moreover, yields have depleted by half between November and December, from

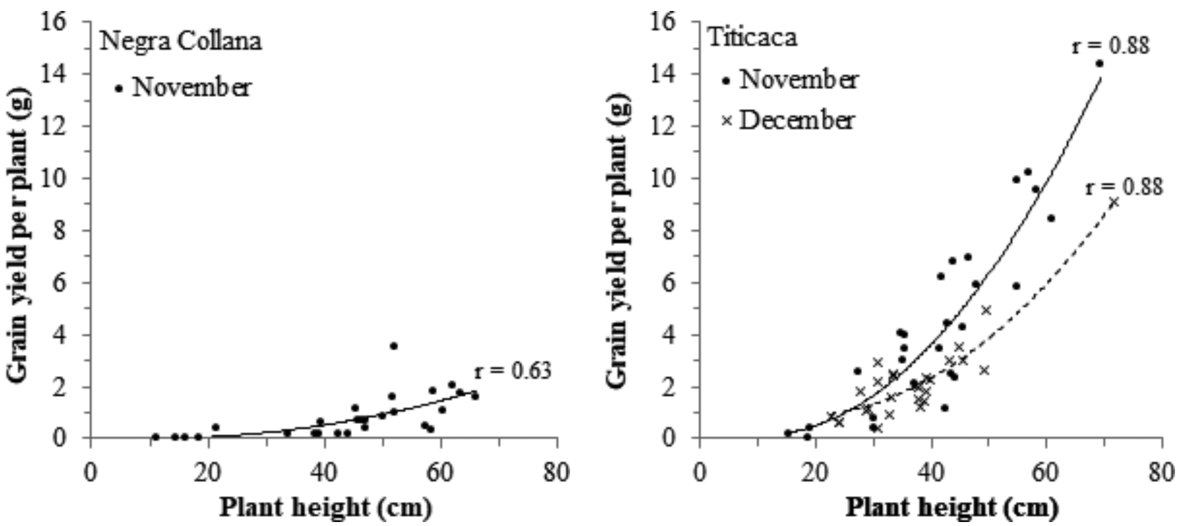

Fig. 6. Relationship (linear regression) between grain yield per plant (g) and plant height (cm) at harvest for Titicaca and Negra Collana.
Fig. 6. Relazione tra resa di granella per pianta (g) e altezza della pianta (cm) alla raccolta per Titicaca e Negra Collana.
Note: r shows Pearson correlation coefficient; Negra Collana (sowing date: December) was removed from the graphs due to high seed abortion in plants.

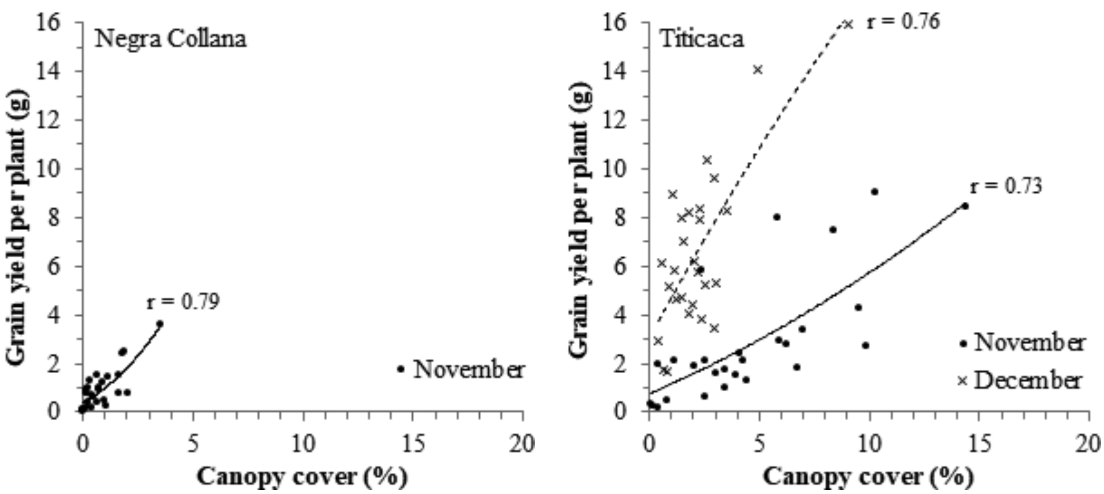

Fig. 7. Relationship (linear regression) between grain yield per plant (g) and canopy cover (%) for Titicaca and Negra Collana.
Fig. 7. Relazione tra resa di granella per pianta (g) e canopy cover (%) per Titicaca e Negra Collana.
Note: r shows Pearson correlation coefficient; Negra Collana (sowing date: December) was removed from the graphs due to high seed abortion in plants.

2.69 to 1.22 g plant^{-1} (average of both varieties). In fact, extreme temperatures during flowering, higher than 39 °C, have resulted in high seed abortion in plants. For Titicaca sown in November under DI and 25 kg N ha^{-1} fertilisation was the most performant, with yields of 9.5 g plant^{-1} (equivalent to 1.9 t ha^{-1}). However, for the sowing in December, higher yields (4.05 g plant^{-1}, equivalent to 0.8 t ha^{-1}) were observed under PD and 50 kg N ha^{-1}. Harvest index (HI, as a ratio of harvested grain to total dry matter) have shown statistical significant differences ($p<0.001$) between the two varieties, 0.38 and 0.05 HI for Titicaca and Negra Collana (average of both sowing dates), respectively. In addition, statistical significant differences ($p<0.001$) between quinoa varieties were observed when analysing the weight of thousand grains (TGW) for both sowing dates; having Titicaca seeds doubled the weight of Negra Collana seeds, 1.94 and 1.00 g, respectively.

Chlorophyll content (CL), N in the leaf, has shown statistical significant differences ($p<0.001$) amongst quinoa varieties, with higher N values for Titicaca sown in November. This was probably the consequence of N redistribution from leaf to storage organs, hence leading to leaf senescence and fostering seed filling. Canopy cover (CC) had varied between quinoa varieties, with 3 times more vegetation coverage for Titicaca than for Negra Collana. Quinoa sown in December has shown statistical significant differences ($p<0.05$) among the heights of the two varieties, 44 and 39 cm for Negra Collana and Titicaca, respectively (average of both sowing dates). Strong relationships, using Pearson correlation coefficient (r), were observed between plant height and GYP (Figure 6), with values of 0.88 and of 0.63 for Titicaca and Negra Collana, respectively. Figures 6 and 7 show the notable enhancement of GYP (5 g per plant^{-1}, equivalent to 1 t ha^{-1}) once the plant exceeded 50 cm height. On the other hand, the relationship between GYP and CC (Figure 7) was robust, showing a correlation coefficient higher than 0.7 for both varieties and sowing dates. In fact, greater canopy was responsible of an increase in light interception, enhancing assimilation and plant growth.

4. DISCUSSION

Despite of the amount of research examining quinoa's water requirements under water-stress conditions, there were no studies displaying such low water inputs than those observed in this research (231 mm Titicaca and 437 mm Negra Collana, average of both sowing dates under DI). Furthermore, this study's average WUE results (0.53 kg m^{-3} Titicaca and 0.34 kg m^{-3} Negra Collana) were similar to those recorded in Bolivia (0.21-0.45 kg m^{-3}) (Geerts *et al.,* 2008), but lower to those observed in Italy and Morocco (0.6 and 1.7 kg m^{-3}, respectively) (Hirich *et al.,* 2014a; Hirich *et al.,* 2014c; Riccardi *et al.,* 2014). In fact, drought stress conditions at key phenological stages (pre-flowering, flowering and pasty grain formation) have had a negative effect both on grain yield per plant and WUE (Geerts *et al.,* 2008). GYP results were in harmony with those modelled in AquaCrop showing that quinoa can be highly performant under DI (Geerts *et al.,* 2009; Cusicanqui *et al.,* 2013). Titicaca's harvest index (HI) results (0.38, average of both sowing dates) were lower to those observed in Morocco (0.57-0.67), but higher than those of Iraq (0.28) (Hirich *et al.,* 2014c; Hassan, 2015).

Moreover, recent research in Algeria, Lebanon, Mauritania, Yemen and Iraq have suggested that 35 °C was the critical threshold at flowering, if exceeded quinoa plants would become sterile (Breidy, 2015; CNRADA, 2015; Djamal, 2015; Hassan, 2015; Saeed, 2015). Nonetheless, this research has proven that Titicaca can stand temperatures above 35 °C during flowering and still be highly performant (up to 1.9 t ha^{-1}). In regards to Negra Collana, long cycle variety, the effect of temperatures above 39 °C has resulted in a very low number of plants with seeds. This is because pollen viability is a function of pollen moisture content which is strongly dependent on vapour pressure deficit (Hatfield and Prueger, 2015). At high temperatures, vapour pressure deficits were highest resulting in pollen desiccation and low pollen viability. In this line, further research would be required to better understand the effect of temperature on plant fertility.

In contrast with other studies, this research did not bring to light any relevant information on yield enhancement with increasing nitrogen fertilisation (Kaul *et al.,* 2005; Shams, 2012). But was in harmony with other investigations (Moreale, 1993), showing that N-fertilisation does not play a crucial role on crop growth nor seed yield, and that quinoa's N uptake was of 25 kg N ton^{-1} of seed produced (1:40 ratio). In addition, the combination of high temperatures and soil moisture in sandy-loam soils during fertilisation could have resulted in urea volatilization (ammonia losses) and hydrolysis. Overall, this investigation has shown that quinoa can adapt and be highly performant in poor structured (sandy-loam texture) and low fertility soils (<0.5 % organic matter and 0.03 % N), typically of the Sahel.

5. CONCLUSIONS

This research confirms that quinoa is a climate resilient crop that can cope with high temperatures and drought-stress conditions. It has a good adaptation to slightly acidic, poor structured and low fertile soils, besides of having low N-requirements. Moreover, Titicaca yields could attain 900 kg ha^{-1} if sown in November (average of all treatments), and could be exceeded if appropriate agronomic practices are followed. For the time being, it will be important to prioritize the use of short-cycle varieties (Titicaca, 85 days), rather than long cycle varieties (Negra Collana, 150 days). By sowing short cycle varieties in November, the effect of extreme temperatures occurring in mid-February until the onset of the rainy season will be diminished. In fact, quinoa's sowing could be advanced by several weeks towards northern parts of the country. Moreover, organic amendment is highly recommended at the rate of 1 t ha^{-1}

or higher prior to sowing; besides of a two-time mineral fertilisation in the form of ammonium nitrate, rather than urea, at the rate of 50 kg N ha^{-1}. Mechanised tilling, at 10-20 cm depth, would be advised, and if irrigated frequent soil aeration would be recommended to avoid soil adhesion that allows effective root development. For that, sowing in furrows would also be supported. Furthermore, research on plant-breeding should target higher-temperature and wind tolerant varieties capable of standing the warmest months and winds occurring during the Harmattan. This could potentially broaden the spatial distribution and sowing time across the country, as well as to other hot-spot regions to climate change. Overall, this research has allowed settling a provisional quinoa crop-calendar, besides of describing ideotype cultivars and suitable agro-meteorological zones for quinoa production in Burkina Faso. For that, quinoa regional programmes implemented by FAO, TCP/SFW/3404 and TCP/RAF/3602 (Burkina Faso, Cameroun, Niger, Senegal, Chad, Togo and Ghana), need to be further supported and its production scaled-up.

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7. REFERENCES

Adolf, V. I.; Jacobsen, S. E.; & Shabala, S. 2013. Salt tolerance mechanisms in quinoa (Chenopodium quinoa Willd.). Environmental and Experimental Botany, 92, 43-54.

Allen, R. G.; Pereira, L. S.; Raes, D.; & Smith, M. 1998. In Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56, FAO, Rome, 300(9), D05109.

Azurita-Silva, A.; Jacobsen, S. E.; Razzaghi, F.; Alvarez-Flores, R.; Ruiz, K.; Morales, A.; & Herman, S. 2015. In State of the Art Report of Quinoa in the World in 2013. Chapter 2.4: Quinoa drought responses and adaptation, 157-171. Rome: FAO and CIRAD.

Benlhabib, O.; Jacobsen, S. E.; Jellen, E. N.; Maughan, P. J.; & Choukr-Allah, R. 2015. In State of the Art Report of Quinoa in the World in 2013. Chapter 6.1.5: Status of quinoa production and research in Morocco, pp. 478-491. Rome: FAO and CIRAD

Bertero, D. 2015. In State of the Art Report of Quinoa in the World in 2013. Chapter 2.1: Environmental control of development, pp. 120-130. Rome: FAO and CIRAD

Breidy, J. 2015. In Final Report on quinoa Evaluation Trials in Lebanon. Rome: FAO

Ceccato, D.; Delatorre-Herrera, J.; Burrieza, H.; Bertero, D.; Martínez, E.; Delfino, I.; Moncada, S.; Bazile, D.; Castellión, M. 2015. In State of the Art Report of Quinoa in the World in 2013. Chapter 2.2: Seed physiology and response to germination conditions, pp. 131-142. Rome: FAO and CIRAD

Centre National de Recherche Agronomique et de Développement Agricole (CNRADA). 2015. In Mauritania Final Evaluation Report on quinoa. Rome: FAO

Cusicanqui, J.; Dillen, K.; Garcia, M.; Geerts, S.; Raes, D.; & Mathijs, E. 2013. Economic assessment at farm level of the implementation of deficit irrigation for quinoa production in the Southern Bolivian Altiplano. Spanish Journal of Agricultural Research, 11 (4). 894-907.

Djamal, S. 2015. In Technical assistance for the introduction of quinoa and appropriation / institutionalization of its production in Algeria-Second Evaluation Report. Rome: FAO

Eruola, A.; Bello, N.; Ufeogbune, G., & Makinde, A. 2013. Effect of climate variability and climate change on crop production in tropical wet-and dry climate. Italian Journal of agrometeorology, 17(1), 17-22.

Fghire, R.; Wahbi. S.; Anaya, F.; Issa Ali, O.; Benlhabib, O.; & Ragab. R. 2015. Response of quinoa to different water management strategies: field experiments and SALTMED model application results. Irrigation and Drainage, 64 (1), 29-40.

Garcia, M.; Raes, D.; & Jacobsen, S. E. 2003. Evapotranspiration analysis and irrigation requirements of quinoa (Chenopodium quinoa) in the Bolivian highlands. Agricultural Water Management, 60 (2), 119-134

Geerts, S.; Raes. D.; Garcia, M.; Vacher, J.; Mamani, R.; Mendoza, J.; & Taboada, C. 2008. Introducing deficit irrigation to stabilize yields of quinoa (Chenopodium quinoa Willd.). European journal of agronomy, 28 (3), 427-436

Geerts, S.; Raes, D.; Garcia, M.; Taboada, C.; Miranda, R.; Cusicanqui, J.; & Vacher, J. 2009. Modelling the potential for closing quinoa yield gaps under varying water availability in the Bolivian Altiplano. Agricultural Water Management, 96 (11), 1652-1658.

Hargreaves, G. H.; & Samani, Z. A. 1985. Reference crop evapotranspiration from temperature. Applied engineering in agriculture, 1(2), 96-99

Hassan, L. 2015. Iraq Final Evaluation Report on quinoa. Rome: FAO

Hatfield, J. L., & Prueger, J. H. 2015. Temperature extremes: Effect on plant growth and development. Weather and climate extremes, 10, 4-10.

Hirich, A.; Jelloul. A.; Choukr-Allah, R.; & Jacobsen, S. E. 2014a. Saline water irrigation of quinoa and chickpea: seedling rate, stomatal conductance and yield responses. Journal of Agronomy and Crop Science, 200 (5), 378-389

Hirich, A.; Choukr-Allah, R.; & Jacobsen, S. E. 2014b. Quinoa in Morocco–effect of sowing dates on development and yield. Journal of Agronomy and Crop Science, 200 (5), 371-377

Hirich, A.; Choukr-Allah, R.; & Jacobsen, S. E. 2014c. Deficit irrigation and organic compost improve growth and yield of quinoa and pea. Journal of Agronomy and Crop Science, 200 (5), 390-398

Jacobsen, S. E.; Mujica, A.; & Jensen. C. R. 2003. The resistance of quinoa (Chenopodium quinoa Willd.) to adverse abiotic factors. Food Reviews International, 19 (1-2), 99-109

Jensen, C. R.; Jacobsen, S. E.; Andersen, M. N.; Nunez, N.; Andersen, S. D.; Rasmussen, L.; & Mogensen, V. O. 2000. Leaf gas exchange and water relation characteristics of field quinoa (Chenopodium quinoa Willd.) during soil drying. European Journal of Agronomy, 13 (1), 11-25.

Kaul, H. P.; Kruse, M.; & Aufhammer, W. 2005. Yield and nitrogen utilization efficiency of the pseudocereals amaranth, quinoa, and buckwheat under differing nitrogen fertilization. European Journal of Agronomy, 22 (1), 95-100.

Moreale, A. 1993. In The quinoa project: Wageningen University. [Accessed on 27th August 2018] Available at: http://edepot.wur.nl/354101

Morsy, M.; El Afandi1, G.; Naif, E. 2018. CropSyst Simulation and Response of Some Wheat Cultivars to Late Season Drought. Italian Journal of Agrometeorology 1, 15-24. DOI:10.19199/2018.1.2038-5625.015

Piva, G.; Brasse, C.; & Mehinagic, E. 2015. In State of the Art Report of Quinoa in the World in 2013. Chapter 6.1.2: Quinoa D'Anjou: The beginning of a French quinoa sector. pp. 447-453. Rome: FAO and CIRAD

Razzaghi, F.; Ahmadi. S. H.; Adolf. V. I.; Jensen. C. R.; Jacobsen. S. E.; & Andersen. M. N. 2011. Water relations and transpiration of quinoa (Chenopodium quinoa Willd.) under salinity and soil drying. Journal of Agronomy and Crop Science, 197 (5), 348-360

Razzaghi, F.; Plauborg, F.; Jacobsen, S. E; Jensen, C. R.; & Andersen, M. N. 2012. Effect of nitrogen and water availability of three soil types on yield, radiation use efficiency and evapotranspiration in field-grown quinoa. Agricultural water management, 109, 20-29.

Repo-Carrasco, R.; Espinoza, C.; & Jacobsen, S. E. 2003. Nutritional value and use of the Andean crops quinoa (Chenopodium quinoa) and kañiwa (Chenopodium pallidicaule). Food reviews international, 19 (1-2), 179-189

Riccardi, M.; Pulvento, C.; Lavini, A.; d'Andria, R.; & Jacobsen, S. E. 2014. Growth and ionic content of quinoa under saline irrigation. Journal of agronomy and crop science, 200 (4), 246-260

Saeed, A.L. 2015. In Yemen Progress Report on quinoa. Rome: FAO

Shams. A. S. 2012. Response of quinoa to nitrogen fertilizer rates under sandy soil conditions. Proceedings 13th International Conference Agronomy. Faculty of Agriculture, Benha University, Egypt, 9-10

Steduto, P.; Hsiao, T. C.; Fereres, E.; & Raes, D. 2012. In Crop yield response to water. Chapter 3.4: Herbaceous crops: quinoa. pp. 230. Rome: FAO.

Vacher, J. 1998. Responses of two main Andean crops, quinoa (Chenopodium quinoa Willd) and papa amarga (Solanum juzepczukii Buk.) to drought on the Bolivian Altiplano: Significance of local adaptation. Agriculture, ecosystems & environment, 68 (1), 99-108.

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Table of contents