Food and Agriculture Organization of the United Nations

ICARDA
Science for resilient livelihoods in dry areas

Establishing and Operating a Regional Network for Field Measurement of Actual Crop Water Consumption (Evapotranspiration)

NENA Regional ET-Network

Output-1: Membership of the Regional Network

Activity 1.2: Assessment of Available Field Instruments for Each Institution and Calibration Status, and Recommend Possible Additional Instruments to Complement the Existing Ones

submitted by
International Center for Agricultural Research in the Dry Areas (ICARDA)

to

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The Project

Establishing and Operating a Regional Network for Field Measurement of Actual Crop Water Consumption (Evapotranspiration)

There are several conventional field methods used to determine ETa, including: 1) the Eddy covariance/energy balance method; 2) the Bowen-ratio/energy balance method; 3) Weighing lysimeters; 4) Soil-moisture depletion method; 5) Large Aperture Scintillometer; and 6) the Penman Monteith method. These methods have their own specific advantages and limitations based on the theory behind and on the instrumentation requirements. However, what they have in common is, among others, the restricted sampling area and the complexity and extremely high costs when attempting to scale-up to larger areas. For large scales (e.g., irrigation schemes, watershed, sub-national, national and basin scales) the only feasible and affordable methods for ET determination are through satellite Remote Sensing (RS), due to progress and advances in space science in recent years. There are several well-established RS-based algorithms for the determination of ET_a, including SEBAL (Surface Energy Balance Algorithm for Land), METRIC (Mapping Evapotranspiration at high Resolution with Internalized Calibration), SEBS (Surface Energy Balance System), ETLook, ETMonitor, etc. Unfortunately, also these methods have their own specific advantages and limitations and are all suffering from a generally limited and scattered field validation. Virtually no validations are systematically carried out in the NENA Region. Therefore, the ET_a field measurements established through this ET-Network could effectively be used to validate and calibrate the remote sensed based estimations.

In this regional ET-Network (having Egypt, Jordan, Lebanon, Morocco, and Tunisia as initial countries), the overarching objective is to establish and operate a NENA Regional Network of specialized Institutions, within the countries of reference, to conduct field measurements of actual ET, over selected crops, in order to evaluate the accuracy of existing RS based ET estimates. The Network has been named NENA-ETNet. This regional network was established by ICARDA and financially supported by FAO.

Keywords: Evapotranspiration, ET network, water productivity, water management

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1. Background

As a preparatory procedure of this ET project, the preliminary step was to visit the selected countries based on the prior communication with various NARS partners and ICARDA local offices about the feasibility of implementing the NENA-ETNet with recommendation for potential sites that can be equipped to be the benchmark sites in this project. The main criterion for country-site selection was the identification of partners where prior in situ ET measurements were carried out through various past projects and that would facilitate the use of already available ET measurement instrumentation, as having sufficient knowledge, manpower and crop field.

Based on an initial survey and data collection from the field, five institutions (one each for the five participating countries) were identified. They were ARC-Egypt, NARC-Jordan, LARI-Lebanon, IAV-Morocco and INRGREF-Tunisia. While this was already done during the proposal preparation phase and during the FAO-led Land and Water Days meeting, we also considered the congruency of sites with the Sida-funded project working on water productivity as well as ICARDA research vision of enhancing water productivity in the dry areas of MENA. In June 2019, several field missions were conducted to inspect and understand the prospects of the sites and scouting for potential sites in each institution, instrument availability and related maintenance and calibration status, and recommend possible additional instruments to complement the existing ones.

The main objective of this activity was to carry out fact-finding missions in each country, visiting the managerial and technical representatives of the selected Institutions. Preliminary results of the mission are reported in Table 1.

Table 1. ET_a measurement methods, history of measurements and approaches at the different sites in NENA-ETNet

Country	On-Going method	History	Pending Requirements	Recommended: CORDOVA-ET stations
Jordan	Lysimeter	Ongoing	Site characterized	1 with 4 nodes
Lebanon	Lysimeter SM depletion	Ongoing	Partial site characterization needed	1 with 4 nodes
Morocco	Eddy covariance SM depletion	New Site	Full site characterization needed	1 with 4 nodes
Tunisia	Eddy covariance SM depletion	New Site	Full site characterization needed	1 with 4 nodes
Egypt	Energy balance Eddy covariance	Ongoing	Partial site characterization needed	1 with 4 nodes

The following sections describe the country-site characteristics based on a comprehensive data collection process which was collected through field missions and communications with country focal points included factors such as:

1. General site queries
2. Details of Instrumentation

3. Measurement History

Among these five sites, there are some that are new, hence there is no historical information that help us to characterize them and hence more site characterization is required. This includes Morocco and Tunisia.

2. Jordan Site (Dyar Ala, Jordan Valley)

The site is located at the National Agricultural Research Center (NARC) / Dyar Ala Station in the Central Jordan Valley (32°N, 35°30' E) with an elevation of 224 meters below sea level. This location receives 270 mm rainfall annually and offers unique meteorological conditions. It is a hub-location for irrigated agriculture in Jordan valley, focusing mainly on cultivating vegetables and cereals. There is already an on-going ET measurement study funded by USDA (ending this year). The ICARDA project team went to the Dyar Ala station for site characterization. The assessment results are reported in next sessions.

2.1. Salient features of the Dar-Al'a research station

The major ET_a measurement method is the weighing Lysimeter. The weighing Lysimeter funded by USDA is installed on a 2.5-ha farm in the NRAC station. Its size is 3.75m (l) x 2.5m (w) x 2.5m (d). The soil is composed by silty clay loam. Currently, a cucumber crop is grown on it under greenhouse conditions. They are ready to make it an open field by removing the greenhouse structure and change the crop as required. The main irrigation method is drip irrigation. The ET data are measured at half-hourly interval manually with an accuracy of 0.5 mm day^{-1}. Most of the crops in the Jordan valley are cultivated during the winter with some sporadic crops in the summer (maize and okra). Historical data are available from 2010 but can be openly distributed only after they are published. Future improvements on this Lysimeter can be the addition of modem-based data transmission facility so that diurnal variation of ET_a can be recorded automatically. Currently, only day-time ET measurements are being recorded manually with high accuracy and confidence.

While an eddy covariance system (EC) is available, along with the full set of core and allied instrumentation, NARC (and local ICARDA Office) staff were not confident in using it due to lack of qualified personnel and skilled technicians, and reduced maintenance capacity.

In this site, the project team's recommendation is to use (i) the existing Lysimeter (after some specific improvements in data transmission etc.), (ii) the Soil Moisture Depletion method, and (iii) the addition of the CORDOVA-ET station.

There are also some other sites (ICARDA-managed) in Badia (rangeland) where the project team could add some other CORDOVA-ET stations, depending on FAO plans and budget.

2.2. Site Soil and Water Characteristics

Soil and water characteristics are significant to the local water balance. These include both the physical and chemical properties of the soil. The quality of irrigation water affects the field water balance to a certain extent and hence the ET_a. At this site, the soil is predominantly a heavy clayey soil with 55% clay fraction. This has a major influence on the plant water availability both in terms of the soil water property dynamics, as well as plot-scale hydrology, due to the cracking and swelling characteristic. Water for agriculture is primarily through groundwater with salinity issues. Tables 2 and 3 show the salient features of soil hydraulic properties and chemical properties, respectively, at the Dyar Ala research station the Dyar Ala research station.

A synoptic view of the Dyar Ala research station is reported in Fig. 1

Table 2. Hydraulic properties of soil at Dya Ala Research Station in the Jordan Valley

Soil depth	BD	FC	PWP	Sand (%)	Silt (%)	Clay (%)	Textural class
0 - 15	1.33	31.00	19.95	13.9	31.9	54.2	Clay
15-30	1.35	32.50	21.59	10.3	33.7	56.0	Clay
30-45	1.32	33.00	21.95	13.7	28.4	58.9	Clay
45-60	1.45	34.50	22.90	8.2	32.0	59.8	Clay
60-75	1.46	34.80	22.95	11.6	32.1	56.3	Clay
75-90	1.50	35.69	23.00	14.9	32.2	52.9	Clay

BD =Bulk Density [kg m^{-3}] FC= Field Capacity [%] PWP= Permanent Wilting Point [%].

Table 3. Salient Physico-chemical properties of soil and water in Dyar Ala site

Soil depth	N%	P (ppm)	K (ppm)	pH	EC_e (dS m^{-1})
0-15	0.112	67	812	7.8	3.2
15-30	0.089	62	696	7.7	2.2
30-45	0.056	70	627	7.7	2.4

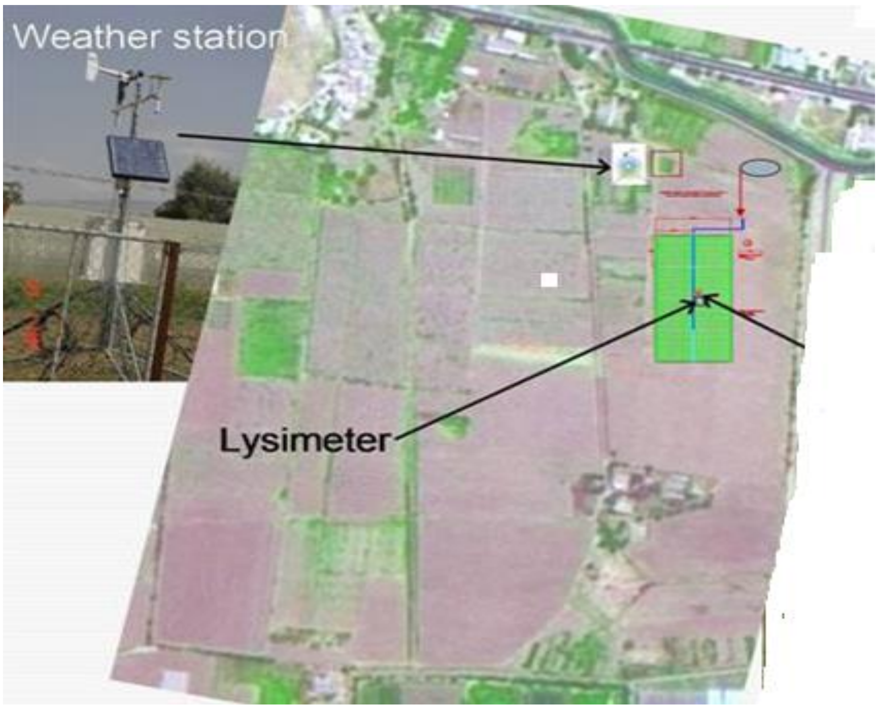


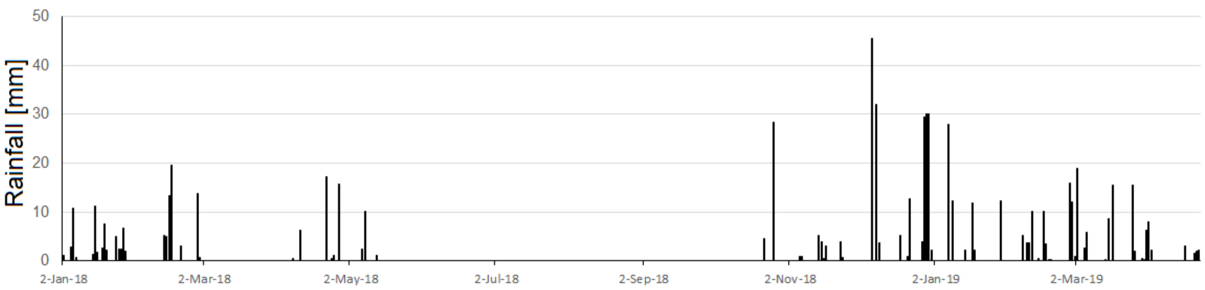
Fig 1 - Location of the Lysimeter in the Dyar Ala experimental station, Jordan.

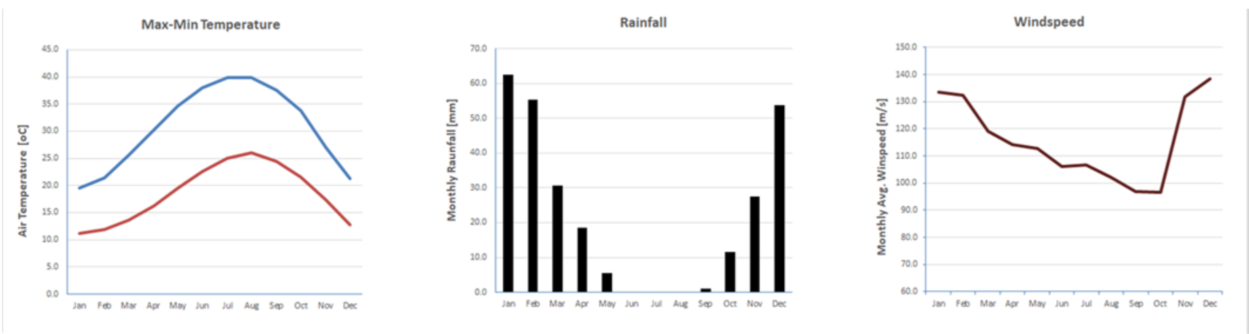
2.3. Cropping Pattern

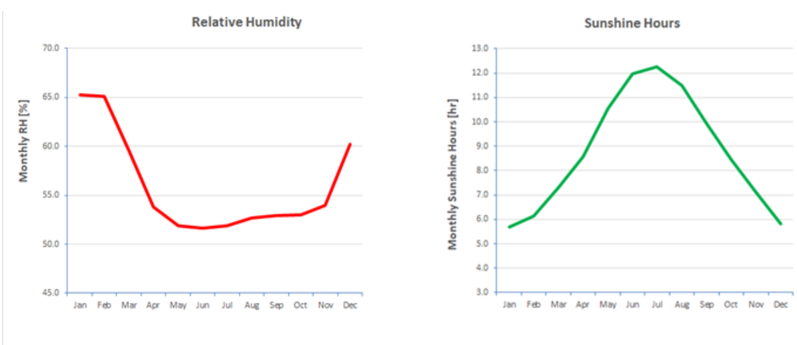
The conventional crop pattern at the research station mainly includes winter vegetables grown under large plastic greenhouses. The main vegetables grown are tomato, cucumber and sweet pepper. The growing season starts from October to December. The main summer crop is maize and grown in open fields in May and June. Last year, the main crop was cucumber. Because the microclimate under greenhouse conditions are drastically different from outside (and hence the ET), for our experiments in this project, it is important that we consider open field crops to fit the standard protocol. Thus, the working crop will be wheat.

2.4. Local Hydrometeorology

The local precipitation pattern reflects the fact that the site is a typical Mediterranean agroecosystem with most of the rains in the wintertime. The summers are usually hot and dry. The most intensive rain events occur in December to January. The duration of the rainy season lasts from November to May (6-7 months). Typical seasonal patterns of weather variables at Dyar Ala station are reported in Fig. 2. The seasonal pattern of temperature (maximum and minimum) reveals that the lowest values are in January and the maximum is in July-August. The relative humidity sharply drops at the onset of Spring and remains relatively lower until the end of Autumn. The sunshine hours follow the classical sinusoidal pattern with the peak in June-July, which is typical of this latitude. The wind speed drops towards the Autumn and it sharply increases as the Winter approaches.







Mean Annual Climate Normals	2001-2016
Mean Maximum Air Temperature (°C)	30.7
Mean Minimum Air Temperature (°C)	18.5
Total Rainfall Amount (mm)	266.4
Mean Relative Humidity (%)	55.9
Mean Sunshine Hours	8.8
Mean winspeed (km/hr)	115.9

Fig. 2 - The seasonal pattern (climate normal) for the crucial hydrometeorological parameters affecting ET at Dyar Ala site.

2.5. Main available ET Measuring Facilities

The main available facilities include one large scale weighing lysimeter (2.4m*3m=7.2 m^2 with 2.5m depth) installed inside single plastic tunnels (430 m^2) and an open field (2 ha) surrounding the lysimeter. This weighing lysimeter has been operational as part of several on-going projects. (e.g. USAID project). Figure 3 shows an example of ET_a and ETo estimated using measurements taken at this site. The data is shown only for the period when there was no irrigation water applied so that the Lysimeter measured weight differences directly related to ET losses. Note that towards the end of the time period the ET_a is much lower than ETo, due to the full senescence of the onion crop (no more ET_a).

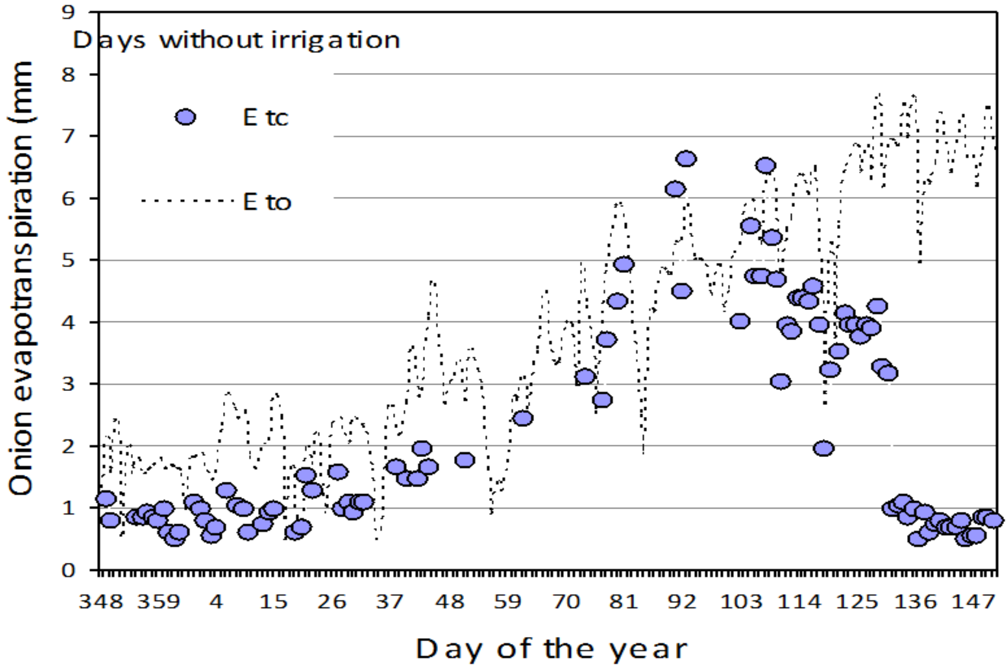


Fig. 3 - Comparison of the ETo (shown as Eto) vs ET_a (shown as Etc) at Dar Alia over an Onion crop measured using the weighing lysimeter.

2.6. Notable Projects History

[1] IMIS Project - The Irrigation Management Information System (IMIS) project is funded by the U.S. Department of State and developed/managed by the U.S. Department of Agriculture-Agricultural Research Service-Office of the International Research Programs (USDA-ARS-OIRP). It is part of the Middle East Peace Initiative. IMIS is a cooperative regional project bringing together participants from Israel, Jordan, Palestinian Authority, and the United States. (2003-2010). The objectives of IMIS include the following:

1. Improve water management in the Middle East by developing a regional database system for dissemination of agro-meteorological information, providing data for scheduling irrigation and other crop management decisions to increase irrigation efficiency in the region.

2. Install automated weather stations and lysimeters to develop and improve water management models and irrigation scheduling practices at both the field and watershed scale in the Middle East and the United States.

3. Apply irrigation scheduling methodology in farmer fields and, through interaction with farmers, farm advisors and extension personnel, promote the implementation of the IMIS system to ensure wide acceptance and sustainability.

[2] The IRRIMED Project - Improved management tools for water-limited irrigation: combining ground and satellite information through models (from the final report, covering period from April 1 2003 to March 31, 2007). The general scientific objective of IRRIMED is the assessment of temporal and spatial variability of water consumption of irrigated agriculture under limited water resources condition. Measurements with sophisticated equipment is used to combine ground and satellite data into models, to ultimately produce simple and robust methods to assess evapo-transpiration (ETR) over large areas. Two European institutions (IRD-cesbio, France; WU, the Netherlands) associated with seven participants from four Mediterranean partner countries (Jordan, Morocco, Syria, Tunisia) have carried out the ambitious IRRIMED program http://www.documentation.ird.fr/hor/fdi:010065242

3. Lebanon site (Tel Emara, Beka Valley)

LARI already manages several agrometeorological stations across the country including the Bekaa valley, which is the breadbasket of Lebanon. The soil of Tal Amara LARI station is principally Loamy Clay with a variety of crops in the farm including wheat, potatoes, aromatic plants and fig trees. The plan is to have Lysimetric and 'volumetric soil moisture content' (VSMC) methods as standards to estimate ET_a. LARI has already trained personnel who are actively engaged in the measurements of ETo but needs supplemental funds to sustain them. The Tal Amara LARI station has a Lysimeter installed by John Monteith (the author of the world-wide known Penman equation for the determination of ETo) but needs maintenance to make it operational. They also have facilities for VSMC-based ET estimation method (Fig. 4).

Fig. 4 - Location of LARI Tal Amara field plot where the measurements will be taken.

3.1. Salient Characteristics of Tal Amara Site

Fig. 5 - An aerial photograph at the LARI Tal Amara station.

3.2. Site soil and water Characteristics

Soils of the ET experimental site are deep where the root zone might extend more than 2 m. It is a fairly drained soil with a slope gradient of less than 1%. The soil texture is Clayey with 28% sand, 28% silt and 44% clay with a medium level of Organic Matter (1.47%). The soil is mostly alkaline with pH value of 7.8. Salinity is very low with EC of 0.21 ds/m. The soil bulk density is about 1.4 g/cm3. The field capacity and the wilting point reach about 38% and 20% on volumetric base, respectively. The hydraulic conductivity is about 40 mm/day. The soil is poor in total nitrogen with 0.15% but rich in potassium (414 ppm K_2O).

3.3. Cropping Pattern

The area of the project is only used for field crop cultivation. Throughout the last nine years, the site was cultivated with winter wheat, potato, maize, zucchini, beans, and sorghum/millet. The crop rotation is mainly cereals and vegetables with one year of bare soil. In the coming season the area will be cultivated with summer potato followed by fababean for nitrogen fixation process.

3.4. Local Hydrometeorology

The general climate of the area (Bekaa Valley) is typically Mediterranean but it is affected by the surrounding presence of two elevated mountain chains. The area is characterized by semi-arid type of climate with a hot dry summer and relatively cold-rainy winter. The average annual rainfall is about 590 mm with 95% of the rain occurring between November and March. The rainy month is January with an average of about 145 mm. The average temperature is about 17 °C. The rain ceases in mid-May and sometimes starts in mid-September. The dry winter season had rain as low as 280 mm while the rainy winter season reached a maximum 1,250 mm. Typical seasonal rainfall pattern is reported in Figure 6, while patterns of the other agro-meteorological variables are reported in Figure 7.

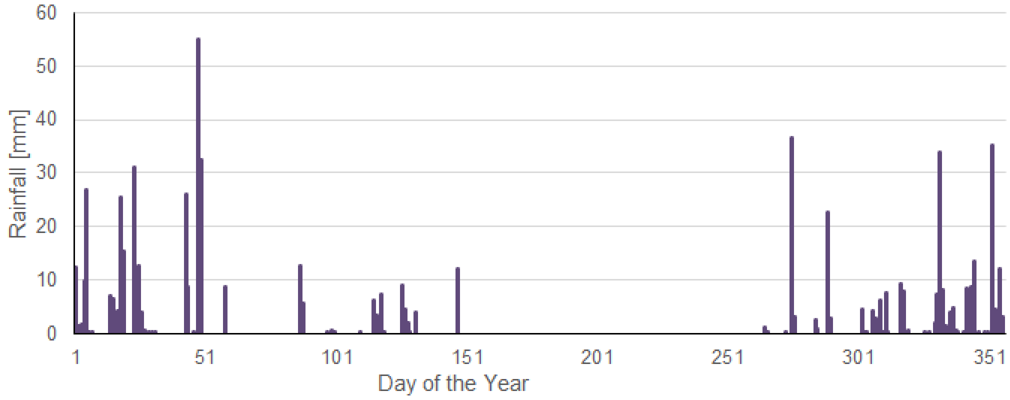


Fig. 6 - Seasonal pattern (2018) of the rainfall distribution in Tal Emara. Note the well distributed rainfall except in the peak summer season, signifying that this is a relatively wet agroecosystem.

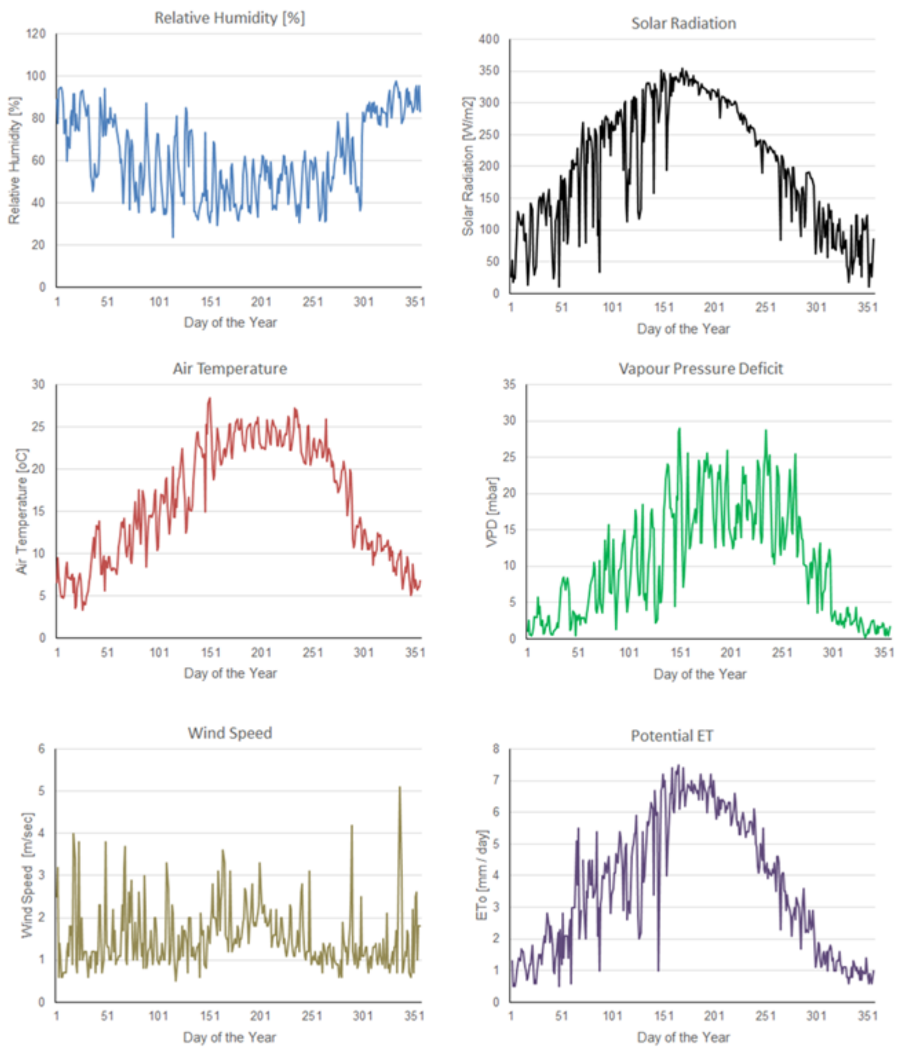


Fig. 7 - Seasonal pattern of various hydrometeorological variables at Tal Amara, Lebanon.

3.5. Main available ET Measuring Facilities

The site is equipped with a weighting Lysimeter of Davis-California type with dimensions of 3x3 m top and 3 m depth. The Lysimeter is connected to a counter-reader and laptop installed in a shed at 100m distance. The recording software is DAQ Master that can register momentarily the weighing balance of the Lysimeter. The lysimeter is close (70 m distance) to the Automated Weather Station (AWS) of iMETOS Pessl Instruments, Austria. The recording sensors are rainfall rate, solar radiation, barometric pressure, maximum-minimum temperature, soil moisture, soil temperature, wind direction/speed, relative humidity. The weather data are used to determine reference evapo-transpiration (ETo). Typical seasonal values of ETo at Tal Amara are reported in Figure 8. The AWS is maintained monthly thorough regular visits on monthly basis and the data are checked for accuracy before being sent for storage.

Gravimetric measurements are another possibility to monitor soil moisture and eventually estimate ET. Soil augers for 1 m depth exist to be used for testing soil moisture on various depths. Oven-dry and weighing balances are in the Labs of LARI at a distance of 150 m from the site.
The station is equipped also with soil moisture sensors of TDR type that are made by Decagon. The sensors are connected to a data logger from Hobo technology, USA.

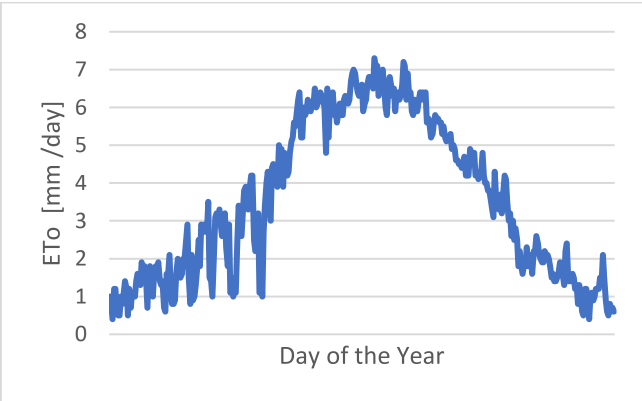


Fig. 8 - An example of the seasonal dynamics of ETo measured at this site, Lebanon.

3.6. Notable Projects History

Trials, in the 1960s were performed to test accuracy of different reference evapotranspiration methods. This work was with FAO and LARI to have more experience on the use of empirical methods of ET determination. Several trials were performed, since 1997, on various crops (wheat, Maize, Sorghum, Zucchini, beans, etc.) regarding also deficit irrigation. These crop trials were carried out by the Department of Irrigation and AgroMeteorology of LARI.

4. Morocco Site (Berchid)

As part of the project aims and objectives, ICARDA selected the Agronomic and Veterinary Institute (IAV) in charge of the Morocco country site. A new agrometeorological station will be established where ETa measurements at plot level and the efficiency of water use in the region’s main irrigated crops will be studied in detail at Mr. Ibrahimi's (a local farmer) farm. The meteorological station will record measurements for two agricultural seasons. The ICARDA team visited the site on 24 October 2019 to review the selection of the site and to understand the necessary instrumentation and the associated sensors. The main criteria for appropriate site selection were the commitment of the owner/manager of the farm to ensure the safety of the station and to facilitate access for project teams and to practice irrigating cropping system, representative of the region.

4.1. Site Characterization

Brief characteristics of the site are reported in Table 4.

Table 4. Brief description of the new Morocco Site

Surface area	500 ha
Crops	Cereals, quinoa, rapeseed, olive tree, alternative crops (coriander, flax, goji berry, shia)
Irrigated crops	Cereals, olive tree
Possibility for the station's installation	Implementation of the CORDOVA-ET station with a Gateway and the 4 nodes on a plot having 2 crops and 2 different types of soil.
Advantages	- Secure site, far from housings, surveillance camera - Easy access - Ready to shelter the station immediately - Research of innovation, introduction of quinoa saponification machine, new varieties, new crops - Possibility to adapt the crops according to the project's needs
Drawbacks	No historical data available as the site is new

4.2. Moisture and particle size analysis of soil samples

Because the site is new, very limited historical datasets exist that characterize the hydraulic properties of the farm soil. Nevertheless, some efforts were done to understand the soil texture in a detailed way. As such, textural studies were conducted at two depths and at six places in the farm. The data are shown in Table 5. The general trend is that the soil is primarily of loamy texture. However, more studies are required to determine the hydraulic characteristics of soil (Field Capacity and Wilting Point) that would greatly enhance our understanding of ET_a. It is also recommended to have monitoring of soil moisture in this site so that it can be related to the estimated ET_a, as influenced by the irrigation events.

Table 5. Brief description of the hydraulic properties of the soil at the new Morocco site

Depth (cm)	Coarse sand %	Fine Sand %	Coarse Silt %	Fine Silt %	Clay %	Texture
0-20	3.70	35.72	19.34	20.94	20.30	Loamy soil
20-40	4.65	36.50	17.33	21.19	20.34	Loamy soil

4.3. Local Hydrometeorology

The farm is located in a semi-arid temperate climate. The proximity of the Atlantic Ocean has a very important influence, to ensure high air hygrometric degree. Temperatures are moderate with an average of 17,4°C. Rains regularly fall in autumn and winter from October to March. The annual average of rainfall is 315 mm.

4.4. Main available ET Measuring Facilities

Although there were no previous active ET_a monitoring activities in this site, IAV acquired an eddy covariance system recently and it has been set up as per the standard protocols (Fig. 9). The details of the eddy covariance system are briefly mentioned below

This site's EC system consists of an Open field gas analyser with a 3D sonic anemometer, specifically designed for studies of turbulent flows, Eddy Covariance, Eddy Correlation or turbulent correlation (Campbell Scientific EC150 gas analyser and CSAT3A sonic anemometer). It measures absolute carbon dioxide, water vapor density, air temperature, atmospheric pressure, three-dimensional wind speed and sonic air temperature simultaneously. The EC system has a micro logger with an energy balance calculation program. Besides these, the allied meteorological instrumentation is also deployed at the tower site. This includes: a soil temperature sensor to measure the average temperature 6 to 8 cm deep from the ground for energy balance measurement systems; a net radiometer to measure the energy balance; volumetric soil moisture using reflectometric probe for measuring soil moisture (TDR); air temperature and relative humidity.

Fig. 9 - Newly-established field site by the IAV team in Morocco where the CORDOVA-ET station is installed.

Eddy Covariance Data Processing Approach
Because EC is more of a modelling activity than the measurement itself, a series of calculation steps are involved that includes several corrections and quality control protocols to retrieve the ETa. Thus, the site will use a standardized EC data processing and quality control protocol similar to other sites using the ECPACK software (Van Dijk et al., 2004). This ensures that all the EC sites follow the same approach of processing EC data. More studies on the boundary layer turbulence will be described to characterize this site as the measurements proceed in the future. In addition to this, quality control using integral turbulence test and stationarity test will be employed and the ETa will be reported as described in the Protocol Document.

5. Tunisia Site (Jendouba)

The Institute National des Grandes Cultures (INGC) platform (GPS :36°32’47.83’N ; 9°00’50.00’’E) in El Koudia was chosen for the installation of an experimental device for the measurement of evapotranspiration (ET) in the agricultural region of Jendouba, using different methods (Fig. 10). The station is new and will be subjected to an agro-ecological characterization and monitoring of necessary parameters for the interpretation of the results concerning the estimation of ET_a by different methods.

5.1. Site soil and water characteristics

The El Kodia soil belongs to the slightly-developed soil class according to the "Commission de Pedologie et de Cartographie des sols" (CPCS, 1967). The site has a deep, non-saline (EC ≃ 0.2 mS/cm; pH=8), calcareous soil (total carbonate=22.5% and active carbonate=7.2%) with clay loam texture. The site soil has a low organic matter (1.1%) and a high Cation-exchange capacity (16.0 meq/100g).

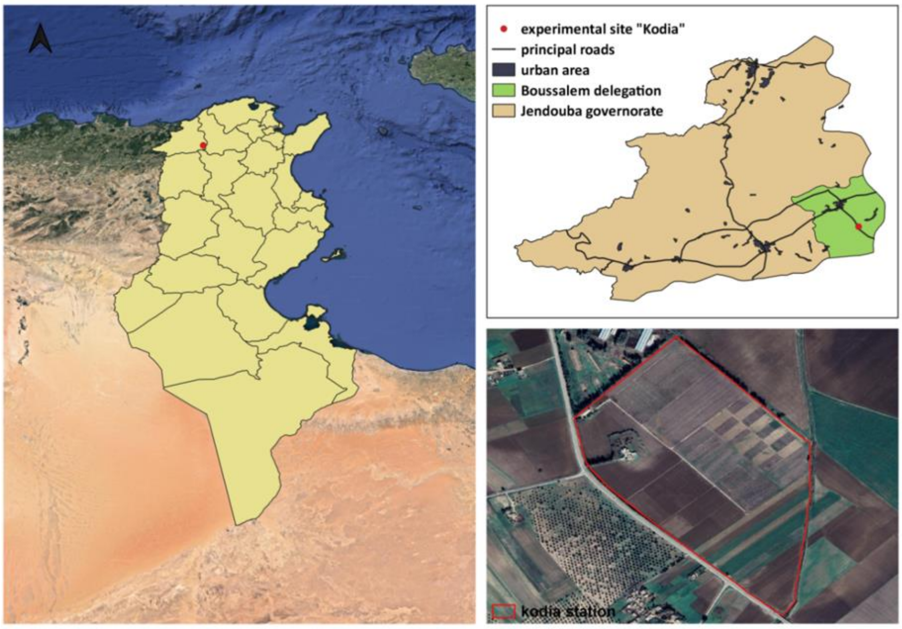


Fig. 10 - Location of Jendouba site in Tunisia and an aerial photograph of the farm

5.2. Cropping System

The main cultivated crop in this experimental farm are durum wheat, fababean, sugar beet and rapeseed using conventional or direct sowing methods. The experimental plot was planted with durum wheat on December 3, 2019 using direct seeding. In mid-Februry 2020, the wheat cover reached the tillering stage with a eight of around 35 cm.

5.3. Main available ET Measuring Facilities

Although there were no active ETa monitoring activities in this site before, INRGREF recently acquired an eddy covariance system and it has been set up as per the standard protocols (Fig. 11). The details of the eddy covariance system is briefly mentioned below.

A three-dimensional sonic anemometer CSTA 3 (Campbell Sc, Logan USA) and a Krypton hygrometer (KH20 Campbell Sc Logan USA) were installed in December 2019. The data are acquired and recorded at 20Hz frequency. The four components of solar radiation (incoming and outgoing short- and long-wave solar radiation) are measured through NR01 (Hukseflux, Netherland). Finally, soil heat flux (Shf, HFP,Hukseflux, Netherlands) were recorded at 1s and averaged and stored over 15 min. There is no historical data to characterize the turbulence of the site. A CORDOVA-ET station is planned to be mounted on a wheat crop as well. The team at INRGREF has several other eddy covariance sites across Tunisia and has a sound technical expertise in this methodology of ET_a determination.

Fig. 11 - Location of the ET monitoring field site in Tunisia.

Eddy Covariance Data Processing Approach
The site will use the same standardized EC data processing and quality control protocol adopting the ECPACK software (Van Dijk et al., 2004), as for to other sites. The coordinate rotation correction method will be used as well to ensure that all the EC sites follow the same approach of processing EC data. Once the flux will be calculated, the Horst et Weil (1994) model will be used to analyse the flux footprint. Using the measurements of the four-energy component, the balance 'closure' will be analysed at hourly and daily scales. More studies on the boundary layer turbulence will be described to characterize this site as the measurements proceed in the future. In addition, quality control using integral turbulence test and stationarity test will be employed and the ET_a will be reported as described in the Protocol Document.

5.4. Notable Projects History

The INRGREF team is quite experienced in using eddy covariance and has participated in several projects, as listed below.

- Since 2004 – today ORE OMERE long term observatory of soil and water ressources. One of the site is at CapBon region in Tunisia,
- 2009-2013 Land surface – atmosphere exchanges within hilly watersheds (Labex Agro Agropolis Fondation - France)
- 2013-2017 - ANR Transmed: ALMIRA – "Adapting Landscape Mosaics of mediteranean Rainfed Agrosystems for a sustainable management of crop production, water and soil resources".

- 2003-2007 - IRRIMED EU projet FP7 - An Euro-Mediterranean Research Project on Improved Management Tools for Water-Limited Irrigation : Combining Ground and Satellite Information Through Models.

6. Egypt Site (Sakha)

The site: Sakha Agricultural Research Station, Agricultural Research Center, Kafr El-Sheikh governorate, Egypt. It is located at 31°-07N latitude, 30°-57E longitude, with an elevation of about 6 meters above mean sea level, within the Governorate of Kafr el-Sheik (Fig. 12).

6.1. Site soil and water Characteristics

The soil of the site has a heavy clay texture (more than 45% clay) and its structure tends to be granular. Water table is shallow (almost 1m), with salinity ranging from 2.5 to 3 dS/m. Soil can be classified as Entisols (Vertic Torrifluvents). Bulk density is high, in the range of 1.4-1.7 g/cm3. Field capacity is about 42% on mass basis; permanent wilting point is 22.8%. Irrigation depends on Nile water, as rainfall is little and fluctuates from year to year within 150-180 mm/year. Water salinity ranges from 0.8-0.95 dS/m. Drainage system involves both tile and open canals. Irrigation is mostly applied through surface and flood methods. The drainage system uses surface open drains. Typical soil-water characteristics of Sakha station are reported in Table 6.

Table 6 Some physical characteristics and some soil water constants.

Soil Depth cm.	**Particle Size Distribution**			**Texture classes**	**F.C. %**	**P.W.P. %**	**AW %**	**BD Mg m-³**
	Sand%	Silt %	Clay %					
0 – 15	16.6	19.4	64.0	Clay	47.3	25.0	22.3	1.16
15 – 30	19.2	17.9	62.9	Clay	39.9	21.5	18.4	1.19
30 – 45	17.6	19.8	62.6	Clay	38.1	21.1	17.0	1.23
45 – 60	18.8	19.6	61.6	Clay	37.4	20.3	17.1	1.31
Mean	18.1	18.8	62.8	Clay	40.7	22.0	18.7	1.22

Where: F.C. % = Soil field capacity, P.W.P. % = Permanent wilting point, AW % = Available water and BB (Mg m-³) = Soil bulk density.

6.2. Cropping Pattern

There is a wide variety of crops due to the warm climate, plentiful water of the Nile, and exceptionally fertile soil. The site essentially has two seasons, summer and winter; spring and fall are quite short. Major summer crops are rice, maize and cotton; winter crops involve wheat, sugar beet, fababean, clover and barley.

6.3. Local Hydrometeorology

It is a semi-arid region, characterized by the Mediterranean climate, though the Köppen-Geiger climate classification system classified Kafr el-Sheikh as hot desert. Monthly average of maximum temperature is almost 26.8 C°, whereas monthly average of minimum air temperature is nearly 20 C°. Rainfall ranges between 150 to 180 mm/year. From historical and recent climate data, it is noticed that there are changes in climate elements, particularly temperature and rain fall, and consequently evapotranspiration is highly affected.

6.4. Main available ET Measuring Facilities

Historically, in this site, four types of soil moisture estimation techniques are routinely undertaken at this site. This includes 1. Gravimetric Technique; 2. Time Domain Reflectometry (TDR); 3. Eddy covariance; 4. Empirical equations of ET estimation.

Fig. 12 - Location of the field site in Sakha Agricultural Research Station, Egypt and an aerial photograph of the farm.

At this site, the main approaches historically have been eddy covariance and energy balance approach. Although eddy covariance has been deployed many years ago, the calibration was not conducted for the last three years because the seasonal calibration kit was missing, and the gas analyzer is obsolete. The details of the sonic anemometer and gas analyzer are shown in Table 7.

Table 7. Brief description of the eddy covariance instrumentation in Egypt

Sonic anemometer	Open Path Gas Analyzer
Manufacturer: Gill instruments Model: Wind Master 3D anemometer Output: Sonic Temperature, wind vectors (U,V,W) and Wind Direction (0 to 359) Frequency: 10 Hz <u>Wind Speed Specifications:</u> Range:0-50m/s Accuracy: 1.5% RMS @ 12m/s Accuracy: 1.0% RMS @ 12m/s Resolution: 0.01m/s <u>Sonic Temperature Specifications:</u> Range: -40ºC to +70ºC Resolution: 0.01ºC Accuracy: -20ºC to +30ºC within ±2ºC of ambient temperature	Manufacturer: Li-Cor Model: LI-7500 Open Path CO2/H2O Analyzer Type: Absolute, open-path, non-dispersive infrared gas analyzer Bandwidth: 20 Hz

Data logger estimates approximate fluxes from raw high frequency data, and then a PC software is used to obtain fully corrected fluxes. The datalogger program follows the method presented in Foken at al. (2012) to grade the relative quality of CO_2, latent heat, sensible heat, and momentum fluxes.

In addition to the eddy covariance system, the station also includes Energy Balance (EB) sensors which are well maintained and calibrated, so that all the components of the energy balance equation are measured, except latent heat flux (H). The tower (Fig. 13) has various meteorological instruments that measures various components of the surface EB. Sensible Heat (H) estimation is done using EC

Method. For the calculation of H, it records high frequency (10Hz) data for wind 3D vector components (Ux, Uy, Uz) and sonic temperature Ts (81000VRE, Young USA), and then computes the corrected sensible heat from the covariance of vertical wind (w') and sonic temperature (Ts'). The EC Method is used to calculate sensible heat (H) only, total available energy flux (Net Solar Radiation and Ground Heat flux) was obtained by standard measurement techniques. ET_a is then obtained as the residual term of the energy balance equation. Low frequency (1 Hz) data for net solar radiation (NRLite2, Kipp&Zonen) and Soil Heat Flux (HFP01, HukseFlux) is used to obtain 30 min net radiation (Rn) and soil heat flux (G). Soil temperature gradient (TCAV, Campbell Scientific) and soil moisture (CS655, Campbell Scientific) was measured to calculate Heat Storage (S) in the soil surface layer, S canopy was not measured (as negligible for crops).

Other recorded measurements of wind direction (81000VRE, Young USA), air temperature and relative humidity (HS2s3, Rotronic USA), rainfall (TE525MM, Texas Electronics) are being verified. The sensors were mounted to an adjustable height instrumentation tower to facilitate the maintenance of the equipment and adapt to different crops and crop heights, making sure that all the sensors cover the area of interest.

An on-site datalogger (CR3000, Campbell Scientific) computes continuously corrected fluxes every 30 minutes for Net Radiation (Rn), Soil Heat Flux (G), and Sensible Heat Flux (H). Latent heat flux (λE) is then calculated using the surface energy balance equation, $\lambda E = Rn - G - H$. To obtain 30-min ET_a, λE during the 30 minutes is divided by the latent heat of vaporization (λ).

Fig. 13 - The Energy Balance and Eddy covariance tower in Egypt.

In the gravimetric method, soil samples are collected from different depths in the soil moisture boxes. These boxes are weighed using digital weighing scale and their initial weights are noted down. The samples are brought to the laboratory and put in the oven for 24 hours at 105°C. Once the oven drying is complete, the samples are weighed again, and their weights are noted down. After oven drying, the empty weights of soil moisture boxes are measured. Sampling is performed before and after irrigation. Moreover, many points are sampled to achieve a good representation.

6.5. Notable Projects History

There were many previous studies on crop evapotranspiration (ET) based on field scale measurements in the Nile Delta, i.e., Shahin (1985) detected ET for late maize, cotton, and wheat over a 10-day period using soil water balance method in conventional irrigation methods. Swelam et al., (2010) calculated monthly ET for wheat and maize, besides crop coefficient (Kc) for four growth stages, using soil water balance method for maize and weighing lysimeter for wheat, through conventional irrigation methods. Michiaki Sugita et al., (2017) obtained daily, total ET and Kc for maize, rice, cotton (summer crops), as well as for wheat, sugar beets, berseem, and fava bean (winter crops) via eddy correlation method over conventional and water saving irrigation methods.

7. Recommended possible additional instruments in each site

Based on the field missions, the team recommends some additional instruments and maintenance to be considered for some of the sites, which are listed in Table (8). These additional instruments are essential for proper ET_a ground measurement. The CORDOVA-ET station is also recommended. It is planned to scientifically compare the ET_a measurement with the already existing ET_a monitoring facilities at these sites. In this way, there will be a cross-validation between methods, and therefore have a realistic estimate of ET_a at these sites. Thus, we will have a network of benchmark sites that will serve as validation of satellite-derived ET_a data.

There are several issues associated to repair and maintenance of the ET measuring methods. Further, the troubleshooting of the instruments is required if some issues arise. Therefore, a complete knowledge on the functionality of the instruments is of paramount importance. Further, a uniform system of measurement using these ET methods will ensure quality data among all countries. These aspects are covered in Activity 2.1 report.

Table (8) the recommended additional instruments and maintenance for each site

Country	Field Station	Required maintenance/Repair	Additional Instrument	Action taken
Egypt	Sakha, ARC, Kafr El-Sheikh	In the Energy balance and Eddy covariance flux tower: - replace the Net radiometer - replace the ground heat flux plates - calibrate the gas analyser to be able to get the eddy covariance data	- Cordova-ET station	By ICARDA: - replaced the net radiometer and heat flux plates - full maintenance to the energy balance flux tower (costed 15,000 USD)
Jordan	Dyar Ala, Jordan Valley, NARC	- the lysimeter load cell need to be replaced - data logger to be changed - dial-up modem to remotely access the data	- Cordova-ET station - TDR	By ICARDA: - purchased Acclima TDR and installed in Dyar Ala station (costed 7,000 USD) - changed the data logger and installed modem

Lebanon	Tel Emara, LARI	- the lysimeter load cell need to be replaced - data logger to be installed - dial-up modem to remotely access the data	- Cordova-ET station - TDR	By ICARDA: - Acclima TDR and will be shortly installed in Tel Emara station (costed 7,000 USD) - Fix the lysimeter (quotations received for 9,000 USD)
Morocco	Birched, Casablanca (private farm)	In the Energy balance and Eddy covariance flux tower: - All the energy balance components need replacement - Data logger and enclosure needs replacement - Dial-up modem to be installed	Cordova-ET station TDR	By ICARDA: - Full maintenance and repair for the EB and EC flux tower (costed 10,000 USD) By IAV: - purchased 2 TDR and installed in the field
Tunisia	Gendouba, INGC-INRGREF	- Install Dial-up modem to remotely access the data	Cordova-ET station	By INRGREF: - will install the modem

8. References

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