OLIVE4CLIMATE - LIFE

CLIMATE CHANGE MITIGATION THROUGH A SUSTAINABLE SUPPLY CHAIN FOR THE OLIVE OIL SECTOR

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Deliverable 4 ACTION C3:
Catalogue of agricultural practices and their (mitigation/adaptation) performances

Responsible Partner: UNITUS

Author: Dr. Carlo Trotta

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Project coordinator:

Università degli Studi di Perugia
UNIPG

1 Introduction

This document is a brief description of the achieved Deliverable C3.4 after the release of Deliverables C3.1, C3.2, C3.3 and according to the fulfilment of the Milestone C3.1 and the Milestone C3.2.

Within Tasks 1 and 2 of Action C3, the review and collection of data was completed (see Deliverable C3.1), as well as the filling and structuring of a dedicated GeoDataBase (see Deliverable C3.1) to support the process-based modelling of olive tree growth and productivity through the 3D-CMCC-OLIVE model. Results of the modelling are in the final (Output) GeoDataBase containing matrix of results (Deliverable C3.3).

To the original version of the 3D-CMCC-FEM model (Collalti et al., 2018b; Collalti et al., 2018; Marconi et al., 2017; Collalti et al., 2017; Collalti et al., 2016; Collalti et al., 2014) two new modules are added in order to consider the irrigation and the pruning frequency (see also Collalti et al., 2018). The new version of the 3D-CMCC-FEM model is now named '3D-CMCC-OLIVE'.

In the Task 3 a protocol to run simulations was established to test different climate conditions (current and future time horizons with different rates of warming and increasing atmospheric CO_2 concentrations) and alternative management schemes (i.e. pruning and/or irrigation). For each farm a maximum of 28 model runs: 1 baseline + 3 managements (i.e. pruning or irrigation, pruning and irrigation) by 9 different climate (modelled) forcings. The baseline management scheme is defined as the Business As Usual (BAU) under current (i.e. present-day) climate conditions (scenarios EOBS and AGRI4CAST_OBS, see Milestone C3.2 for more details).

The aboveground biomass simulated in the baseline (AGBsim) are used to estimate the performance of the model in respect to the measured aboveground biomass (AGBms) obtained by applying the allometric equation described in Brunori et al. (2017).

The aim is to quantify the effect of the climate and management scenarios on the carbon uptake and on the contribution to mitigate the climate changes of the olive trees.

2 Parameters and calibration

The model needs of some initial eco-physiological information about of Olive trees expressed by numerical parameters (table 1). In the Milestone C3.2 is described as these parameters have been gleaned in the scientific literature (Maselli et al., 2012; Morales et al., 2016; López-Bernal et al., 2018) or calculated by the Bayesian calibration.

The NPP (Net Primary Production; gC m^{-2} day^{-1}) simulated by a different model (DayCent; see Brilli et al., 2018 for details) in an olive orchard situate in Tuscany (near to Follonica: 42°56′N, 10°46′E) in three years (2010, 2011 and 2012) has been used to calibrate the 3D-CMCC-OLIVE. The NPP has been used instead of using the GPP (Gross Primary Production; gC m^{-2} day^{-1}) estimated by eddy covariance tower in a olive orchard near to Castelvetrano (Sicily) in the 2007 (Nardino et al., 2013) because the contribution of the trees and the understory vegetation to 'ecosystem' GPP could not be partitioned among these two different producers (olive trees and understory vegetation).

Meteorological conditions in the Follonica olive orchard differed in the three study years. The first year (2010) was markedly wetter than the second (2011), The third year (2012) is intermediate to the two previous.

To include the effects of the interannual variability in the model performances, the calibration is applied with different datasets:

- one-year-at-time;
- two-years-at-time (2010 and 2011; 2011 and 2012; 2010 and 2012)
- all time series.

The model runs have been launched in two different model configurations:

- Light Use Efficiency (LUE, linear empirical relationship between radiation and photosynthesis)
- BioGeoChemical (BGC, biochemical representation of photosynthesis)

At the end of the calibrations each set of parameters has been applied to simulate all the three years.

To assess model performances DayCent model results and the NPP estimate by the 3D-CMCC-OLIVE have been pairwise compared through two different statistical indexes:

- Coefficient of determination (r, better performances if near to 1)

- Percent Bias (PBIAS, better performances if near to zero)

The Light Use Efficiency (LUE) configuration and calibration with the years 2010-2011 shows the best of the performances (r = 0.8; PBIAS = -2.97%) while the BGC shows r = 0.76 and PBIAS = -7.35%. This set of model parameters (table 2) was then used to run all the simulations in the farms involved in the Olive4Climate project.

Table 1: Units and description of the 3D-CMCC-FEM and 3D-CMCC-OLIVE model parameters.

PARAMETER	Unit	Description
LIGHT_TOL	DIM	Light Tolerance 4 = very shade intolerant (cc = 90%), 3 = shade intolerant (cc 100%), 2 = shade tolerant (cc = 110%), 1 = very shade tolerant (cc = 120%)
PHENOLOGY	DIM	PHENOLOGY 0.1 = deciduous broadleaf, 0.2 = deciduous needle leaf, 1.1 = broad leaf evergreen, 1.2 = needle leaf evergreen
ALPHA	molC / molPAR	Canopy quantum efficiency
K	DIM	Extinction coefficient for absorption of PAR by canopy
ALBEDO	DIM	Canopy albedo
INT_COEFF	%	precipitation interception coefficient
SLA_AVG0	m2 / kgC	Average Specific Leaf Area (juvenile) sunlit/shaded leaves
SLA_AVG1	m2 / kgC	Average Specific Leaf Area (mature) sunlit/shaded leaves
TSLA	m2 / kgC	Age at which SLA_AVG = (SLA_AVG1 + SLA_AVG0)/2
SLA_RATIO	DIM	ratio of shaded to sunlit projected SLA
LAI_RATIO	DIM	all-sided to projected leaf area ratio
FRACBB0	DIM	Branch and Bark fraction at age 0
FRACBB1	DIM	Branch and Bark fraction for mature stands
TBB	DIM	Age at which fracBB = (FRACBB0 + FRACBB1)/ 2
RHO0	t / m3	Minimum Basic Density for young Trees
RHO1	t / m3	Maximum Basic Density for mature Trees
TRHO	t / m3	Age at which rho = (RHOMIN + RHOMAX)/2
COEFFCOND	1 / mbar	Stomatal response to VPD
BLCOND	m / s	Canopy Boundary Layer conductance
MAXCOND	m / s	Maximum Leaf Stomatal Conductance
CUTCOND	m / s	Cuticular conductance
MAXAGE	years	Maximum tree age, determines rate of "physiological decline" of forest
RAGE	DIM	Relative Age to give fAGE = 0.5
NAGE	DIM	Power of relative Age in function for Age
GROWTHTMIN	deg C	Minimum temperature for growth
GROWTHTMAX	deg C	Maximum temperature for growth
GROWTHTOPT	deg C	Optimum temperature for growth
GROWTHSTART	deg C	average temperature for starting growth
MINDAYLENGTH	days	Minimum day length for phenology (for deciduous)

PARAMETER	Unit	Description
SWPOPEN	MPa	Leaf water potential: start of reduction
SWPCLOSE	MPa	Leaf water potential: complete reduction
OMEGA_CTEM	DIM	Allocation parameter control the sensitivity of allocation to changes in water and light availability
S0CTEM	DIM	Parameter controlling allocation to stem/minimum ratio to C to stem
R0CTEM	DIM	Parameter controlling allocation to root/minimum ratio to C to roots
F0CTEM	DIM	Parameter controlling allocation to foliage/minimum ratio to C to foliage
FRUIT_PERC	ratio	Percentage of NPP to fruit
CONES_LIFE_SPAN	year	Life span for cones (yr)
FINE_ROOT_LEAF	ratio	allocation new fine root C:new leaf
STEM_LEAF	ratio	allocation new stem C:new leaf
COARSE_ROOT_STEM	ratio	allocation new coarse root C:new stem
LIVE_TOTAL_WOOD	ratio	new live C:new total wood
N_RUBISCO	ratio	Fraction of leaf N in Rubisco
CN_LEAVES	kgC / kgN	CN of leaves
CN_FALLING_LEAVES	kgC / kgN	CN of leaf litter
CN_FINE_ROOTS	kgC / kgN	CN of fine roots
CN_LIVEWOOD	kgC / kgN	CN of live wood
CN_DEADWOOD	kgC / kgN	CN of dead wood
BUD_BURST	days	days of bud burst at the beginning of growing season (only for deciduous)
LEAF_FALL_FRAC_GROWING	DIM	proportions of the growing season of leaf fall
LEAF_FINEROOT_TURNOVER	1 / year	Average yearly fine root turnover rate
LIVEWOOD_TURNOVER	1 / year	Annual yearly live wood turnover rate
SAPWOOD_TURNOVER	1 / year	Annual yearly sap wood turnover rate
DBHDCMAX	cm	Maximum dbh crown diameter relationship when minimum density
DBHDCMIN	cm	Minimum dbh crown diameter relationship when maximum density
SAP_A	cm	a coefficient for sapwood
SAP_B	cm	b coefficient for sapwood
SAP_LEAF	ratio	sapwood_max leaf area ratio in pipe model
SAP_WRES	ratio	Sapwood-Reserve biomass ratio used if no Wres data are available

PARAMETER	Unit	Description
STEMCONST_P	DIM	Constant in the stem mass vs. diameter relationship
STEMPOWER_P	DIM	Power in the stem mass vs. diameter relationship
CRA	DIM	Chapman-Richards a parameter (maximum height, meter)
CRB	DIM	Chapman-Richards b parameter
CRC	DIM	Chapman-Richards c parameter
CROWN_A	DIM	A Crown relationship with tree height
CROWN_B	DIM	B Crown relationship with tree height
SEXAGE	years	Age for sexual maturity
ROTATION	years	Rotation for final harvest (based on tree age)
THINNING	DIM	Thinning regime
THINNING_REGIME	DIM	Thinning regime (0 = above, 1 = below)
THINNING_INTENSITY	% of Basal Area/ N-tree to remove	Thinning intensity
MAX_DBHDC_INCR	ratio	Fraction of maximum dbhdc increment

Table 2: Values of the parameters utilized to run the simulations

PARAMETER	DEFAULT	MIN	MAX	Calibrated	References
LIGHT_TOL	3	NA	NA	3	NA
PHENOLOGY	1.1	NA	NA	1.1	NA
ALPHA	0.048	0.0297	0.057	0.03184	NA
K	0.7	0.35*	1.4*	1.2302	Maselli et al.; Ecological Modelling 244 (2012) 1– 12
ALBEDO	0.07	NA	NA	0.07	Morales et al., 2016, Europ. J. Agronomy 74 93–102
INT_COEFF	0.07	NA	NA	0.07	Gòmez et al., 2001, Agricultural Water Management 49, 65-76
SLA_AVG0	12	6*	24*	17.35628	Maselli et al. 2012; Ecological Modelling 244 1– 12
SLA_AVG1	12	6*	24*	11.8072	Maselli et al. 2012; Ecological Modelling 244 1– 12
TSLA	12	6*	24*	16.92574	Maselli et al. 2012; Ecological Modelling 244 1– 12
SLA_RATIO	2	1*	4*	3.35748	Maselli et al 2012.; Ecological Modelling 244) 1– 12
LAI_RATIO	2	1*	4*	2.18797	Maselli et al. 2012; Ecological Modelling 244 1– 12
FRACBB0	0.19167	0.1	0.3	0.19167	NA

PARAMETER	DEFAULT	MIN	MAX	Calibrated	References
FRACBB1	0.18833	0.1	0.36	0.18833	NA
TBB	18.33333	10	20	18.33333	NA
RHO0	0.565	0.4	0.72	0.565	NA
RHO1	0.665	0.49	0.96	0.665	NA
TRHO	43.66667	4	100	43.66667	NA
COEFFCOND	0.023	NA	NA	0.023	López-Bernal et al., (2018) Front. Plant Sci. 9:632
BLCOND	0.01	0.005*	0.02*	0.01734	Maselli et al. 2012; Ecological Modelling 244 1– 12
MAXCOND	0.0012	6e-04*	0.0024*	0.0022	Maselli et al. 2012; Ecological Modelling 244 1– 12
CUTCOND	1.2e-05	6e-06*	2.4e-05*	6.24E-06	Maselli et al. 2012; Ecological Modelling 244 1– 12
MAXAGE	1000	NA	NA	1000	NA
RAGE	0.78333	0.5	0.95	0.8399	NA
NAGE	6	4	10	6.10522	NA
GROWTHTMIN	9.1	NA	NA	9.1	Morales et al., 2016, Europ. J. Agronomy 74 93–102
GROWTHTMAX	40	NA	NA	40	NA
GROWTHTOPT	20.7	NA	NA	20.7	Morales et al., 2016, Europ. J. Agronomy 74 93–102
GROWTHSTART	0	NA	NA	0	NA
MINDAYLENGTH	0	NA	NA	0	NA
SWPOPEN	-0.54	-1.08*	-0.27*	-0.78625	Maselli et al. 2012; Ecological Modelling 244 1– 12
SWPCLOSE	-3.51	-7.02*	-1.755*	-4.55475	Maselli et al. 2012; Ecological Modelling 244 1– 12
OMEGA_CTEM	0.8	NA	NA	0.8	NA
S0CTEM	0.1	NA	NA	0.1	López-Bernal et al., (2018) Front. Plant Sci. 9:632
R0CTEM	0.45	NA	NA	0.45	López-Bernal et al., (2018) Front. Plant Sci. 9:632
F0CTEM	0.45	NA	NA	0.45	López-Bernal et al., (2018) Front. Plant Sci. 9:632
FRUIT_PERC	0.15833	0	0.5	0.17769	NA
CONES_LIFE_SPAN	1	NA	NA	1	NA
FINE_ROOT_LEAF	1	0*	2*	1.0089	Maselli et al. 2012; Ecological Modelling 244 1– 12
STEM_LEAF	2.2	1.1*	4.4*	2.7898	Maselli et al. 2012; Ecological Modelling 244 1– 12
COARSE_ROOT_STEM	0.22	0.11*	0.44*	0.41274	Maselli et al. 2012; Ecological Modelling 244 1– 12
LIVE_TOTAL_WOOD	0.16	0.08*	0.32*	0.20479	Maselli et al. 2012; Ecological Modelling 244 1– 12

PARAMETER	DEFAULT	MIN	MAX	Calibrated	References
N_RUBISCO	0.04	0.02*	0.08*	0.0664	Maselli et al. 2012; Ecological Modelling 244 1– 12
CN_LEAVES	42	21*	84*	31.82037	Maselli et al. 2012; Ecological Modelling 244 1– 12
CN_FALLING_LEAVES	49	24*	98*	47.69803	Maselli et al. 2012; Ecological Modelling 244 1– 12
CN_FINE_ROOTS	42	21*	84*	61.7253	Maselli et al. 2012; Ecological Modelling 244 1– 12
CN_LIVEWOOD	42	21*	84*	70.31539	Maselli et al. 2012; Ecological Modelling 244 1– 12
CN_DEADWOOD	300	150*	600*	351.8813	Maselli et al. 2012; Ecological Modelling 244 1– 12
BUD_BURST	0	NA	NA	0	NA
LEAF_FALL_FRAC_GROWING	0	NA	NA	0	NA
LEAF_FINEROOT_TURNOVER	0.33	0.165*	0.66*	0.49695	Maselli et al. 2012; Ecological Modelling 244 1– 12
LIVEWOOD_TURNOVER	0.7	0.35*	1*	0.83921	Maselli et al. 2012; Ecological Modelling 244 1– 12
SAPWOOD_TURNOVER	0.7	NA	NA	0.7	NA
DBHDCMAX	0.36	0.2	0.5	0.43087	NA
DBHDCMIN	0.15333	0.14	0.18	0.14231	NA
SAP_A	0.49683	0.034	0.778	0.22663	NA
SAP_B	2.09767	1.917	2.384	1.97612	NA
SAP_LEAF	5850	2600	9700	8060.94359	NA
SAP_WRES	0.1	0.05	0.11	0.08303	NA
STEMCONST_P	0.1436	0.0654	0.1916	0.09028	NA
STEMPOWER_P	2.44326	2.171	2.69	2.23578	NA
CRA	35.744	23.27	52	39.2262	NA
CRB	0.04817	0.038	0.096	0.06642	NA
CRC	1.11967	1.03	1.272	1.13221	NA
CROWN_A	0.3678	0.3	0.413	0.3678	NA
CROWN_B	1	NA	NA	1	NA
SEXAGE	1	NA	NA	1	NA
ROTATION	0	NA	NA	0	NA
THINNING	0	NA	NA	0	NA
THINNING_REGIME	0	NA	NA	0	NA
THINNING_INTENSITY	0	NA	NA	0	NA

PARAMETER	DEFAULT	MIN	MAX	Calibrated	References
MAX_DBHDC_INCR	0.1	0.1	0.9	0.11062	NA

Table 3: Information of the farms simulated

FARM_N	1	2	3	5	6	7	8	10	17	18	19	20	21
Country	Italy	Italy	Italy	Italy	Italy	Italy	Italy	Italy	Italy	Israel	Israel	Israel	Israel
Latitude (dec. degrees)	41.040	41.005	37.643	44.15	44.106	42.542	42.401	42.860	32.510	32.859	32.70	32.374	32.745
Longitude (dec. degrees)	16.844	16.621	12.844	9.94	9.793	11.709	11.582	12.752	35.071	35.374	34.972	35.024	35.286
Altitude (m a.s.l.)	90	177	113	250	250	400	51	300	285	306	76	105	245
Age of trees (years)	47	50	35	100	200	60	19	32	117	77	217	65	420
Density (trees/ha)	434	270	184	302	303	195.12	215	400	100	100	100	100	128
Average stem diameter at 80 cm (cm)	42.94	25.09	27.3	16.22	14.3	50.63	24.38	19	50.22	59.15	61.36	40.39	43.16
Total plant height* (m)	4.635	4.63	5.11	4.42	3.69	5.37	3.97	3.43	4.64	3.39	4.65	3.63	3.9
Reference Year	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017
Irrigation (BAU)	ON	OFF	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF
Pruning Frequency (BAU)	annual	annual	annual*	annual*	biennial	annual	biennial	annual	annual	annual	annual	annual	annual

* pruning frequency missing, annual is considered

3 Validation

To assess model performances the aboveground biomass simulated (AGBsim) in the baseline (BAU + current climate) and the aboveground biomass measured (AGBms) have been pairwise compared.

The AGBms has been obtained by using the following allometric equation (Brunori et al., 2017):

$$AGBms = a*D80^{b} \qquad [Eq. 1]$$

where *a* and *b* are empirical parameters (*a* = 0.1202 and *b* = 2.2159, respectively); D80 is the stem diameter, in cm, measured at 80 cm stem height. The validation was possible only for the farms where D80 have been measured and BAU was available.

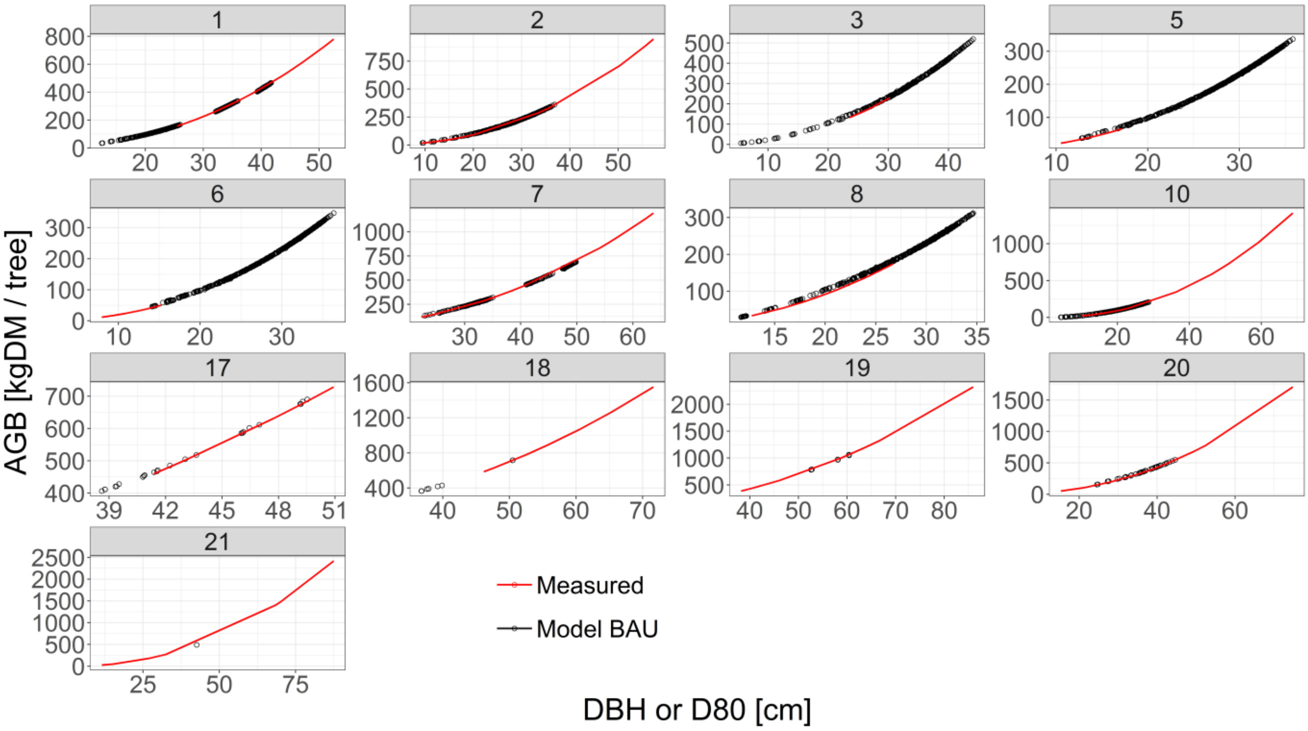


Figure 1 Comparison of the above ground biomass (AGB, kgDM/tree) simulated (Model BAU) and measured for each of the farms involved in the Olive-4-climate project.

The modeled and measured AGB are in agreement, indicating a good capability of the 3D-CMCC-OLIVE to simulate, under the current climatic and BAU conditions, the olive trees growth. Notably, the parameters utilized in all of the simulations are the same (i.e. the model was not calibrated site by site) suggesting the high degree of model applicability in all farms' conditions.

4 Results

In this section the results of the simulations for each farm are showed. Some of the farms are not simulated because of missing information to run the model for those sites (see table 4 for details).

Table 4: Information of the farms not simulated.

FARM_N	**4 ****	**9 ****	**11 *****	**12 *****	**13 *****	**14 *****	**15 *****	**16 *****
Country	Italy	Italy	Greece	Greece	Greece	Greece	Greece	Greece
Latitude (dec. degrees)	38.050	37.927	36.990	36.991	36.991	36.806	36.859	36.979
Longitude (dec. degrees)	12.578	12.745	22.500	22.452	22.453	22.882	22.674	22.153
Altitude (m a.s.l.)	NA	200	232	227	222	89	39	22
Age of trees (years)	20	20	10	10	10	100	15	80
Density (trees/ha)	362	362	279	279	279	100	510	167
Average stem diameter at 80 cm (cm)	15.8	15.8	24.41	24.41	24.41	36.88	19.97	36.84
Total plant height* (m)	NA	NA	4.26	4.26	4.26	4.33	4.75	5.03
Reference Year	2017	2017	2017	2017	2017	2017	2017	2017
Irrigation (BAU)	OFF	OFF	NA	NA	NA	NA	NA	NA
Pruning Frequency (BAU)	annual	annual	NA	NA	NA	NA	NA	NA

* after pruning

** Total plant height after pruning missing

*** Technical annex missing

The table 3 show the information of the 13 farms simulated, 9 are located in Italy and 4 in Israel. In general, the most frequent BAU is irrigation OFF and pruning frequency is annual; the second BAU most used is irrigation ON and pruning frequency annual. The BAU pruning frequency biennial is the less frequent (only 2 farms), and each of these farms apply a different irrigation regime.

The farms located in Israel show identical BAU (irrigation is not applied while the pruning frequency is annual). Italian farms show different BAU: in 2 farms the irrigation is applied and the pruning frequency is annual; in 5 farms the irrigation is OFF and pruning frequency is annual; in 1 farm the irrigation is OFF and pruning frequency is biennial; in 1 farm the irrigation is ON and pruning frequency is biennial.

If all farms in the table 3 are considered, the mean altitude is 204 m a.s.l. with a range in between 50 and 400 m a.s.l.. The farms in Italy show a mean altitude close to 212 meters and a range of values comprised between 51 and 400. The farms in Israel show a mean altitude lower than Italy (183 m a.s.l.) and a range of values between 76 and 306 m a.s.l..

The mean age of all trees in the table 3 is older than 100 years (111 years): 8 farms have trees younger than 100 years (2 in Israel and 6 in Italy); 2 farms in Italy are older than 100 years; 2 farms are older than 200 years (1 in Italy and 1 in Israel); trees older than 400 years-old (420 years) are located in a farm in Israel.

The density of olive orchard is similar in all of the Israel farms (~100 trees/ha), the only one with a greater number of trees is the farm with older trees (~128 trees/ha). The mean density in Italy is 267 trees/ha with the minimum and maximum of 100 and 434 trees/ha, respectively. In Italy in 2 farms the number of trees per hectare is greater than 400 trees/ha, in 5 farms the density is between 215 and 305 trees/ha while 3 farms show density lower than 200 trees/ha.

The mean stem diameters (at 80 cm tree height) in Israel are greater than Italy farms with a mean ~51 and ~30 cm, respectively. The olive trees in Israel have all the mean stem diameter greater than 40 cm, in Italy the olive trees show a mean stem diameter greater than this threshold in 3 farms, in the other cases the mean stem diameters are comprised between 16 and 27 cm. The total tree height after the pruning in the Italian farms is higher (~4.4 m) than in the Israelis olive orchards (~3.8 m). In Israel only one farm shows total tree height greater than 4 m, in only one case this is near to 4 m (~3.9 m) and in the other two cases the values are 3.6 and 3.3 m, respectively. In Italy two farms show total tree height after pruning greater than 5 m, in two cases the height is less than 3.7 m and in the other cases the range is between 4.4 and 4.64 m.

In the follow sections the effects of the different management practices and climate scenarios for each farm are analyzed. When the model can simulate all of the years of the climatic time series, the results are here defined as "Completed", otherwise are indicated as "Not Completed". Note, in general the main cause of the "Not Completed" simulations is the carbon starvation (i.e. a complete depletion of non-structural carbohydrates due to carbon imbalance between photosynthesis and autotrophic respiration) (for further information see also Collalti et al., 2016; 2018, 2018b).

4.1 Farm: 1

The figure 2 show the relation between mean values of the annual AGB, in kgDM (Dry Matter) per tree, and the main meteorological drivers in the farm 1. When the farm is irrigated the number of simulation complete is twice of the no-irrigation management, the pruning frequency seem not influence the AGB.

The AGB is separated in three group: AGB < 150 kgDM/tree; AGB between 250 and 350 kgDM/tree; AGB > 350 kgDM/tree.

The first group (AGB < 150 kgDM/tree) the simulations are complete:

- three cases if irrigation is OFF (B, E and L 58132_DMI_2000, 58132_ETHZ_2000 and 59132_DMI_2000 respectively);
- seven cases if irrigation is ON (A, B, E, H, L, O and R 58132_AGRI4CAST_OBS, 58132_DMI_2000, 58132_ETHZ_2000, 58132_METO_2000, 59132_DMI_2000, 59132_ETHZ_2000, 59132_METO_2000 respectively);

The change in the irrigation practices seem to be the main factor to increase the survival of the olive trees.

The second group (250 < AGB < 350 kgDM/tree) the simulations are complete:

- three cases if irrigation in OFF (C, F and I 58132_DMI_2020, 58132_ETHZ_2020 and 58132_METO_2020 respectively);
- all the cases if the irrigation in ON

The analysis of the results in the second group seem to confirm the effect of the irrigation regime. Furthermore, if the water available in the soil increase, the growth is triple and the olive trees can survive until the end of the simulation.

The third group (AGB > 350 kgDM/tree) the simulations are complete:

- two cases if irrigation in OFF (D and G 58132_DMI_2030, 58132_ETHZ_2030 respectively);
- three cases if irrigation in ON (D, G and N 58132_DMI_2030, 58132_ETHZ_2030, 59132_DMI_2030 respectively);

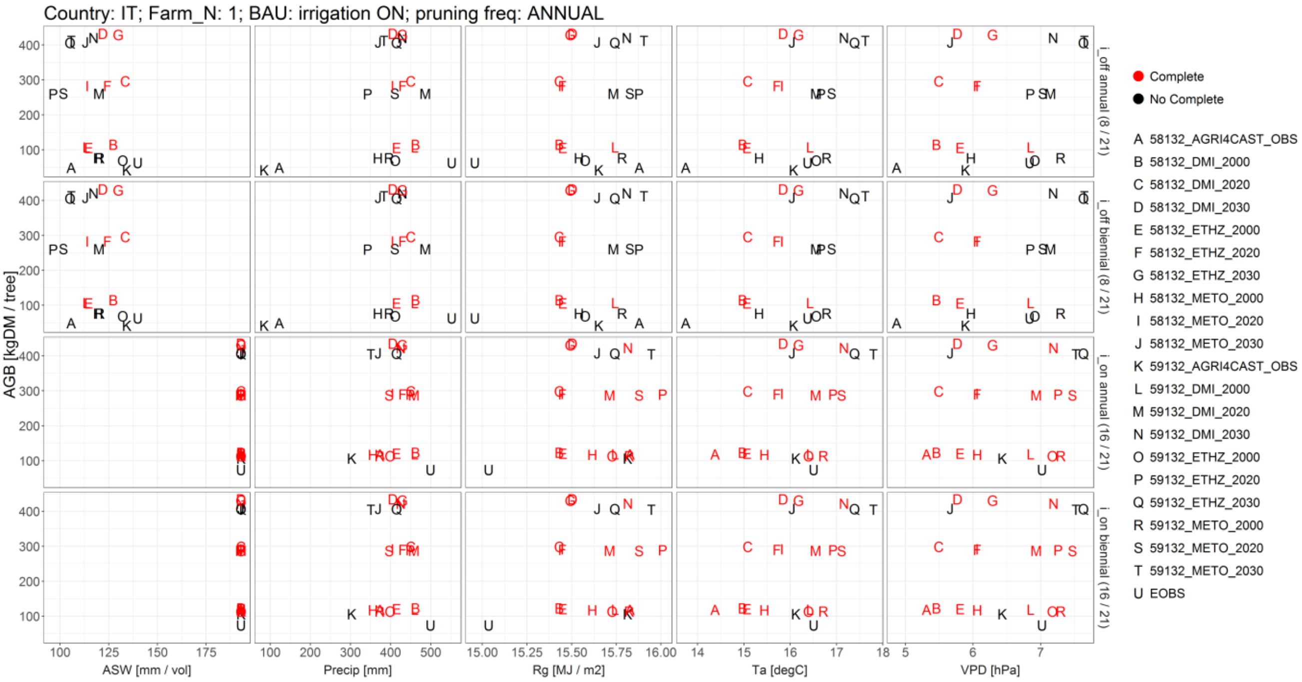


Figure 2: Comparison of the interannual means of the AGB and climatic drivers for the farm 1. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.2 Farm: 2

The figure 3 show the relation with AGB and climatic conditions for the farm 2. When the irrigation is applied all the simulations are completed and, in this case, the AGB is divided in two groups, the first with the values less than 200 kgDM / tree and the second with values greater than this threshold. In general, the pruning frequency have not effect on the growth. When the irrigation is OFF the water of soil and the AGB show opposite trends, if the ASW increase the AGB decrease.

The AGB less than 200 kgDM / tree and irrigation ON is composed of the current climate (AGRI4CAST_OBS and EOBS) and of the time horizon 2000, the second group is composed of the time horizon 2020 and 2030. These results suggest an increase of the growth efficiency and carbon uptake.

Figure 3: Comparison of the interannual means of the AGB and climatic drivers for the farm 2. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.3 Farm: 3

The results of the simulations for the farm 3 are showed in the figure 4. If irrigation is OFF, only one simulation is completed (AGRI4CAST_OBS). This case is the only one with the precipitations greater than 600 mm year^{-1}, in most of the cases the precipitations are less than 400 mm year^{-1} and, based on model results, the olive trees cannot survive. Furthermore, the olive trees cannot survive if the precipitation are greater than 520 mm year^{-1} (EOBS simulation). In general, the irrigations involve a productivity greater than 300 kgDM/tree for the time horizons 2020 and 2030.

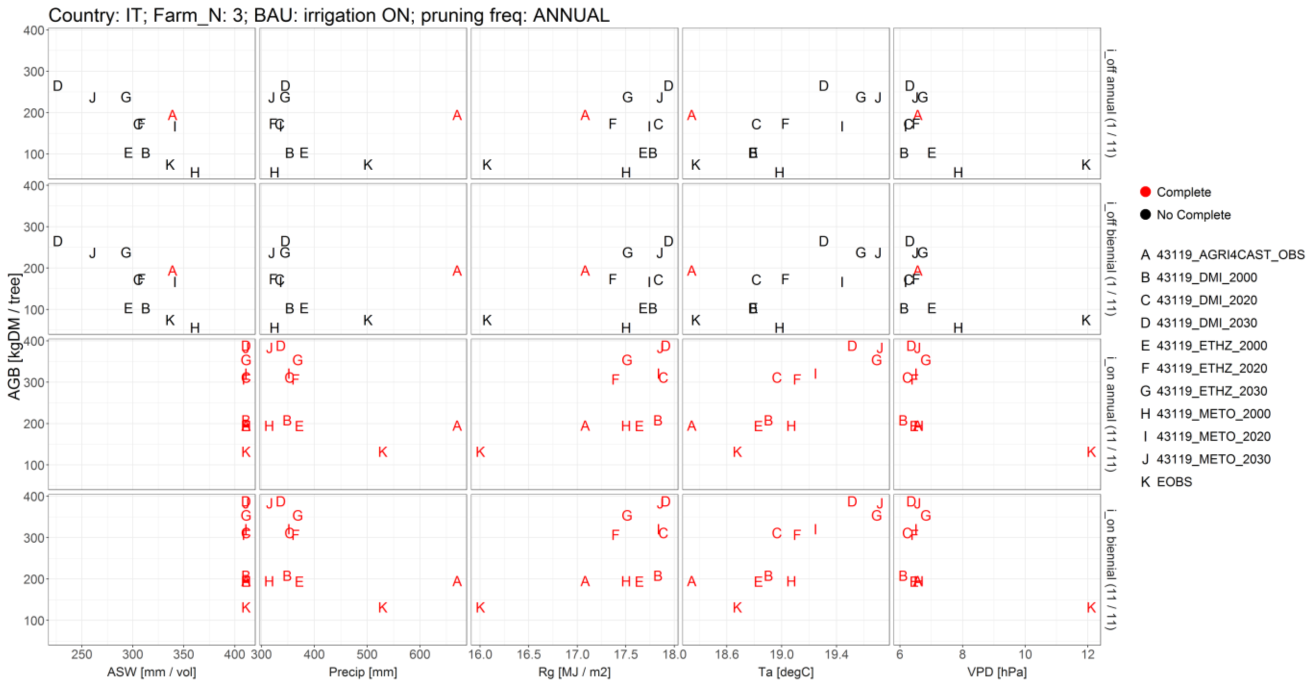


Figure 4: Comparison of the interannual means of the AGB and climatic drivers for the farm 3. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.4 Farm: 5

The results of the simulations for the farm 5 are showed in the figure 5. In general, all the simulations are complete, the only two exceptions are the results A and K (AGRI4CAST_OBS: cells 71109 and 72109, respectively) and irrigation OFF. In these two cases, the precipitation are less than other climatic scenarios (if irrigation is ON and climate is AGRi4CAST_OBS or EOBS, the precipitations are less than 400 mm year^{-1}, else the precipitations are greater than 1200 mm year^{-1}). Furthermore, if the irrigation is OFF and the climate is AGRi4CAST_OBS or EOBS the soil water content is less than 220 mm / vol year^{-1}, in the other cases are greater than 250 mm / vol. year^{-1}. In the other cases, the AGB is greater than 180 kgDM/tree under all the climatic conditions and different management practices. These results suggest that if the precipitations are abundant (e.g. > to 1200 mm year^{-1}), the effect of the irrigation on the growth is negligible.

4.5 Farm: 6

The results of the simulation for the farm 6, showed in the figure 6, are similar to those of the farm 5. The two farms have similar location and plant density (~300 trees/ha) but the age of the trees is double (100 vs. 200 year-old for trees in the farm 5 and 6, respectively). If the precipitations are less than 800 mm year^{-1} and the soil water content less than 200 mm/vol the trees survive (not simulations A, AGRI4CAST_OBS cell 71109, and K, AGRI4CAST_OBS cell 72109). When the precipitations are greater than 1000 mm year^{-1} the AGB is comprised between 180 and 230 kgDM/trees and the differences between different climatic conditions are minimal.

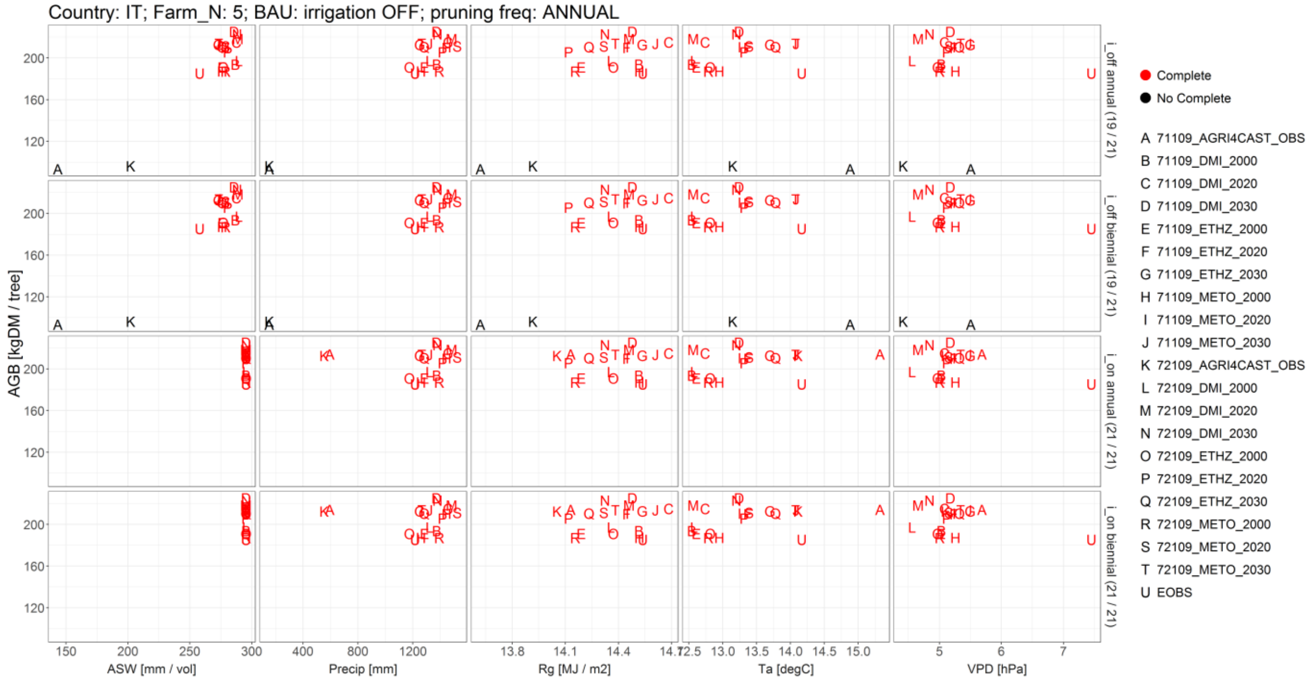


Figure 5: Comparison of the interannual means of the AGB and climatic drivers for the farm 5. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

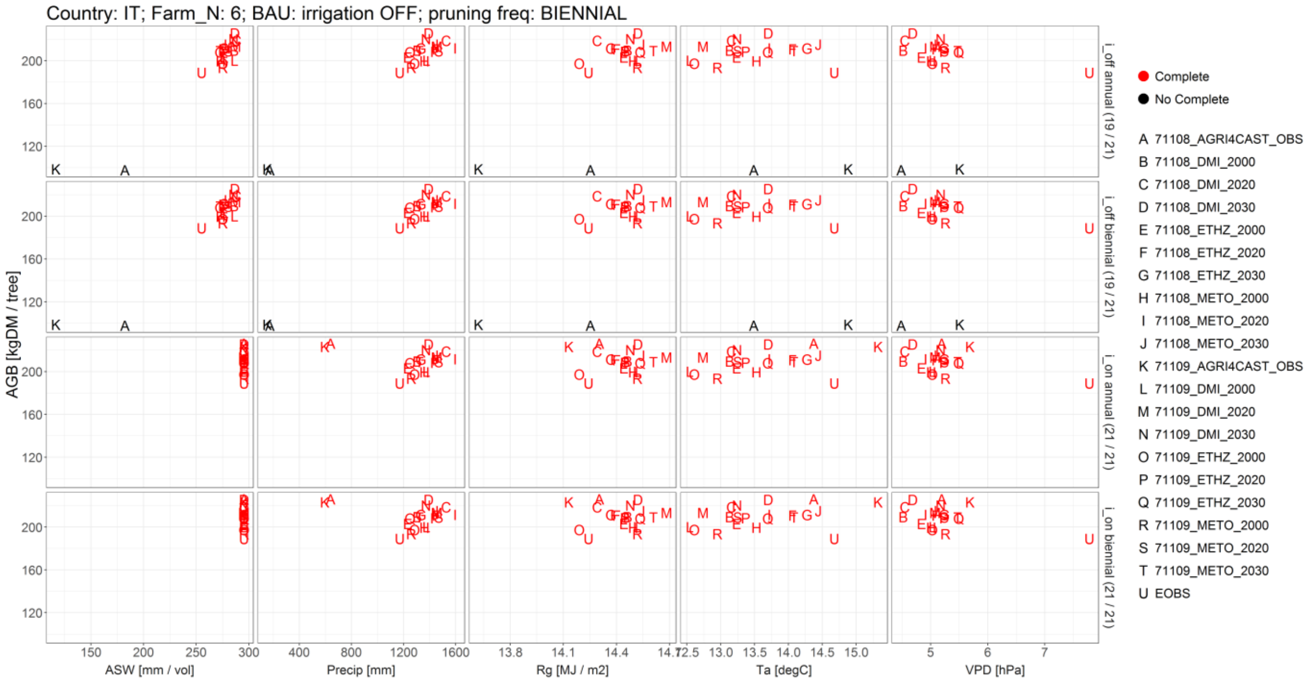


Figure 6: Comparison of the interannual means of the AGB and climatic drivers for the farm 6. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.6 Farm: 7

In the farm 7 the irrigation can be considered as the main factor for the olive trees survival under some climatic conditions (figure 7). When the irrigation is OFF the higher AGB values are with the time horizon 2030. These results show complete simulations only in two of the three climatic models (DMI and ETHZ). The climatic model DMI show complete simulations in all of the time horizons and management practices, for the other climatic models only if the irrigation is ON.

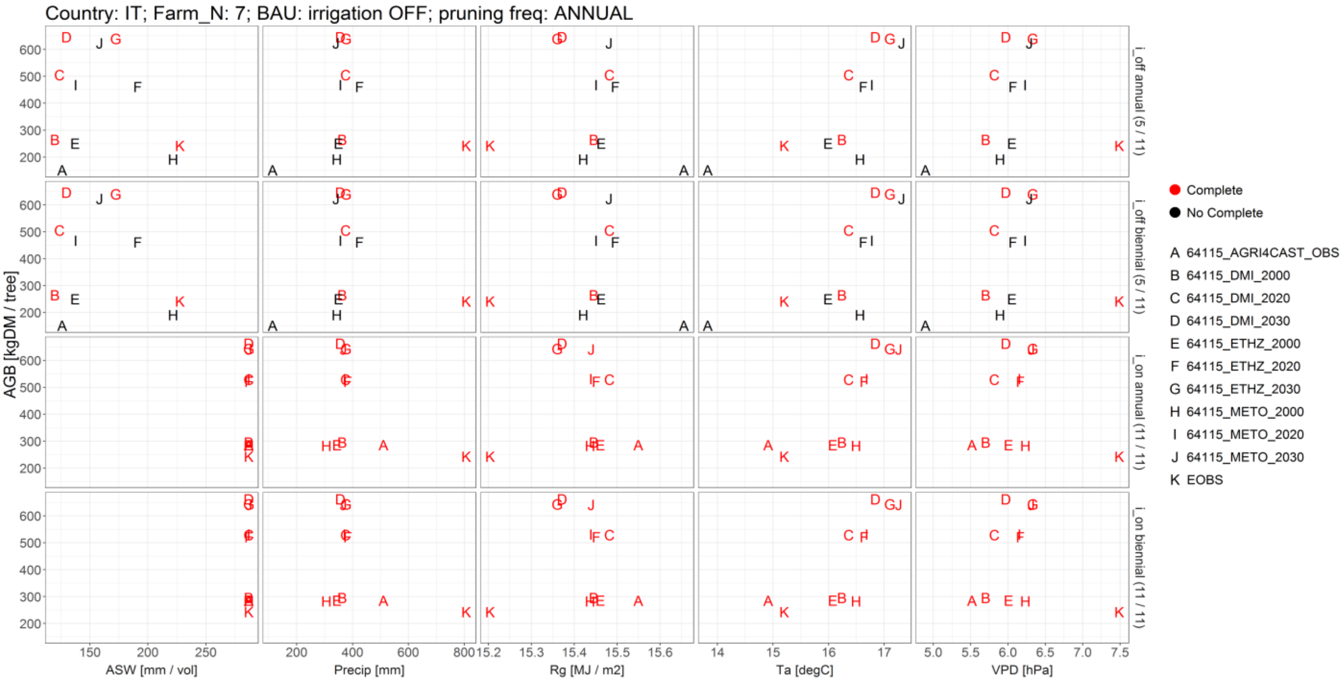


Figure 7: Comparison of the interannual means of the AGB and climatic drivers for the farm 7. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.7 Farm: 8

The trees in the farms 8 are the youngest (19 years-old) across all the farms considered. In this farm all the simulations are complete and the changes in management practices seem be not influence the growth. In general, the AGB increase along time (figure 8), in example the simulations B, C and D shows 120, 160 and 250 kgDM / trees. The time horizon seems as the main factor that may lead to separate the AGB in three group: the simulations OBS and 2000 show AGB less than 150 kgDM/tree; the AGB is comprise between 150 kgDM/tree and 210 kgDM/tree in the simulations 2020; AGB > 210 kgDM/tree for the simulations 2030.

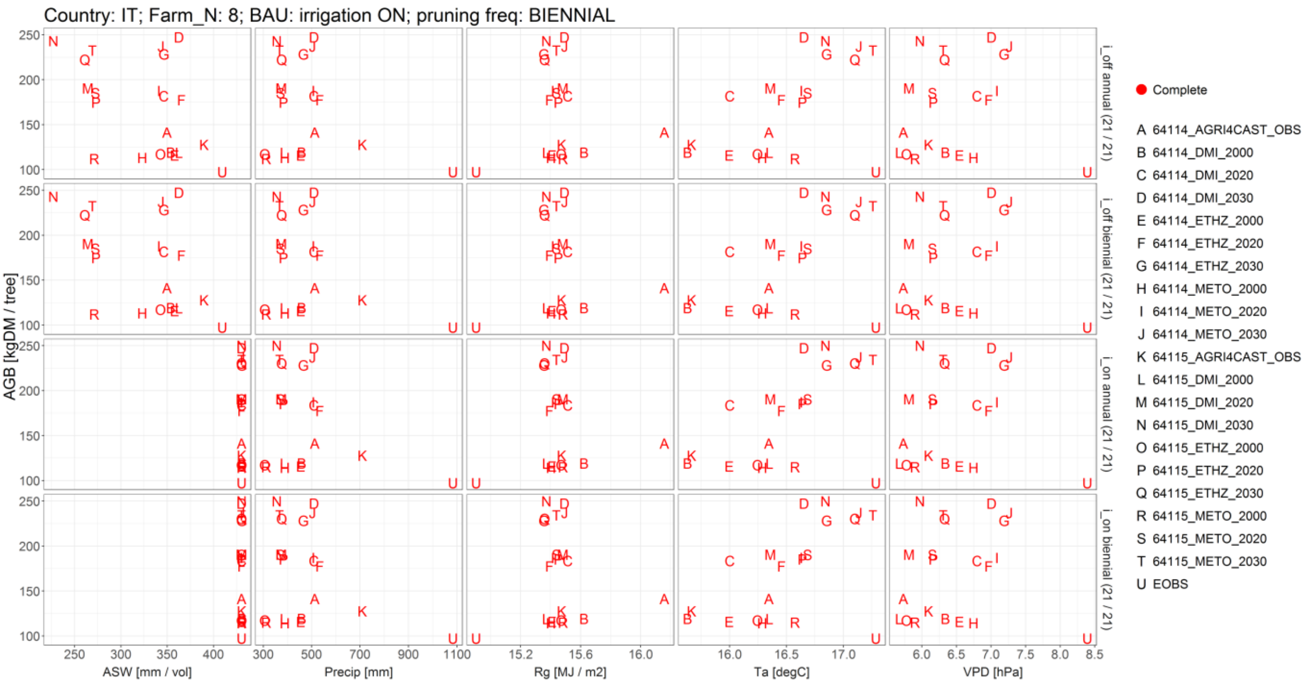


Figure 8: Comparison of the interannual means of the AGB and climatic drivers for the farm 8. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.8 Farm: 10

The trees in farms 10 show (figure 9) results similar to the farm 8. In this farm the changes in management practices seem to not influence the carbon uptake. In general, the AGB increases along with the time and to separate the AGB in three group: the simulations OBS and 2000 show AGB less than 90 kgDM/tree; the AGB is comprise between 110 and 150 kgDM/tree in the simulations 2020; AGB > 150kgDM/tree for the simulations 2030.

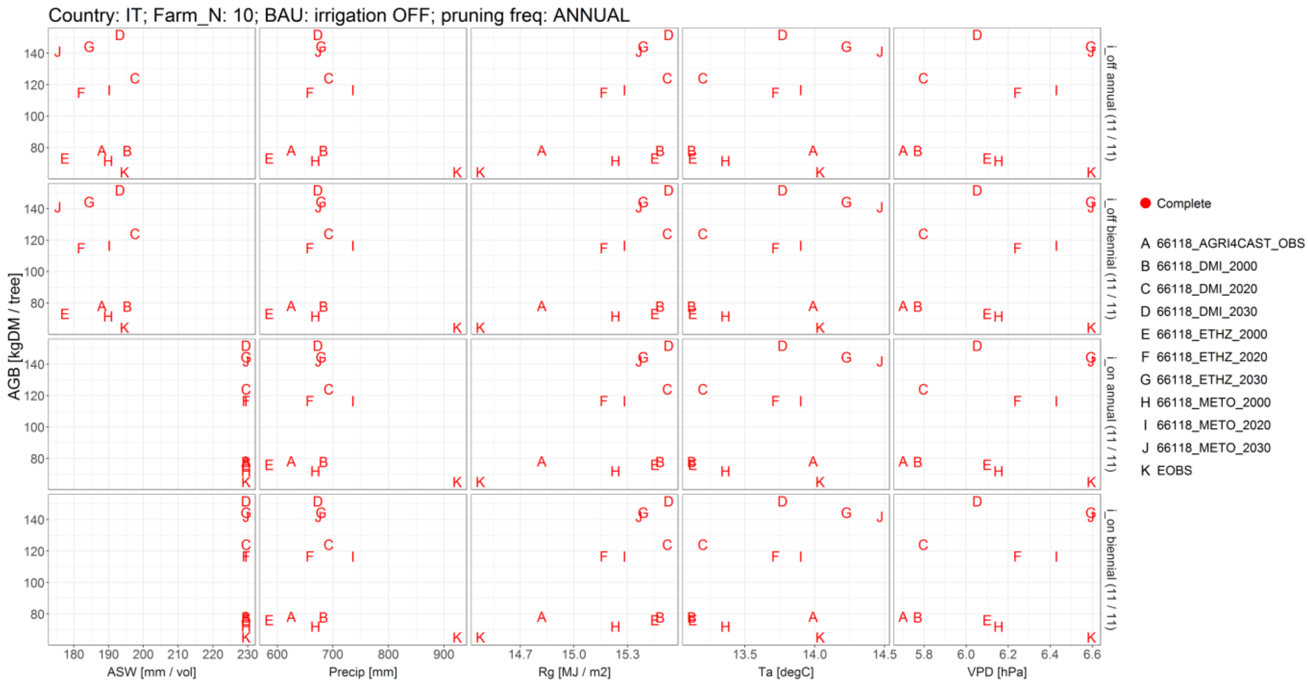
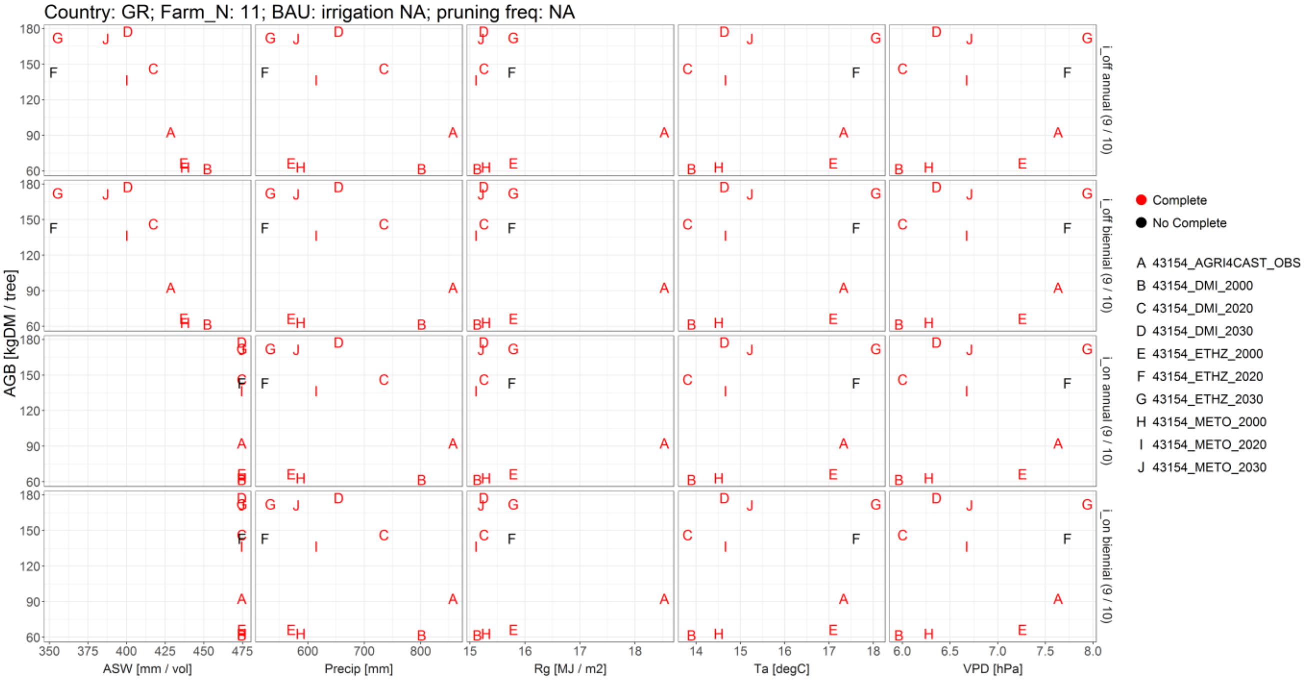


Figure 9: Comparison of the interannual means of the AGB and climatic drivers for the farm 10. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

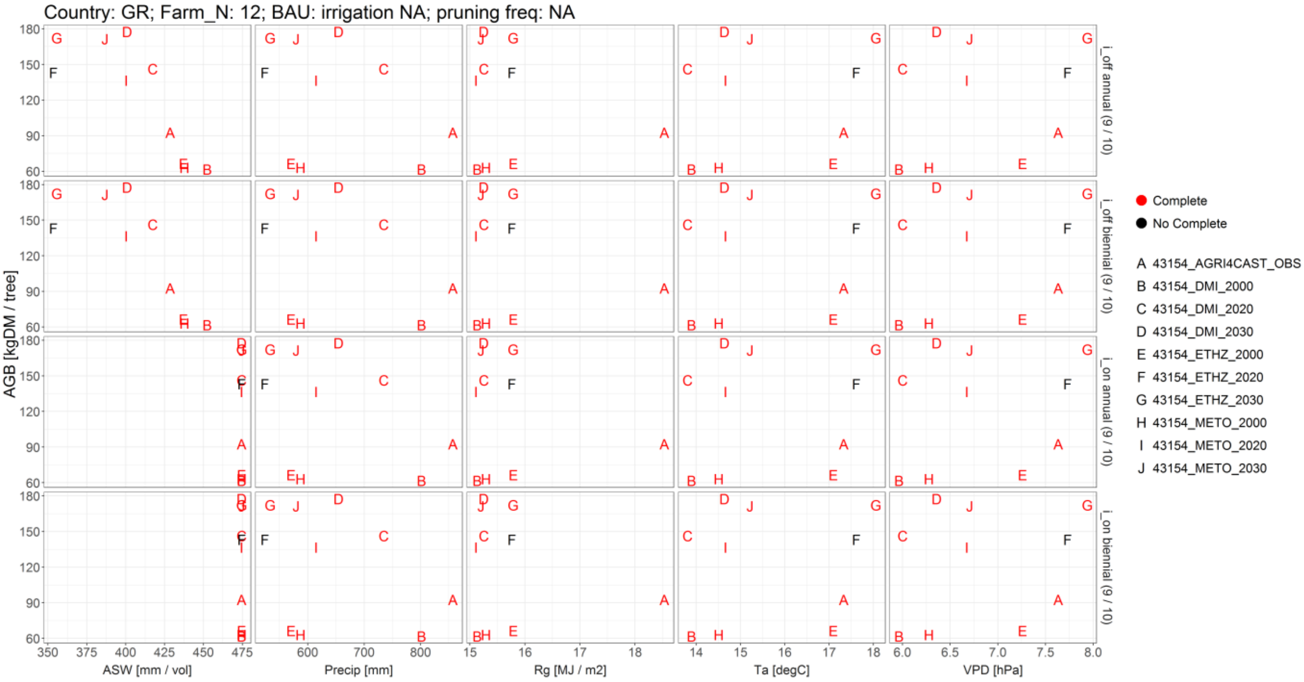
4.9 Farms: 11-12-13

The farms 11-12-13 are located in Greece and the results of the simulations are very similar (figure 10). All the simulations are completed except for the case F. In all of the simulations the management practices have not influence on the olive trees growth, while the time horizon splits the AGB in three group (AGB < 80 kgDM/tree in the 2000; AGB ~90 kgDM/tree in the OBS; AGB > 120 kgDM /tree in 2020 and 2030). In general, the soil water content and the AGB show opposite trend, the growth decreases if the soil water increase. The scarce precipitations and the air temperature greater than 17.5 °C in the simulations F seem to create an unfavorable climate condition to the olive trees.

Country: GR; Farm_N: 11; BAU: irrigation NA; pruning freq: NA



Country: GR; Farm_N: 12; BAU: irrigation NA; pruning freq: NA



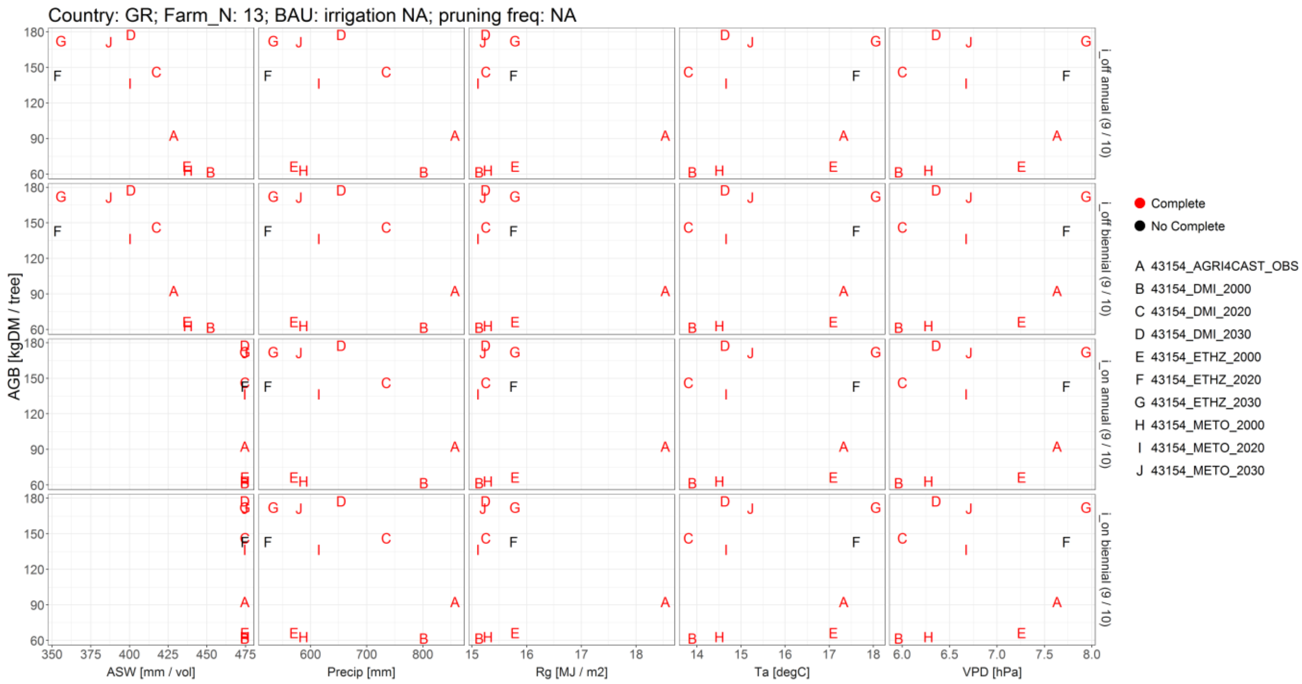


Figure 10: Comparison of the interannual means of the AGB and climatic drivers for the farm 11-12-13. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.10 Farm: 14

The change in the irrigation regime at the farm 14 have effect only in the simulations A and K (AGRI4CAST_OBS, cells 43155 and 43156), in the other cases the change in the management practices seem to influence not the growth (figure 11). Under the AGRI4CAST conditions, the global radiation is higher but if the irrigation is OFF the growth does not increase. If the time horizon is 2000 the AGB are < 600 kgDM/tree, conversely, the AGB is greater than 620 kgDM / tree. The AGB is greater than 600 kgDM/tree if the time horizons are 2020 and 2030 else the AGB is less than these values under the OBS or 2000 climate.

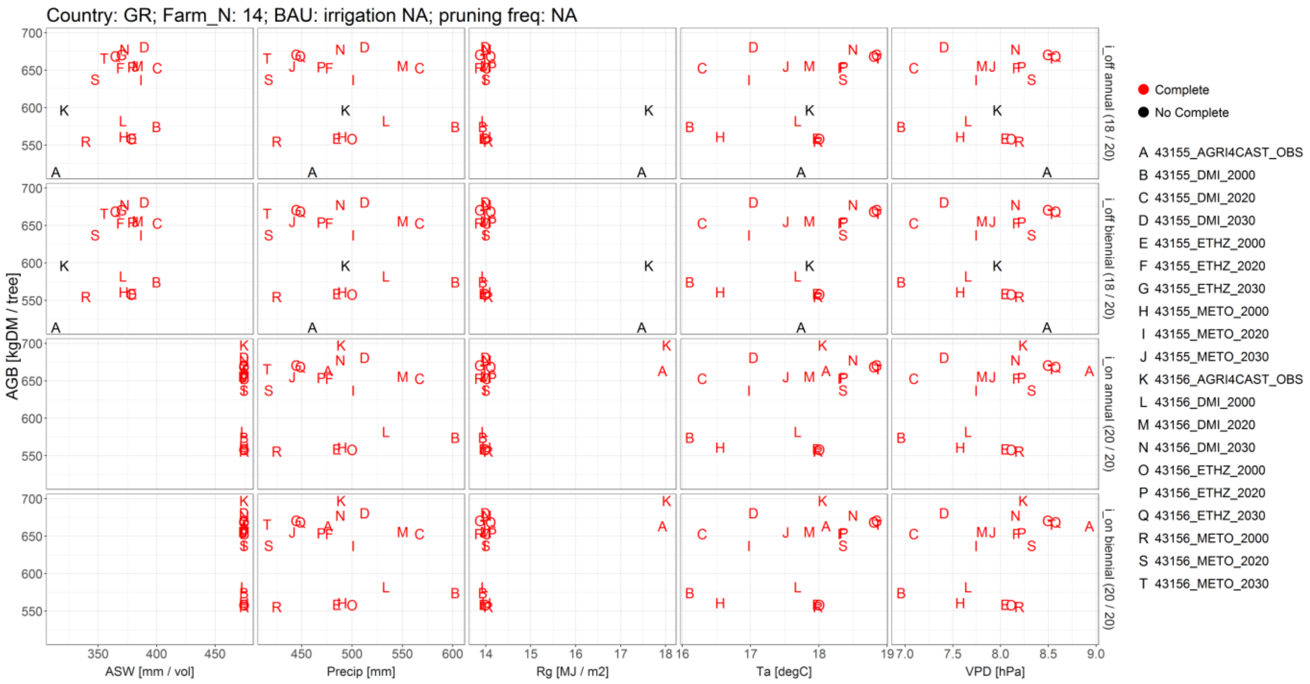


Figure 11: Comparison of the interannual means of the AGB and climatic drivers for the farm 14. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.11 Farm: 15

At the farm 15 the simulations not completed if the climate is (AGRI4CAST_OBS) and and irrigation OFF (figure 12). In these cases the most high global radiation (~19 MJ m^{-2} d^{-1}), the most high VPD (~10 hPa) and most low soil water content can be unfavorable to the survival of the olive trees. Under similar conditions, but the change in irrigation regime can favor the olive trees growth. In the other cases the irrigation is not the main factor influencing growth, i.e. if the olive orchard are irrigated or not the AGB have similar values. The AGB values are grouped, as in the previous farms, in three group: if the climate are OBS or time horizon 2000, the AGB are lower to 60 kgDM/tree; if time horizon 2020, the AGB are comprise between 60 and 80 kgDM/tree; if time horizon is 2030, the AGB are greater than 90 kgDM/tree.

4.12 Farm: 16

At the farm 16 the AGB create two groups, the threshold to separate these is 400 kgDM/tree. In general, the time horizons 2000 shows AGB smaller, in the other cases the biomass if greater than ~420 kgDM/tree. The changes in the management practices and in the climatic models seem to not influence the AGB.

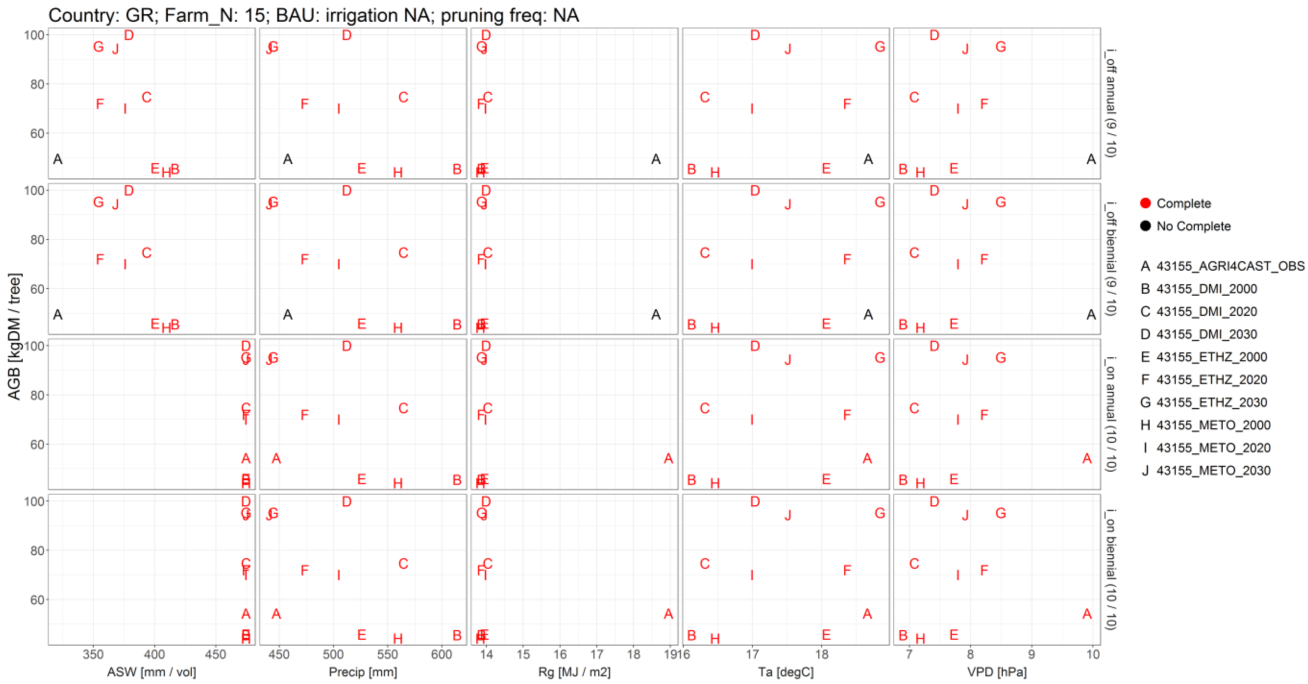


Figure 12: Comparison of the interannual means of the AGB and climatic drivers for the farm 15. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

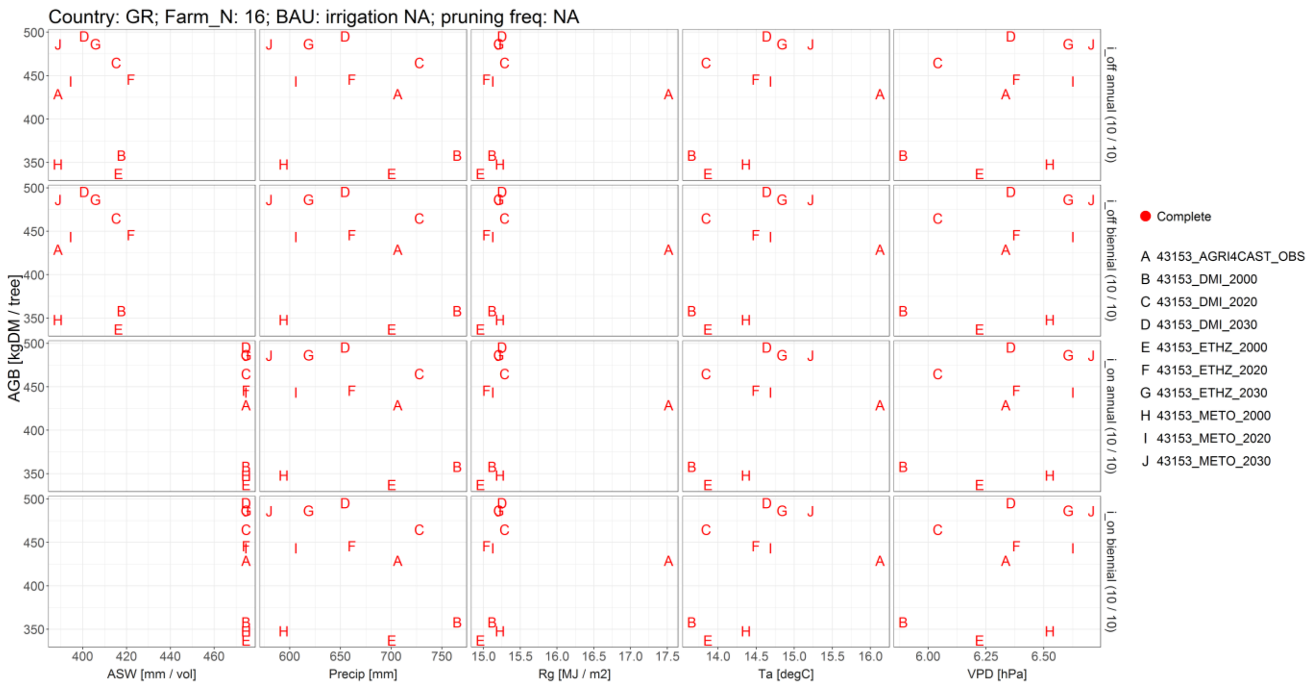


Figure 13: Comparison of the interannual means of the AGB and climatic drivers for the farm 16. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.13 Farm: 17

Not all the simulations at the farm 17 are complete if the irrigation is OFF and the AGB are less than 700 kgDM/tree. When irrigated, the AGB increases (all the values are greater than 600 kgDM/tree) and the olive trees can survive. The AGB under the time horizons 2000 are less than the other simulations (< 700 kgDM /tree).

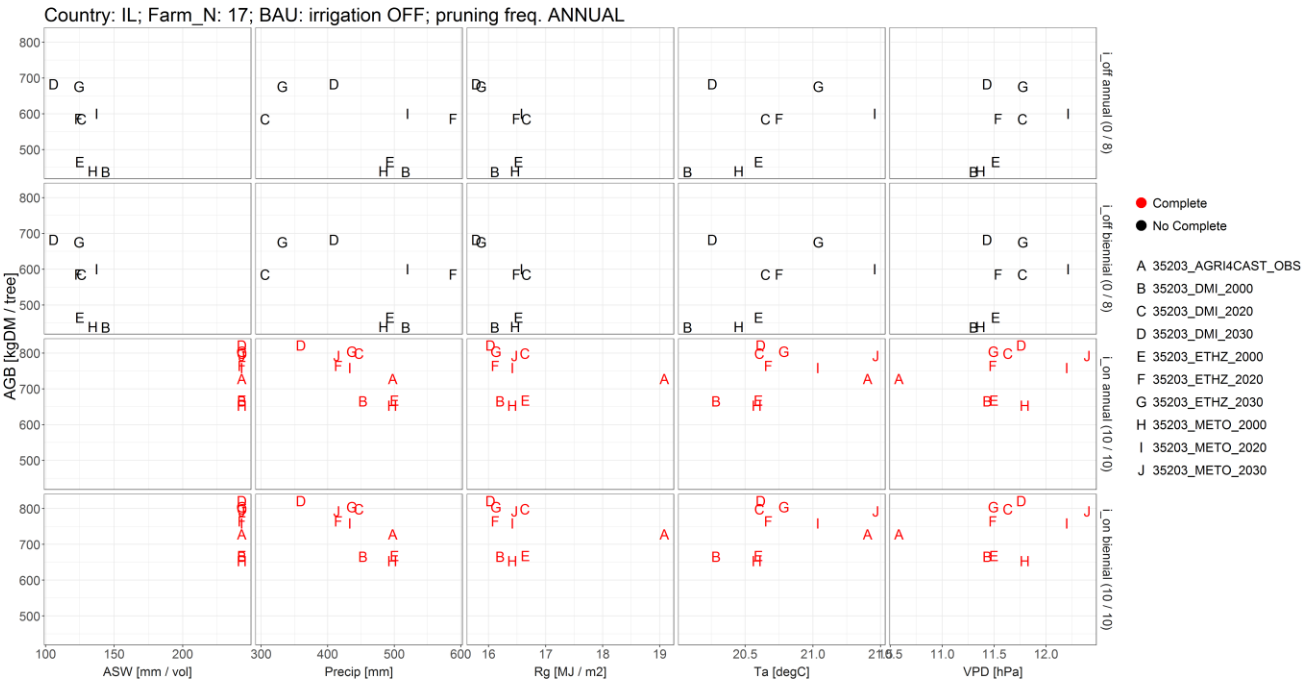


Figure 14: Comparison of the interannual means of the AGB and climatic drivers for the farm 17. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta and vapour pressure deficit (VPD).

4.14 Farm: 18

The farm 18 is the first located in Israel. This farm shows very high AGB (values between 400 and 900 kgDM/tree). In general, all the simulations with no irrigation are incomplete (e.g., the simulations with AGRI4CAST_OBS are missing). When irrigated the model calculates complete time series and the olive trees carbon uptake is more efficient. Under this management type, the minimum in the AGB is simulated with time horizons 2000. When the time horizons are 2020 and 2030 the AGB is greater than 750 kgDM/tree. The simulations with irrigation ON and climate AGRI4CAST_OBS show high values of the AGB. This can be justified by the global radiation over the 18 $MJ/m^2/d^1$ (in other cases the radiations are less than 16.5 $MJ/m^2/d^1$), VPD about 10 (in other case over 11.5 hPa/d^1). The effect of the precipitations in the growth is not clear, e.g. if irrigation is OFF in the simulation C the precipitation are > 600 mm $year^{-1}$ but the soil water content is scarce (< 175 mm/vol.); in the simulation F the precipitation are scarce (about 350 mm year^{-1}) but the soil water available is about 150 mm/vol. In other words, the increase of the precipitations did not show to have a direct effect in increasing olive tree growth.

In this farm, the simulations with the ETHZ climate are missing because the time series are less than 1 year.

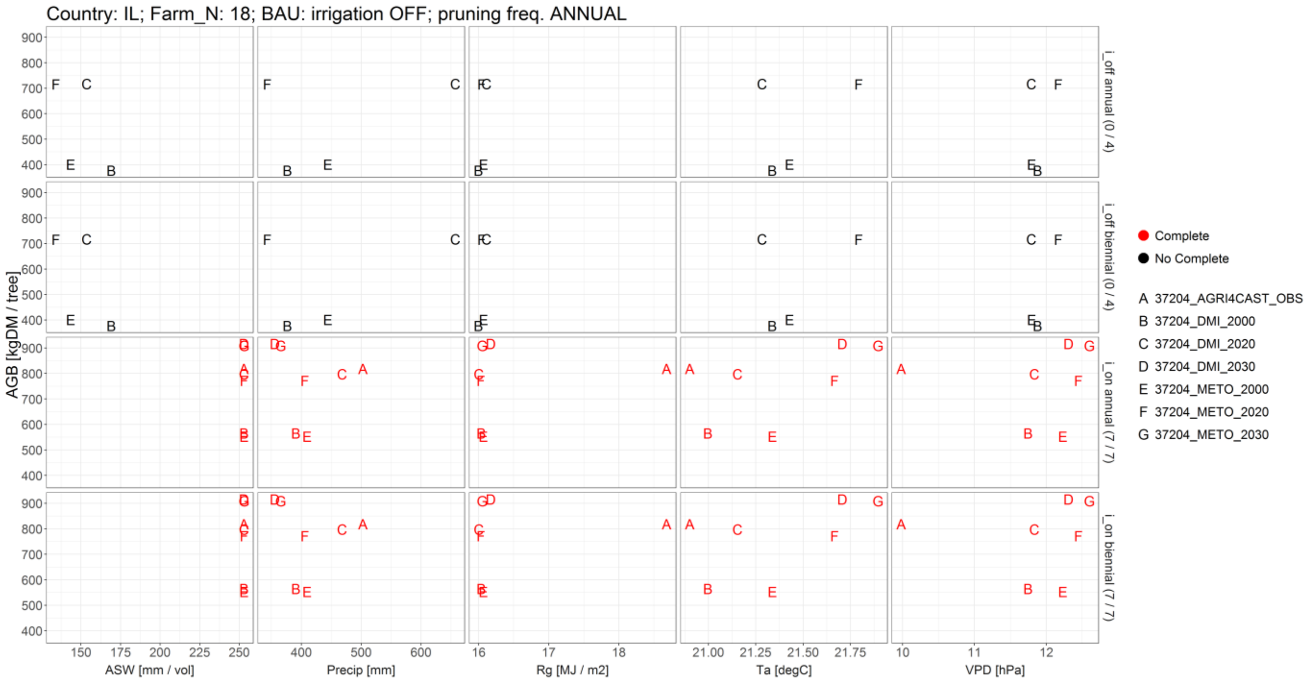


Figure 15: Comparison of the interannual means of the AGB and climatic drivers for the farm 18. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.15 Farm: 19

At the farm 19 the simulations with the irrigation OFF are very poor (4) if compared with the alternative management (pruning annual or biennial and irrigation ON, 19). The time series, with irrigation OFF and greater than 1 year, are available only for the simulation C,E, G and L (ETHZ cell 36202 time horizon 2020; METO cell 36202 time horizon 2000; METO cell 36202 time horizon 2030; ETHZ cell 36203 time horizon 2000; respectively). In some cases the AGB is greater than 950 kgDM/tree in simulations C and G, the AGB is less than 800 kgDM / tree in the simulations E and L.

When the irrigation is ON all the simulations are complete. The simulations B, E, I, L and O show the smaller AGB (less than 900 kgDM/tree) corresponding to the time horizons 2000. If the climate is OBS and time horizons 2020 the AGB is about 1000 kgDM/tree, in the other cases the AGB is greater than 1100 kgDM/tree.

Figure 16: Comparison of the interannual means of the AGB and climatic drivers for the farm 19. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.16 Farm: 20

The number of the simulations in the farm 20 is the same in all the management practices. The irrigation is involved in the survival of the olive trees, .i.e. if irrigated the time series achieve the end of the simulations. When the irrigation is OFF the AGB and the soil water content have a opposite trend. A similar reduction in the carbon uptake is showed in the precipitations, the AGB is less than 400 kgDM/tree if the precipitations are over the 450 mm year^{-1}. Furthermore, if the water in the soil is less than 225 mm / vol. (see simulation A under irrigation ON or OFF) a highest solar radiation seems to not be reflected in increases in AGB

If the BAU irrigation is changed the olive trees, show a better capability to survive. The AGB are always greater than 400 kgDM/ tree. When the time horizons are 2020 and 2030 the AGB is over the 550 kgDM/tree. The AGRI4CAST_OBS results (results A) seem to be the middle between these two groups.

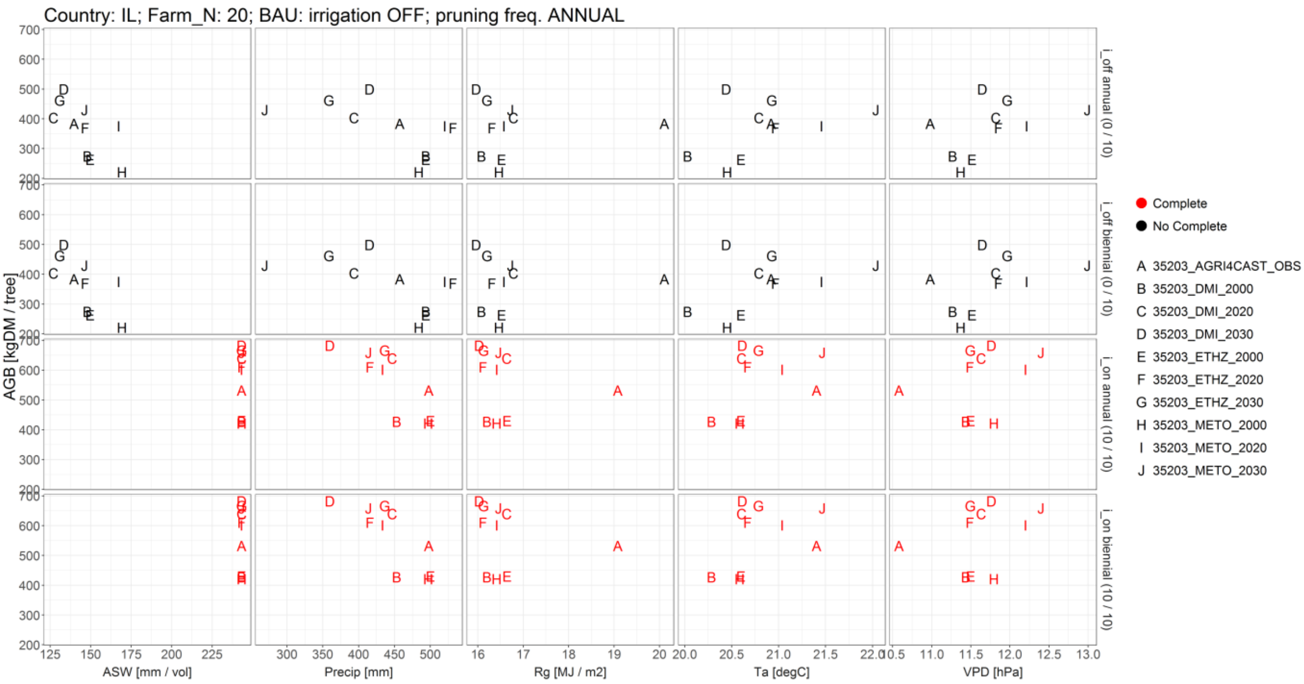


Figure 17: Comparison of the interannual means of the AGB and climatic drivers for the farm 20. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

4.17 Farm: 21

The farm 21 shows extreme conditions to the olive trees survivorship. If the irrigation is OFF the model simulates only the climate F (METO time horizon 2020). In this condition the time series is not complete and the AGB is less than 505 kgDM/tree.

When the irrigation is applied, all the simulations show complete time series. In general, if the precipitations increase, the carbon uptake decreases, the exceptions to this trend are the simulations A and C. The first (simulation A) shows very high radiation and very low VPD. In the second exception (simulation C) the solar radiation and VPD are different to the simulation A while the temperature are very similar.

In all climatic conditions and under different management practices the ETHZ simulations are not available because of the time series modelled by the 3D-CMCC-OLIVE are less than 1 year.

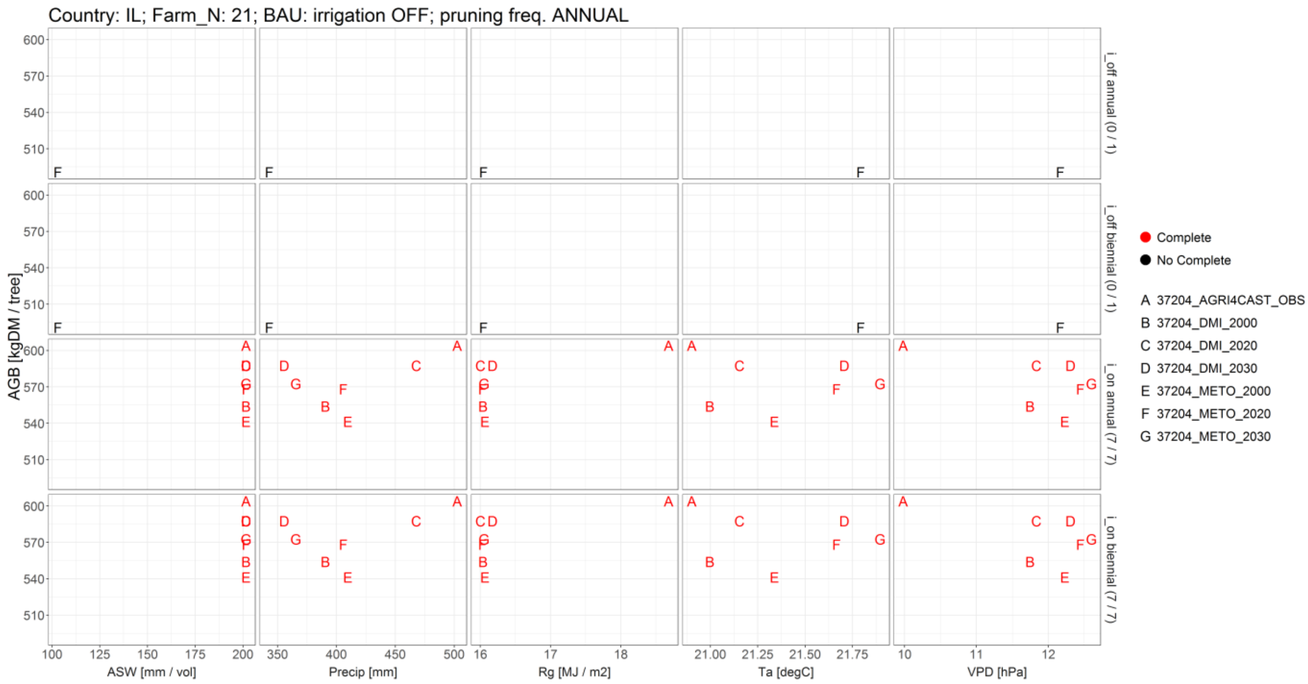


Figure 18: Comparison of the interannual means of the AGB and climatic drivers for the farm 21. The horizontal axes labels indicate: Available Soil Water (ASW); Precipitation (Precip); Global Solar Radiation (Rg); air temperature (Ta) and vapour pressure deficit (VPD).

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