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IRRIGATED AGRICULTURE AND WATER USE EFFICIENCY IN ITALY

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SUMMARY – This document aims to provide a comprehensive review of irrigated agriculture in Italy with a particular emphasis on the Water Use Efficiency (WUE) and water productivity (WP). The data presented include the country climatic characterization, water availability and withdrawal, sources of irrigation water, irrigable and irrigated lands, irrigation methods, irrigated crops and their growing parameters, experimental data on both biomass and yield WUE. The agronomic data of main crops, grown principally in Southern Italy environment, are taken into consideration including tree crops (grapevine, olives, citrus, peach, etc.), field crops (wheat, maize, sugarbeet, sunflower, etc.) and horticultural crops (tomato, potato, watermelon, beans, spinach, etc.). An analysis of: crop production functions, application of irrigation methods, and crop water requirements (in terms of estimation of reference evapotranspiration and crop coefficients), in Italian agriculture is given. The presented crop coefficient data vary for a crop in respect to local climatic conditions, latitude, altitude, time of sowing and applied agronomic practices. Moreover, these data differ notable from those presented in scientific literature: it indicates a necessity for a local calibration and eventual revision of well-known existing FAO documents on crop water requirements and crop response to water. Finally, some common agronomic practices for enhancing WUE & WP have been described, focusing mainly on the situation of Southern Italy. This analysis, based on the evaluation of the national scientific literature and technical reports, has shown how these strategies should aim at increase of beneficial water consumption (transpiration) against the non-beneficial losses by: (i) increasing of marketable yield per unit of water transpired; (ii) maximizing transpiration consumption relative to evaporation losses; (iii) enhancing effective use of rainfall and water stored in the soil.

Key words: water resources, irrigation, water use efficiency, water saving, Italy.

INTRODUCTION

Italy, with a surface area of 301,277 km^2, occupies a central location in the Mediterranean basin. Stretching over 1,200 km between North and South, Italy has shores on four Mediterranean sees (the Ligurian, the Tyrrhenian, the Jonian and the Adriatic) and it has an exceptionally long coastline of almost 7,500 km. About 27% of Italian territory (8,136,207 ha) is along the coast line and 73% (21,997,893 ha) is considered the inland.

The Italian territory can be subdivided naturally into four main physiographic regions:
a) the Alps mountains chain in the North, extending from west to east and reaching up to 4,800 m a.s.l. (with Monte Bianco, the highest peak of Europe);
b) the lowland of the Po river basin, located on the South of the Alps;
c) the peninsula, including the central Apennine massive with the peaks rising up to 2,900 m a.s.l. and the coastline, and
d) two large islands, Sicily on the South and Sardinia on the West of the peninsula

The lowlands, flat and valley areas, cover 6,976,373 ha (23.2% of the territory); the mountain areas occupy 10,611,957 ha (35.25% of the country), while the hill areas cover about 12,542,779 ha (41.55% of the territory).

The precipitations in Italy are relatively abundant (on average about 1,000 mm/year), but as often, they are not evenly distributed between seasons and regions, and high evapo-transpiration in coastal areas causes significant losses. Due to the range of rainfall, hydrological and climatic regimes (from Mediterranean to continental and Alpine), Italy presents a wide diversity of ecosystems, landscapes and agricultural practices. In fact, Italy's agriculture is a typical example of the division between the agricultures of the northern and southern European countries: the northern part produces primarily grains, sugar-beet, soybeans, meat, and dairy products, while the south is specialized in producing fruits, vegetables, olive oil, wine, and durum wheat.

Inasmuch as Italian agriculture is very intensive and market oriented it preserves many local peculiarities especially in the Southern regions. In fact, most farms are small, with an average size of only 7 ha whereas a large working force (more than 1.5 million) is employed. Irrigation represents a common practices in all parts of the country due to market oriented agricultural production and strong variability and uncertainty of climatic factors. However, the cropping pattern, irrigation methods, agronomic practices and water use efficiency vary significantly from region to region and, also, from farm to farm. This paper reports the data describing the irrigated agriculture, crop water requirements and water use efficiency in Italy emphasizing the practices that improve the efficiency of water use and save water for other purposes.

CLIMATIC CHARACTERIZATION

The Italian climate is highly varied due to variety of hydrographic and orographic factors, its North-South elongation and exposition to four Mediterranean seas. These factors influence substantial variation of the main climatic variables as illustrated in Figures 1 and 2. The average temperature in January (the coldest month) varies from several degrees below zero in the Alpine area to more than 6°C in the coastal Mediterranean regions while the average temperature in July (the warmest month) spans between less than 15°C in the Northern Alps and about 30°C in the Southern Mediterranean zones (Fig. 1).

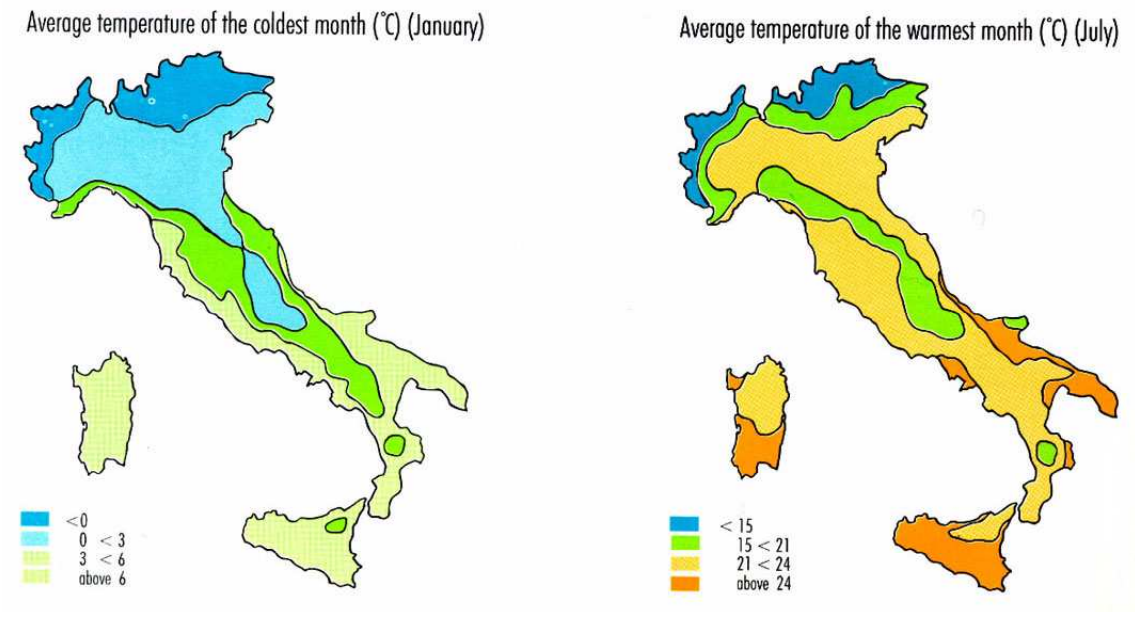

Fig. 1. Spatial distribution of temperature of the coldest month (on the left) and of the warmest month (on the right) based 30 years averages (Source: SAIN-UCEA, Rome, 1995)

The sunshine hours cumulated on annual basis ranges between less than 1800 in the Alps to more than 2200 in the South (Fig 2). The average annual precipitation is relatively abundant and it is estimated to about 1000 mm per year although it is unevenly distributed among regions and seasons. In fact, average annual precipitation goes from less than 400 mm in the coastal Southern zones, receiving almost all precipitation input during the winter season (between October and March), and to almost 3000 mm in the Northern Alpine areas (Fig. 2). The Southern Adriatic regions receive much less precipitation than the Tyrrhenian side due to the characteristic movements of the humid air masses and orographic characteristics of the peninsula. According to the above mentioned parameters and the Köppen climatic classification, the overall Italian climate can be described as moist, mid-latitude subtropical although eight climatic zones can be observed moving from the Northern Alps regions to the South and from the coastal areas to the inner Apennine massive as illustrated in Figure 3.

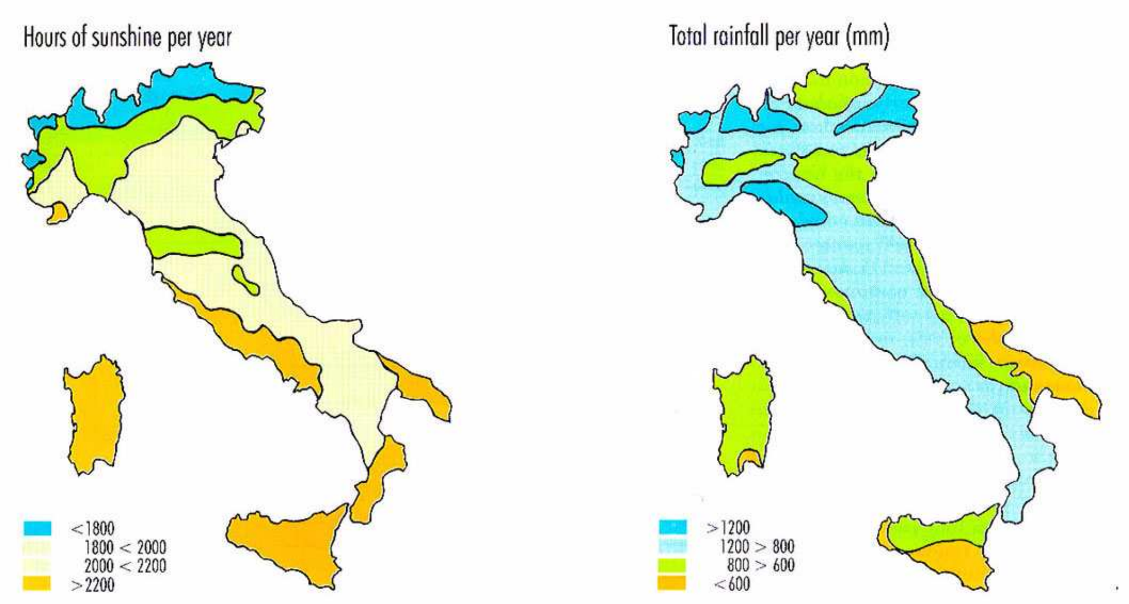

Fig. 2. Spatial distribution of sunshine hours per year (on the left) and of the total annual precipitations (on the right) based 30 years averages (Source: SAIN-UCEA, Rome, 1995)

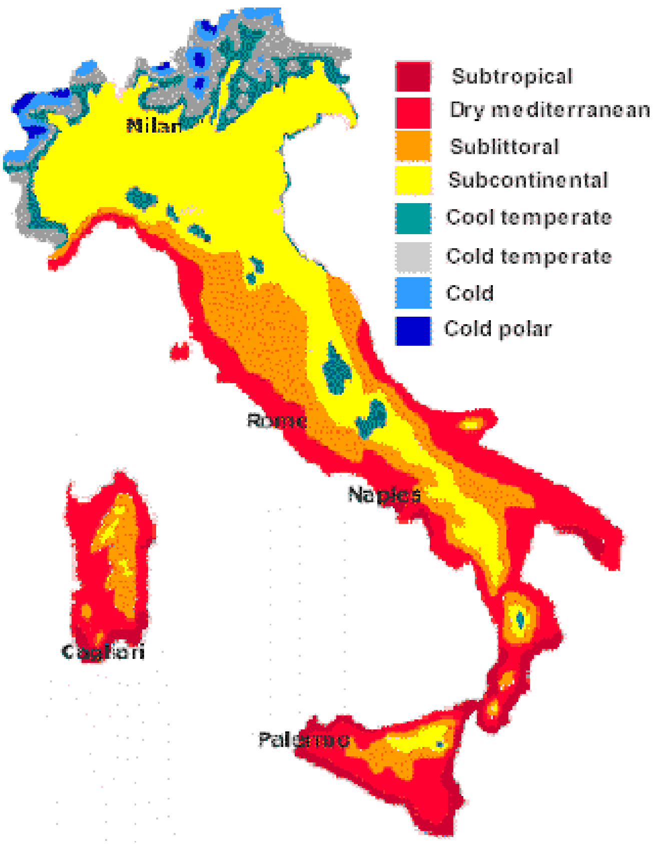

Fig. 3. The main climatic zones of Italy according to the Köppen climatic classification (Source: www.italocorotondo.it/tequila/partner_section/italy_english/)

The coastal zones of Italy are characterized by dry semi-arid Mediterranean climate which passes to sub-littoral and sub-continental as moving into the inner areas of Apennines. The central Northern regions, including the Po river valley (the most important Italian river basin where live about 15.5 million inhabitants), are characterized by sub-continental climatic conditions while the climate of the Alpine mountains goes from cool temperate to cold polar. Some high peaks of Apennines are also characterized by cool temperate climatic conditions.

WATER RESOURCES AVAILABILITY AND USE IN ITALY

Water resources availability

The analysis of water resources availability in Italy is based on the data coming from several sources (ANPA, 2001; IRSA CNR, 1999; EUOSTAT, 1998; AQUASTAT, 1998, Blue Plan, 2001) and a synthesis of results is presented in Table 1.

The precipitation over the Italian territory generates every year a total flow of about 296 km^3. However, due to the presence of large areas characterized by semi-arid Mediterranean climate, the evapotranspiration losses are estimated to 129 km^3/year while the subsurface flow to the sea is in average of about 12 km^3/year. This means that the internal renewable water resources account to approximately 155 km^3/year which represents about 52.3% of total flow generated by precipitation. External runoff is calculated to 7.6 km^3/year (from Switzerland 51%, from Slovenia 43% and from France 6%) while spring outflow contribution from local aquifers is estimated to about 3.5 km^3/year. This means that the total renewable water resources of Italy are about 166.1 km^3/year. It is estimated that only two/thirds of that volume (or about 110 km^3/year) are technically and economically available for exploitation.

The total groundwater availability is about 40 km^3/year but the greatest part of it (about 30 km^3/year or 75%) contributes to the recharge of regional aquifers and only 25% (10 km^3/year) represents the recharge of local aquifers. Only one/third of it (about 3.5 km^3/year) is related to the spring outflow as mentioned previously.

Table 1. A synthesis of water resources availability in Italy (data elaborated from the following sources: ANPA, 2001; IRSA CNR, 1999; EUOSTAT, 1998; AQUASTAT, 1998, Blue Plan, 2001)

Average precipitation [mm/year]	982
Flow generated by average precipitation [km^3/year]	296
Average evaporation [mm/year]	428 (438*)
Evaporation losses [km^3/year]	129 (132*)
Subsurface flow to the sea [km^3/year]	12 (9*)
Internal renewable water resources [km^3/year]	155 (=296-129-12)
External runoff – inflow from other countries [km^3/year]	7.6
Total groundwater availability [km^3/year]	40
Groundwater recharge of local aquifers [km^3/year]	10 to12
Spring outflow from local aquifers [km^3/year]	3.5
Total renewable water resources [km^3/year]	166.1 (=155+7.6+3.5)
Potentially usable water resources [km^3/year]	110

* there is some difference between data coming from different sources

Therefore, the total renewable water resources availability per person can be estimated as about 2914 m^3/year/capita, or 1930 m^3/year/capita by means of potentially usable resources. These values are much more greater than those of the Southern Mediterranean countries (e.g. total renewable water resources availability in Middle East and North Africa Region is about 1250 m^3/year/capita, or about 43% of Italian availability). However, they are significantly lower than the average renewable water resources of Western Europe countries, which is estimated to about 5183 m^3/year/capita (World Resources Institute, 2000).

Furthermore, it is important to highlight that water resources are not regularly distributed over the Italian territory (Fig. 4): in the Northern part is located about 59.1% of potentially usable water resources whereas the rest of the country accounts on the 40.9% of resources. This disparity becomes even more evident when expressed by the availability of potentially usable resources per capita (Fig. 4b) which indicates that water resources availability per capita in the North is almost 3.5 times greater than in the Islands and it represents about 175% of water availability in the continental Southern regions. These data emphasize the seriousness of water problems in the Southern regions especially during the summer months when in those areas water demand is strongly increased due to important vocation to tourism and consequent high population inflow.

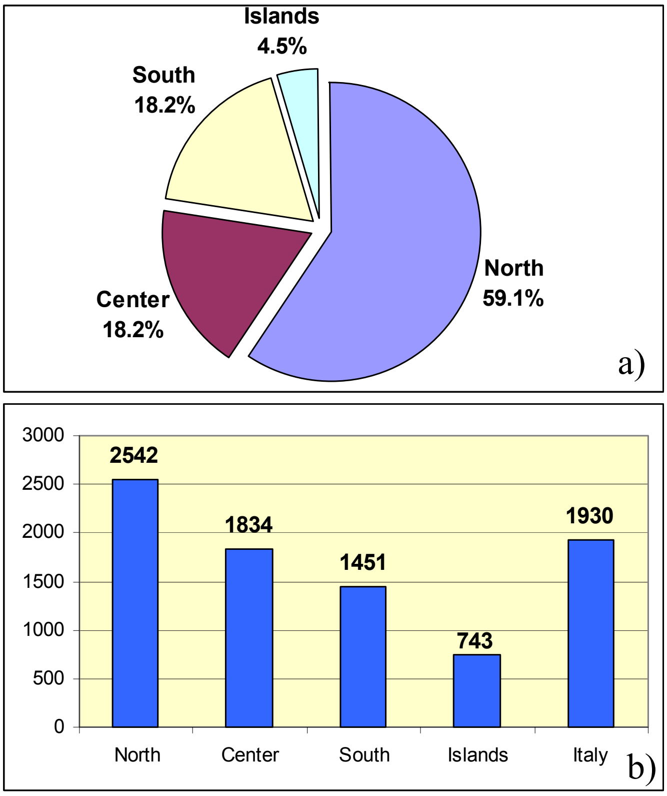

Fig. 4. Regional distribution of potentially usable water resources in Italy as a percentage of total resources (a) and as water availability in m^3/year/capita (b) (Source: IRSA CNR, 1999)

Water withdrawal and sectorial water use

The average water withdrawal in Italy is estimated to about 51.820 km^3/year which represents about 31% of the gross annual available water resources and 47% of the water resources technically and economically available for exploitation. (IRSA, CNR, 1999). This amount, translated to a mean annual per capita withdrawal of 910 m^3, is significantly greater than EU average of 662 m^3/capita/year and it is, together with Egyptian water withdrawal per capita (however, Egypt uses 100% of exploitable resources), the greatest in the Mediterranean region. Nonetheless, it is significantly lower than in some other highly developed countries (e.g. USA - 1873 m^3/capita/year and Canada - 1736 m^3/capita/year).

The greatest part of water withdrawal belongs to surface water resources (39.673 km^3/year or 76.6%) which includes the storage capacity of artificial accumulation reservoirs of about 8.426 km^3. The contribution of groundwater is estimated to about 12.147 km^3/year, which corresponds to 23.4%

of total water withdrawal. Nevertheless, it is important to underline that the knowledge about groundwater resources is far from accurate due to frequent non-authorized water abstraction for irrigation especially in the Southern regions.

The water withdrawal varies from year to year between 40 and 56 km^3/year according to the availability and demand, and also, it is very variable from region to region. In general, about 65% of withdrawal belongs to the Northern part of the country, 15% to the Central regions and 25% to the South and the Inlands. Water withdrawal is the highest in the North-East region of 1975 m^3/capita/year (even greater than in the USA and Canada), and it the lowest in the Apulia region (220 m^3/capita/year). In some regions, water shortage is attenuated with the water transfer from other regions, as it is the case of the Puglia region, which receives more than half of its water demand from Basilicata region and partially from Campania region. This was possible thanking to the "CASSA PER IL MEZZOGIORNO" (Southern Italy Development Fund), promoted and implemented by Italian authorities during the 50-ties, 60-ties and 70-ties of the last Century. The realization of new accumulations and water delivery systems is still in progress and, together with an inter-regional action program for management of common water resources, represents the keystone of strategies for facing water shortage problems in the South.

The partitioning of water withdrawal between different sectors changes from year to year (Table 2) depending on the overall availability and water demand. Nonetheless, on the basis of average historical data, can be stated that, in general, about 60 per cent of water withdrawal is used for irrigation, 25 per cent for industry, and 15 per cent for domestic use (Fig. 5). Certainly, when water availability is scarce, the reduction is applied primarily to irrigation sector as illustrated in Table 2.

Table 2. Sectorial water use in Italy for a hydrological normal (1991) and a dry (1999) year (Source: ISTAT, 1991; IRSA-CNR, 1999; MPAF, 2004)

Sectors of water use	1991 (a normal year)		1999 (a dry year)	
	Water use [km^3]	Water use [%]	Water use [km^3]	Water use [%]
Domestic	8	16.0	7.9	19.6
Industry	12	24.0	8.0	19.7
Energy*	-	-	4.5	11.1
Agriculture	30	60.0	20.1	49.6
Total	*50*	*100.0*	*40.6*	*100.0*

* includes only the use of freshwater for thermoelectric plant cooling

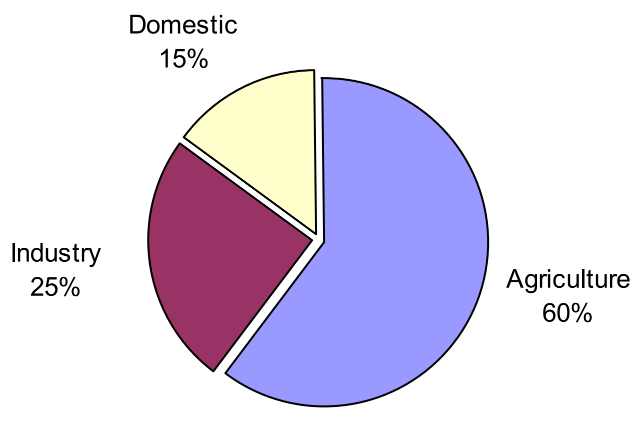

Fig. 5. Water withdrawal by sectors in Italy

The use of water for irrigation is not regularly distributed all over the country: 67% of it belongs to the Northern Italy, 28% to Southern Italy with islands and only 5% to the Central part of the country. Main sources of irrigation water are rivers (67%), followed by groundwater from wells (27%) and by reservoirs (6%). The water withdrawal for domestic purposes reaches almost 370 liters/person/year and it is obtained mainly from groundwater aquifers (50%) and springs (40%) and only marginally from surface water (10%). Groundwater withdrawals in the Po Basin are considered to have reached their maximum, with over-exploitation already occurring in some sub-basins (e.g. Lambro-Sveso-Olana, Parma, Panaro rivers).

IRRIGATED LAND AND IRRIGATION PRACTICES IN ITALY

Agricultural, irrigable and irrigated land

The total utilized agricultural area (UAA) in Italy is estimated to about 131,941 km^2 which corresponds to 43.8% of total surface area. The agricultural land area is continuously decreasing: since 1970 the utilized agricultural area diminished by 2.8 million hectares (-16%) according to data from the most recent survey of farm structures. This is a phenomenon which affects all developed and industrialized countries. Between 1991 and 2001, the utilized agricultural area has decreased progressively by 11.1% per inhabitant, from 0.3 to 0.26 hectares per capita (INEA, 2003), which is in the range of other EU countries (-10.9%). Land is, thus, becoming an ever-more precious resource, especially in countries which, like Italy, have a high population density and where national territory is subject to considerable variation in altitude.

A synthesis of land use in Italy and other European countries is given in Table 3 as a percentage of total surface area. In general, the data indicate an intensive use of land in Italy and a substantial difference in respect to other EU Mediterranean countries and to the EU territory. This is probably due to the fact that Italian territory is exposed to many very different climatic zones (eight), from cold polar to subtropical, which caused a strong variation in land use. Approximately 37% of the Italian territory is used for arable agriculture, which is much more greater than EU average of 27%. Nevertheless, due to many arid and semi-arid zones, the percentage of bare ground is two times greater than the EU average. Moreover, the urban, unproductive areas, cover about 2.1 million hectares which is 7% of the country, while the EU average is 5% and average of other EU Mediterranean countries is 4%.

Table 3. Land use in Italy and EU countries (%) (Source: INEA, 2003, on the basis of EUROSTAT survey)

	Italy	Other EU Mediterranean countries (*)	Central EU countries (**)	Total EU (***)
Arable land (1)	37	33	32	27
Permanent crops (2)	29	26	32	37
Moorland (areas over 20% covered by shrubs)	8	20	4	8
Permanent meadows and pastures	10	11	20	12
Bare ground	6	5	3	3
Inland waterways and wetlands (3)	3	1	3	8
Unproductive areas and other land (4)	7	4	6	5
TOTAL AREA (000 ha)	30,133	72,988	110,172	292,105

(*) Greece, Spain, Portugal.
(**) France, Germany, Belgium, Luxemburg, Denmark, The Netherlands,
(***) Excluding UK and Ireland,
(1) Including temporary forage crops and set aside.
(2) Tree and other permanent crops (woods and forests).
(3) Including glaciers and eternal snow.
(4) Man-made and industrial settlements, infrastructure, rocks and barren land; ornamental parks and gardens, roads, railways, etc.

According to the General Agriculture Census carried out in 2000, the irrigable land amounts to 3,887,387 hectares which is equivalent to 29% of total national utilized agricultural area (UAA). A comparison with the 1990 Census, indicates that irrigable land has remained almost the same although it varies considerable from region to region (Table 4). The Northern regions, endowed with significantly greater water resources than Central and Southern regions, could potentially irrigate about 50% of their UAA.

The average irrigated area is estimated to approximately 2.65 million hectares which corresponds to 68% of the total irrigable land and to about 20% of UAA. According to the Census, the irrigated area in 2000 was slightly smaller (2.47 million hectares), with substantial differences between the regions (Table 4). Slightly less than two thirds of the irrigated area is in the Northern Regions, involving 34.9% of farms with UAA and with an average area per farm of 6.5 hectares. In the Centre, only about 17.9% of farms are irrigated, whereas in the South the practice is carried out on 25% of farms with a total area of 758 thousand hectares, equivalent on average to 2.2 hectares per farm. According to the official data of National Institute for Statistics (ISTAT), about 63.2% of irrigated land in located in the North, 7.2% is in the Central part of the country while 29.6% is situated in the South.

There are two main factors limiting irrigation in Italy: the availability of water resources and the presence of infrastructures for water accumulation and delivery to the fields. Accordingly, the largest irrigated areas are located in Lombardia Region, covering about 554,382 ha and corresponding to almost 80% of UAA. Then, irrigation is fully developed in Piemonte Region (on 335,800 ha), Veneto (265,253 ha), Emilia Romagna (252,377 ha), and Puglia Region (248,814 ha). Nonetheless, it is necessary to recognize a drawbacks of official statistics which have difficulties to consider the farms, located mainly in the South, subjected to non-authorized irrigation from private wells.

Table 4. Irrigable land in Italy and area irrigated in 2000 (Source: ISTAT, 2002)

Region	Irrigable land [ha]	Irrigated land [ha]	Irrigated/Irrigable [%]
Piemonte	448,947	335,800	79.25
Valle d'Aosta	26,212	23,623	90.12
Lombardia	700,140	554,382	79.18
Liguria	11,244	7,191	63.96
Trentino Alto Adige	61,774	57,768	93.51
Veneto	435,845	265,253	60.86
Friuli Venezia Giulia	91,876	63,202	68.79
Emilia Romagna	565,573	252,377	44.62
Toscana	111,603	47,286	42.37
Umbria	66,927	32,117	47.99
Marche	49,470	25,070	50.68
Lazio	150,088	74,052	49.34
Abruzzo	59,358	29,995	50.53
Molise	20,881	11,812	56.57
Campania	125,305	86,414	68.96
Puglia	389,617	248,814	63.86
Basilicata	80,640	42,325	52.49
Calabria	117,143	66,922	57.13
Sicilia	209,036	161,044	77.04
Sardegna	165,709	62,315	37.60
ITALY	**3,887,387**	**2,467,763**	**63.48**

Irrigated crops

The Census on agriculture, referring to the year 2000, provides the data about irrigated crops in Italy and a synthesis of elaborations is given in Figure 6. The data indicate that almost 86% of cultivated citrus crops were irrigated (corresponding to 113,600 ha in respect to total cultivated area of 132,500 hectares). Then, the irrigation was very intensive in the areas cultivated with vegetables (70%), potato (67.4%) and maize (58%), followed by fruit-tree crops (38%), sugarbeet (36.2%), soya (34.5%), vineyards (25.5%), etc.

The maize is the crop which is irrigated on the greatest surface areas in Italy, i.e. on 622,000 ha, mainly located in the North-West regions. Then, large irrigated areas are covered by forage crops (267,000 ha), vegetables and potato (217,000 ha), fruit-tree crops (189,000 ha), vineyards (183,000 ha), sugarbeet (81,000 ha), etc. Inasmuch as the cereal cultivation covers the greatest part of UAA (2,233,00 ha), the cereal crops are irrigated on 99,500 ha which represents only 4.5% of their total cultivation.

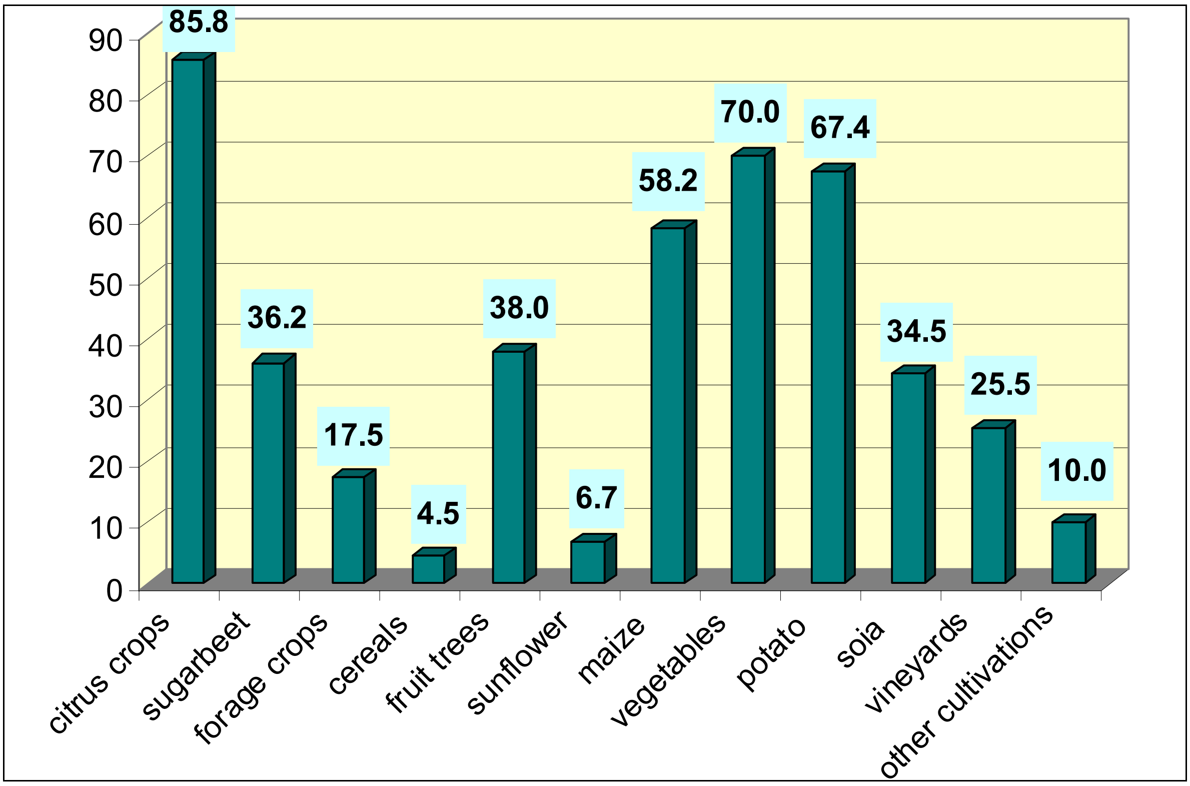

Fig. 6. Irrigated crops in Italy (as percentage of total cultivated area of each crop) according to the Census in 2000 (Source: ISTAT, 2002)

The citrus crops are almost fully irrigated (up to 95%) in the Southern regions, especially in Sicily and Basilicata. The fruit-tree crops are irrigated almost completely in Trentino Alto Adige (93%), while the percentage is lower in other regions: 72% in Veneto, Friuli Venezia Giulia and Basilicata and 61% in Emilia Romagna. Sugabeet is irrigated principally in Trentino Alto Adige (96%), Sardegna (83%), Campania (83%) and Umbria (81%). Vineyards are irrigated particularly in Trentino Alto Adige (67%), Puglia (62%) and Valle d'Aosta (54%). The irrigation practices are strongly related to the availability of water resources, especially in the South, where the irrigation strategies and irrigated crops are selected on the basis of economic parameters and increase of profit. In fact, the irrigated area for the most crops, except maize and vineyards, has decreased substantially in respect to the census in 1990. The most significant decrease of irrigated land was observed for soya and forage crops, of about 123,000 ha (60%) and 172,000 ha (40%) respectively. On the other side, an increase of irrigated land was observed for maize, of about 115,000 ha (23%) and for vineyards, of about 20,000 ha (13%). The irrigated land in 2000 was for about 100,000 ha lower than in 1990.

Irrigation methods

The irrigation methods vary in respect to the irrigated crops, quantity and quality of available water, size and type of management of irrigated farms, and soil and climatic characteristics. In general, the sprinkler irrigation method is the most utilized (on 1,047,000 ha), followed by surface and furrow irrigation (850,480 ha), localized irrigation (366,018 ha) - mainly drippers (290,700 ha), flooding irrigation (202,000 ha) and other methods (2,300 ha) as illustrated in Fig. 7. During the last twenty years, there is a general trend of almost all irrigation methods, except localized irrigation, to shrink the surface area of application.

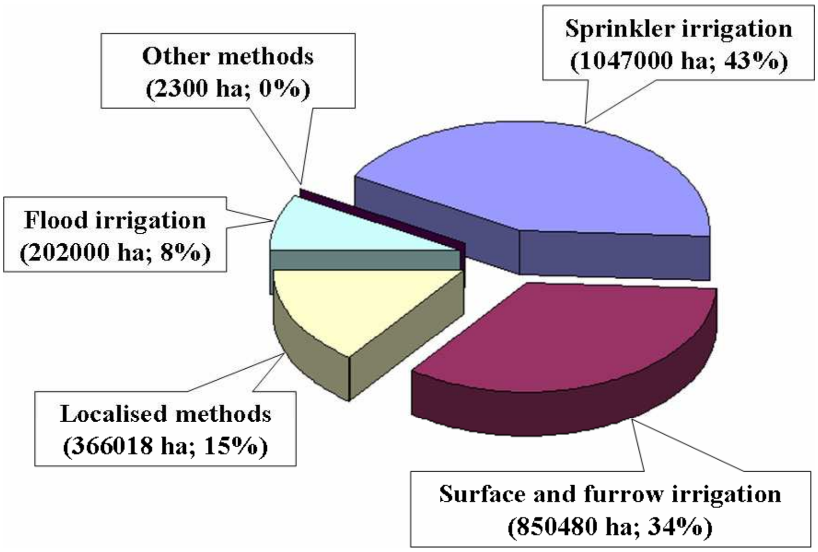

Fig. 7. Irrigation methods in Italy

The sprinkler irrigation method is frequently used in Emilia Romagna (162,500 ha), in Veneto (157,500 ha) and in Lombardia (138,500 ha) where field crops as maize, forage crops, sugarbeet, etc are cultivated.(Fig. 8). The surface and furrow irrigation, characterized by low application efficiency, high volumes of water supply, well-managed and dense water distribution networks and well-leveled irrigation fields, are extended mainly for irrigation of herbaceous crops in Lombardia (350,000 ha), Piemonte (211,500 ha), Veneto (86,000 ha) and Emilia Romagna (45,000 ha). The furrow irrigation method is utilized also in Campania, on the surface area of 40,000 ha, for irrigation of vegetables. In this case, short furrows (about 10 m length) with the water flow between 5 and 10 l/s are utilized, realizing in such a way a sort of flooding by furrows.

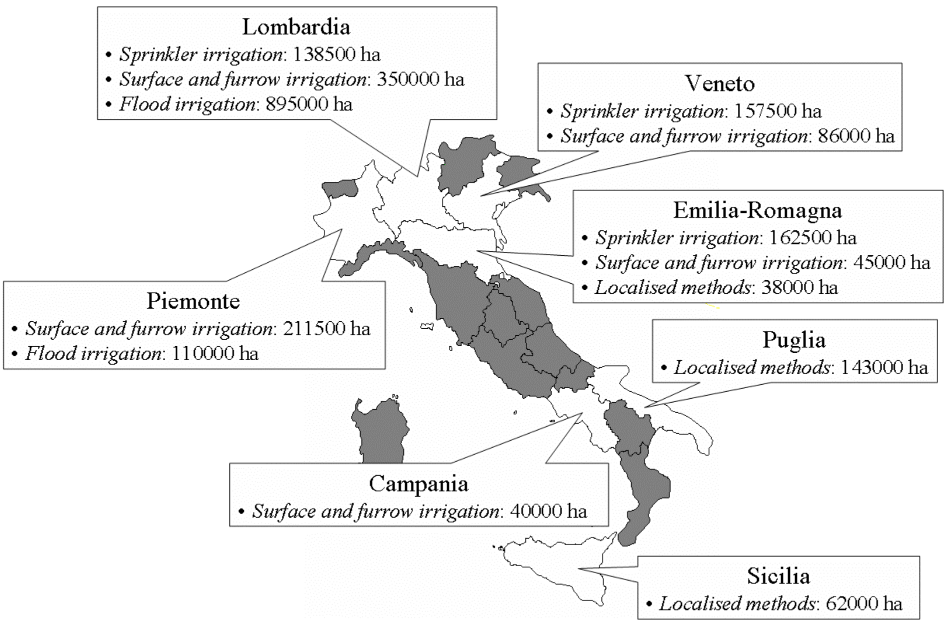

Fig. 8. The most utilized irrigation methods in the Italian regions with the highest irrigation surfaces

Moreover, in Lombardia, where the winter temperatures are very low and frequently below zero, the surface irrigation is utilized with anti-frost purposes on permanent forage crops in order to have green forage during the winter season. For this purpose it is necessary to provide an appropriate field land leveling which permits fast flow of water in the normal direction to the longitudinal axis of irrigation units. In these cases, the irrigation is performed by using a single or double lateral land grading (Fig. 9). The slope of land along the axis perpendicular to the longitudinal irrigation unit is 4 to 10% and the length of water course is between 5 and 20 m. In such a way, the time of flow-off is lower than the time necessary for the conversion of water from liquid to solid state, allowing the superficial soil layers to have temperature greater than zero and to permit the growing of vegetation having green forage also during the winter time.

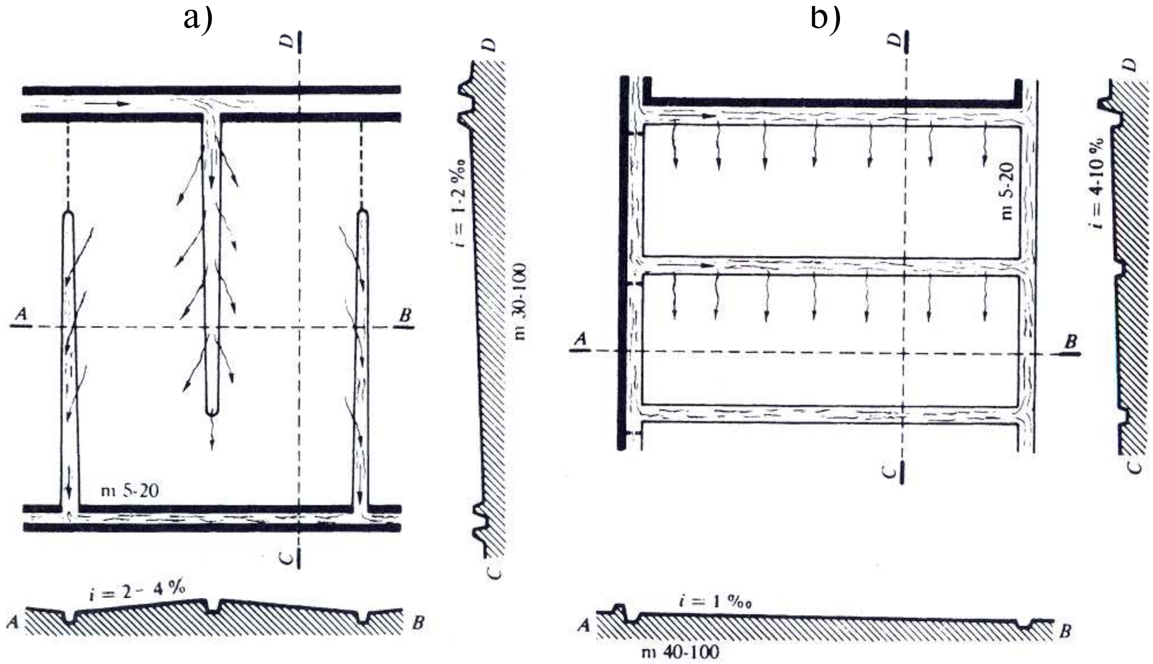

Fig. 9. Surface irrigation method with double (a) and single (b) lateral land grading (Source: Giardini, 2002)

The flooding irrigation method is utilized almost exclusively to irrigate rise, in Piemonte on the surface area of more than 110,000 ha, in Lombardia on the surface area of about 89,500 ha, and in Veneto, Emilia-Romagna, Sardegna and Calabria on a total surface area of about 15,000 ha (Fig. 8).

The localized low-pressure irrigation methods (drip, sprayers and "capillary" sub-irrigation) are extended mainly in the Southern regions of Italy, and particularly in Puglia (143,000 ha) and in Sicilia (62,000 ha) while in the North they are utilized prevalently in Emilia-Romagna (38,000 ha). These methods guarantee a high water application efficiency and they are used mainly for the irrigation of orchards and vegetables in the areas where water supply is limited.

The sub-irrigation method by regulation of water table depth is used in Veneto, in the areas where shallow water table is controlled by sub-surface drainage systems, and it is applied as a supplementary intervention to rise water table when necessary. The capillary subsurface irrigation is practiced on orchards in Emilia-Romagna, Puglia, Sicilia and Basilicata, burying the dripping laterals with drippers that release slowly herbicides (Trifluralin) to avoid intrusion of roots into drippers.

Sprinkler irrigation is realized mainly with self-propelled devices which use side-roll laterals with long jets (sprinklers) which can be substituted sometimes with sprinkling laterals in order to improve water use efficiency and to reduce the working pressure of the system. These equipments have been widely used by farmers for irrigation of field crops due to their capacity to adapt at different field conditions, to move easily, to limit labor requirements and application cost. Recently, there is an attempt to improve distribution efficiency of the high pressure sprinklers with large wetted diameter in windy areas through the application of new generation turbine sprinklers with slow return fluctuating arms and with adjustable angle of the jet until reaching the horizontal position (Fig. 10)

Fig. 10. New generation turbine sprinklers with slow return fluctuating arms and adjustable angle of jet

The devices with mobile and fixed wings (lateral sprinklers) are presented rarely for irrigation of vegetables while permanents irrigation devices are used prevalently for irrigation of orchards. The irrigation devices like "rangers" and "center pivots" are not frequently used due to small size of farms and presence of obstacles in the field (trenches, windbreaks, electrical cables, etc.). Surface irrigation is applied provided that land leveling was done with adequate furrow distances and sometimes by open ditches 20-30 m far away. This type of lateral infiltration irrigation is used in soils which crack superficially and water can run laterally over long distances.

Crop yield response to irrigation water

A more significant development of irrigation techniques in Italy coincides with the general reconstruction of country after the World War 2nd. It was particularly relevant in the Southern parts of the country, where the water shortage problems imposed the construction of dams and water accumulation lakes. At the same time, an intensive research in the field of irrigation had been promoted by the National Research Council (Consiglio Nazionale delle Ricerche - CNR). In 1962-63, these activities resulted in the constitution of a Group for Irrigation Studies (Gruppo di Studio sull'Irrigazione – GRU.S.I.) which has been operated up-to-date in an informal way. At the beginning, GRU.S.I. conducted research prevalently on the yield response to irrigation of herbaceous and tree crops with the aims to evaluate crop water requirements from the agronomic point of view and to optimize both the quantitative and qualitative aspects of crop production under different Italian environments. In fact, it is well known that optimal agronomic crop irrigation requirements do not coincide with the maximum evapotranspiration.

The research activities on irrigation have been conducted mainly in Southern Italy where the crop productivity is strongly influenced with limited precipitation, and irrigation represents a fundamental practice in order to increase and stabilize agricultural production over the years. These researches have been conducted prevalently on vegetables and field crops (tomato, pepper, bean, sugar-beet, maize, sorghum, etc.) and, also on the olive trees and vineyards since they are well-adaptable to water stress conditions.

The results of numerous experimental works highlighted that the seasonal irrigation volume represents the most important irrigation parameter in the determination of the production of crops under specific environmental conditions. Accordingly, the crop responses to water are presented in this document as the variation of yield, expressed as a percentage of the maximum obtainable yield, in relation to the specific seasonal volume of irrigation. In order to make possible a comparison between the crop productivity of different cultivars in different years and under different environmental conditions, the specific seasonal irrigation volume is expressed as a percentage of the maximum crop evapotranspiration (ETc).

In most of the experimental works on the crop response to water, the irrigation events have been programmed using the soil water balance approach with the reference to the maximum crop evapotranspiration (ETc), estimated with different methodologies and with the crop coefficient values (Kc) adopted from the literature or defined for the study areas. The methods based on the monitoring of the soil water content and/or the plant water status have been rarely adopted in the past. In general, different irrigation strategies have been compared maintaining fixed the irrigation intervals and changing the volumes of water applied as a percentage of the optimum water supply corresponding to the 100% of crop evapotranspiration.

An example is given for some herbaceous crops in Figure 11 showing the relations between the crop yield, expressed as a percentage of the maximum yield obtained during the experimental period, and the specific seasonal irrigation volume, expressed as a percentage of ETc, obtained in Metapontino (Policoro, Southern Italy). The relationships reported in Figure 11 are obtained adapting to the experimental points the Mitcherlich model modified by Giardini and Borin (1985) as:

$$y = y_m \left[1 - 10^{-c(b-d)}\right] \cdot \left[10^{-k(b+d)^2}\right] / \left[1 + 10^{1-c(b-d)}\right]$$

where: y is crop yield; y_m is the maximum obtainable crop yield under non-limited supply of the factor (parameter) under study; c is a coefficient of action (or of increase), indicating the rapidity of the achievement of the maximum yield; k is a coefficient of depression, indicating the tendency of y to decrease after the achievement of the maximum value; b is the quantity of the factor under study available for the crop in natural conditions, and d is the quantity of the factor under study applied under specific experimental conditions.

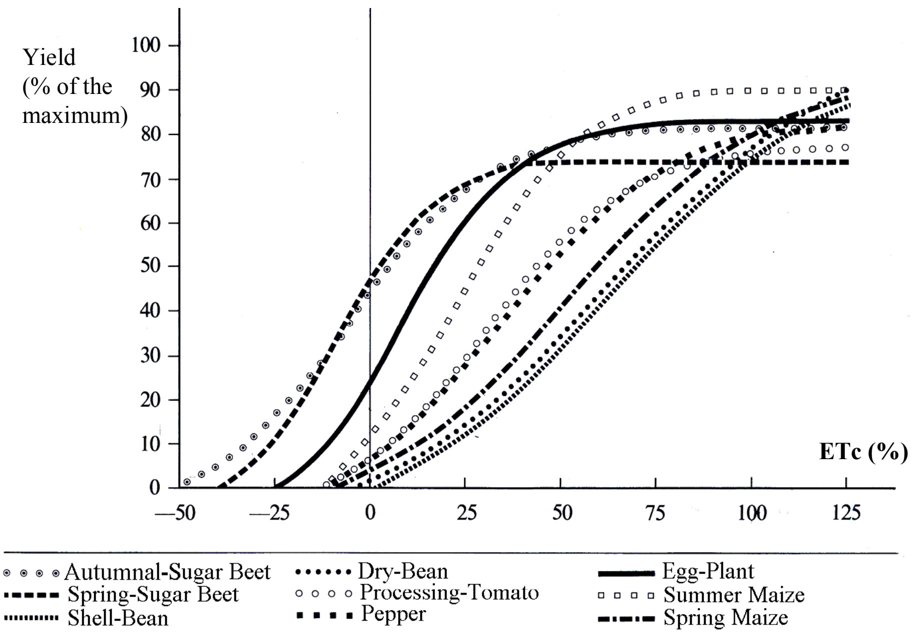

Fig. 11. Trend of some herbaceous crops yield expressed as percentage of the maximum obtainable yield in relation to the seasonal irrigation volumes expressed as percentage of ETc. The curves have been obtained adapting to the experimental points Mitscherlich model modified by Giardini and Borin. Negative values indicate the quantities of natural water, from precipitation, groundwater table and soil water content, utilized by the crops (adapted after Venezian Scarascia et al., 1987).

The research work was carried out in a deep, silty clay loam soil with moisture levels at field capacity and wilting point equal to 31.5 and 15% of dry soil weight, respectively; the water table was between 150 and 200 cm below the ground surface during the rainy season and in the dry months, respectively. The climate is typically Mediterranean with 600 mm average annual rainfall and 16°C as mean annual temperature. As an average, 79% of rainfall occurs in autumn-winter season (from October to March) while the highest averages temperatures (between 22° and 25°C) are recorded in June, July and August; consequently, the dry period extends from the beginning of May to the end of August.

The crops considered in the study were autumnal and spring-sown sugar-beet, shell bean and dry bean, tomato, pepper, eggplant, spring and summer-sown grain maize. Utilization of natural water resources (rainfall and ground water) by crops increased as the cycle extended into the rainy season. In this regard, figure 11 shows that the amount of natural water actually used by summer-cycle crops (shell bean, sown in June) is only about 2-3% of ETc and rises to as much as 50% with crops sown in autumn and harvested in summer (autumnal sown sugar beet): the corresponding water volumes are 150-180 and 3000 m^3 ha^{-1}, respectively. Moreover, the yield irrigation water efficiency is much greater for crops whose cycle extends - at least in part - into the rainy period (maize grown as the main crop, eggplant, sugar beet whether sown in spring or in autumn) than far spring-summer, or summer crops (pepper, tomato, maize grown as cash crop); for the first group of crops indeed the curves are steeper, as compared to the second group, because of the higher values of the action coefficient (c) which means better water use efficiency (Fig. 11 and Table 5).

Table 5. The parameters of the Mitscherlich equation, flex point coordinates and seasonal irrigation volumes at 100% of yield

	Equation-parameters			Flex point coordinates			Seasonal irrigation volume at 100% of
	Ym	b	c	Water volume		Yield	
	(% of the max yield)	(% of the ETc)	(ha / %ETc·10^{-3})	% of ETc	m^3/ha	(% of the max)	(m^3/ha)
Tomato	78.5	13.9	23.0	29.6	1435	35.3	4734
Pepper	84.9	15.1	20.1	34.6	2004	38.2	5800
Spring maize	91.0	15.4	27.6	20.8	994	41.0	4181
Summer maize	94.9	10.0	16.4	51.0	1603	42.7	3085
Eggplant	82.9	23.1	30.4	9.8	441	37.3	4795
Shell-bean	96.9	2.2	15.8	61.1	1898	43.6	3109
Dry-bean	102.0	4.9	14.9	62.1	2121	45.9	3413
Spring sugar beet	75.9	39.1	32.7	-8.6	-	34.2	7193
Autumnal sugar beet	82.0	49.4	23.1	-6.2	-	36.9	4961

Consequently, the greatest increments in yield were recorded with seasonal irrigation volumes around 61-62% of ETc (1898-2191 m^3 ha^{-1}) for bean (a typically summer crop) between 34 and 20.8% of ETc (2004-994 m^3 ha^{-1}) for pepper and maize grown as the main crop (spring-summer cycle crops), and without irrigation for sugar beet (grown either as spring or autumnal crop): the yields corresponding to such maximal increments were respectively 43.6, 45.9, 38.2, 41.0, 34.2 and 36.9% of peak yields recorded during the trial period (Fig. 12 and Table 5 to compare the flex point coordinates of the curves: the amounts of water and the corresponding yields).

These results stress the fact that yields are less affected by irrigation when dealing with spring-summer and autumn-summer crops, than with summer crops. Fig. 13 shows indeed that to obtain as much as 70% of the yield recorded during the trial period the seasonal amount of irrigation water had to be as high as 75% of the calculated ETc for summer and spring-summer crops and about 25% of the calculated ETc for autumn-summer or winter-summer crops. Seasonal irrigation volumes corresponding to 100% of estimated ETc ranged from minimum of 3100 m^3 ha^{-1} to a maximum of 7200 m^3 ha^{-1} according to the length of the crop cycle and the season of the year during which the crop cycle develops. The lowest seasonal irrigation volumes were recorded for very short cycle crops (72 days) – including summer crops like shell bean - and also for those crops which crop cycles develop during seasons with a low evaporative demand of the atmosphere, as it happens in the case of maize grown as a forage crop. Conversely, the heaviest seasonal volumes were recorded for longer-cycle crops (more than 150 days) growing during the months when the evaporative demand increases, such as spring sown sugar beet (Fig. 14).

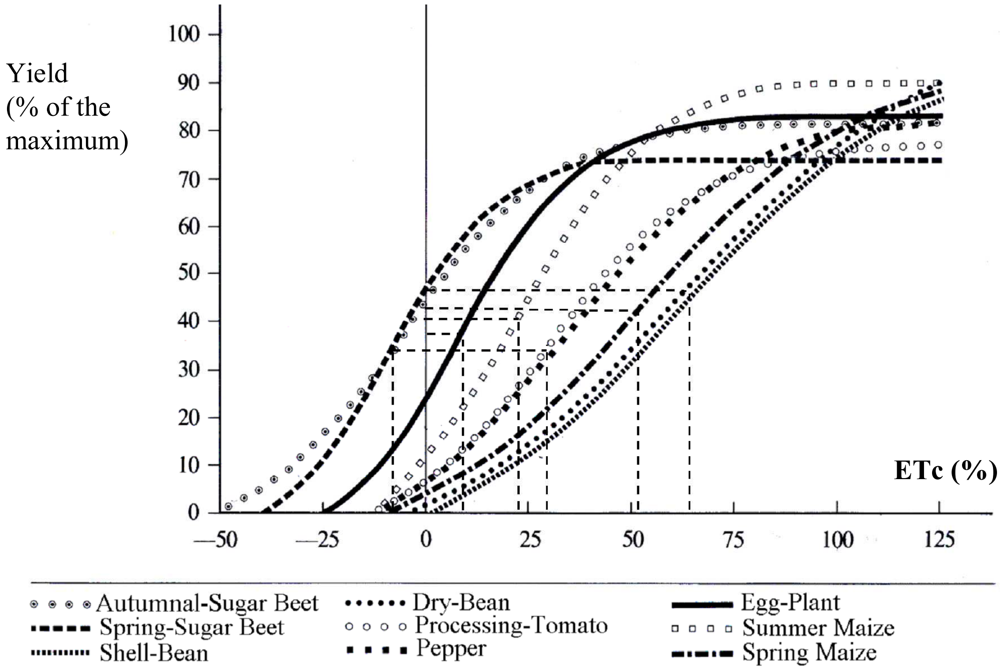

Fig. 12. Yield of some herbaceous crops as a function of seasonal water volumes expressed as percentage of estimated ETc with the indication of the flex points of different curves (adapted after Venezian Scarascia et al., 1987).

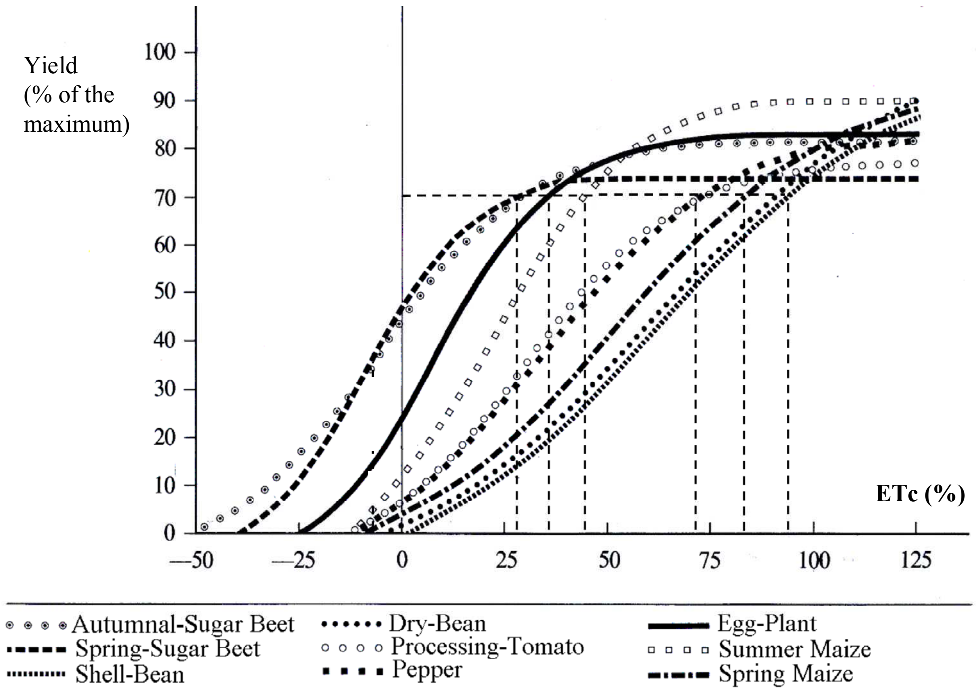

Fig. 13. Yield of some herbaceous crops in relation to the seasonal irrigation volumes, with the indication of the seasonal irrigation volumes corresponding to the 70% of the maximum yield (adapted after Venezian Scarascia et al., 1987).

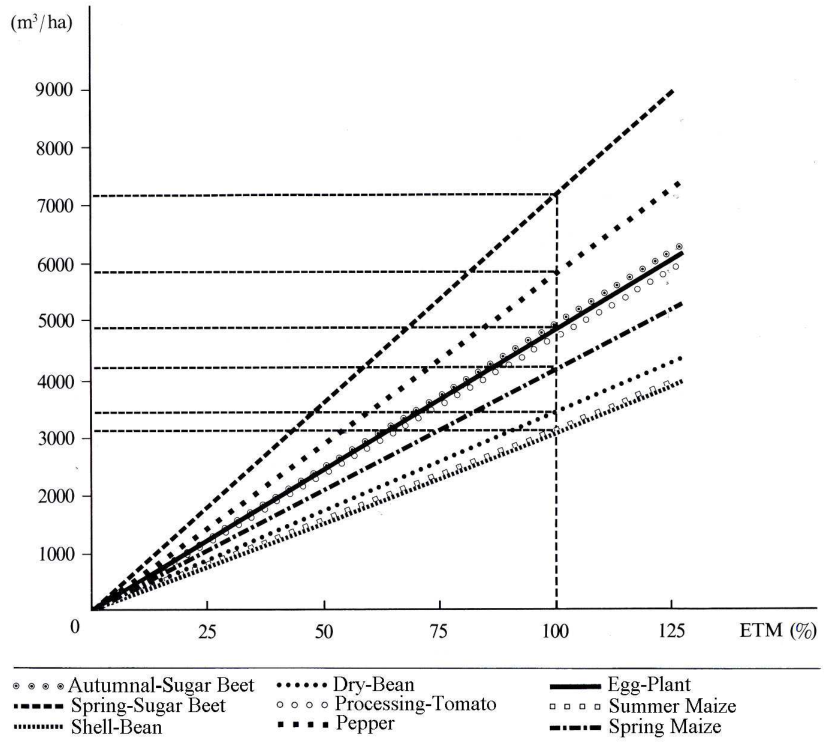

Fig. 14. Seasonal irrigation volumes of several horticultural crops in relation to the adopted irrigation regime (adapted after Venezian Scarascia et al., 1987).

In conclusion, a very short cycle of crops makes the best use of irrigation water, irrespective of the season of their growth cycle. Similar inference can be drown for crops sown in autumn or early in spring as they make a good use of natural available water resources. When irrigation water is limited and crops that respond rapidly to irrigation (such as sugar beet and maize grown as main crop) are grown simultaneously to crops that respond gradually (such as pepper, tomato, maize grown as forage crop and shell bean), then, the latter group of crops should be irrigated more than the former.

Deficit irrigation strategies

A particular attention has been given to the studies on regulated water stress based on different crop sensitivity to water supply during various phenological stages and on the crop physiological mechanisms of response to water stress. Deficit irrigation techniques have demonstrated a high validity for water saving in the case of various tree crops without particular negative effects on crop production and farmer's income in both Southern and Northern Italy. However, the technique of controlled deficit irrigation can be applied on the already grown trees since the deficit irrigation can provoke negative impacts (later start of production and overall decrease of productivity) if applied during the first three-four years since plantation.

A synthesis of results of the numerous deficit irrigation experiments carried out in Emilia-Romagna (Northern Italy) on peach tree is given in Fig. 15 subdividing the vegetative cycle of peach tree in 4 principal phases:

- phase 1 – from the start of flowering to the formation of small fruits (of 3-4 cm of diameter);
- phase 2 – from the end of the previous phase until the hardening of the pit;
- phase 3 – from the hardening of the pit until the harvesting;
- phase 4 – from the harvesting until the fall of the leaves.

Figure 15 illustrates that the water stress was induced during the phases 2 and 4. A controlled water stress during the phase 2 does not favour development of shoots which reduces the competition for assimilates between the shoots and fruits; similarly, during the phase 4 it reduces vegetative growth and favours the induction of buds to flowers and fruit leader. The overall reductions of irrigation volumes in respect to full irrigation in a normal year under Emilia-Romagna climatic conditions were estimated between 56 and 68% for the medium early and early cultivars and clay soil and between 20 and 23% for the late cultivars without significant differences related to the soil type (Table 6). The results (Fig. 16) indicate that the regulated deficit irrigation technique has increased crop production in respect to traditional irrigation, has maintained the average weight of fruits, has improved the flowering in the successive years and has reduced the necessity for pruning. Similar results have been obtained also in the experiments on peach and nectarine trees carried out under Southern Italy climatic conditions.

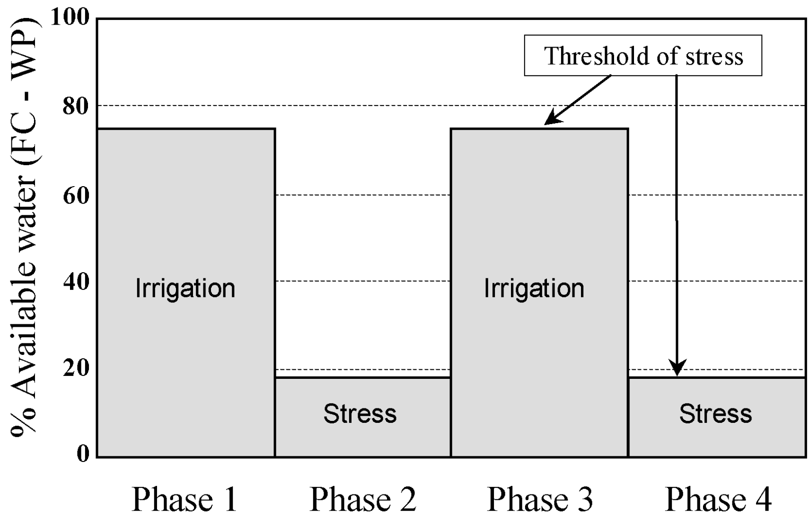

Fig. 15. Graphical presentation of the stress thresholds to apply on the peach tree under regulated deficit irrigation treatments (adapted after Mannini, 2004)

Table 6. Percentage of seasonal irrigation volumes saved by controlled water stress on peach in respect to normal irrigation regime (Source: Mannini, 2004)

SOIL	Interspace between rows cultivated			Interspace between rows grassy		
	Early cultivars	Medium early cultivars	Late cultivars	Early cultivars	Medium early cultivars	Late cultivars
Sandy	44	38	20	38	34	20
Loam	58	59	20	52	46	23
Clay	68	56	22	60	51	23

The studies of regulated deficit irrigation has been done also on the herbaceous crops in Southern Italy giving different results in respect to those obtained with orchards. In fact, serious drops of production can be observed even in the cases of limited water reduction during the non-critical phenological stages.

Four years of investigation on the regulated deficit irrigation of maize have been done in Southern Italy (Policoro, Basilicata). The experiment was based on suspending one or two irrigations or doubling irrigation volumes in correspondence to different phenological phases (a – when crop has achieved 1 m height, during the crop growing stage; b – at the tassel emission; c – at beginning of the milky stage; d – at the beginning of the waxy stage). The results have shown that all phenological phases demonstrated certain sensitivity to water stress. Anyway, the most sensitive phase almost always corresponded to the tassel emission and, in particularly dry years, to the phase of intensive crop growth. These results indicated that maize is not well adaptable to the Southern Italy climatic conditions where the spring-summer periods are characterized with scarce precipitations and very high evapotranspiration demand. Consequently, maize should be fully irrigated under these climatic conditions. In fact, maize is rarely cultivated under Southern Italy climatic conditions because this crop is very sensitive to water stress and it should not be grown under deficit irrigation practices.

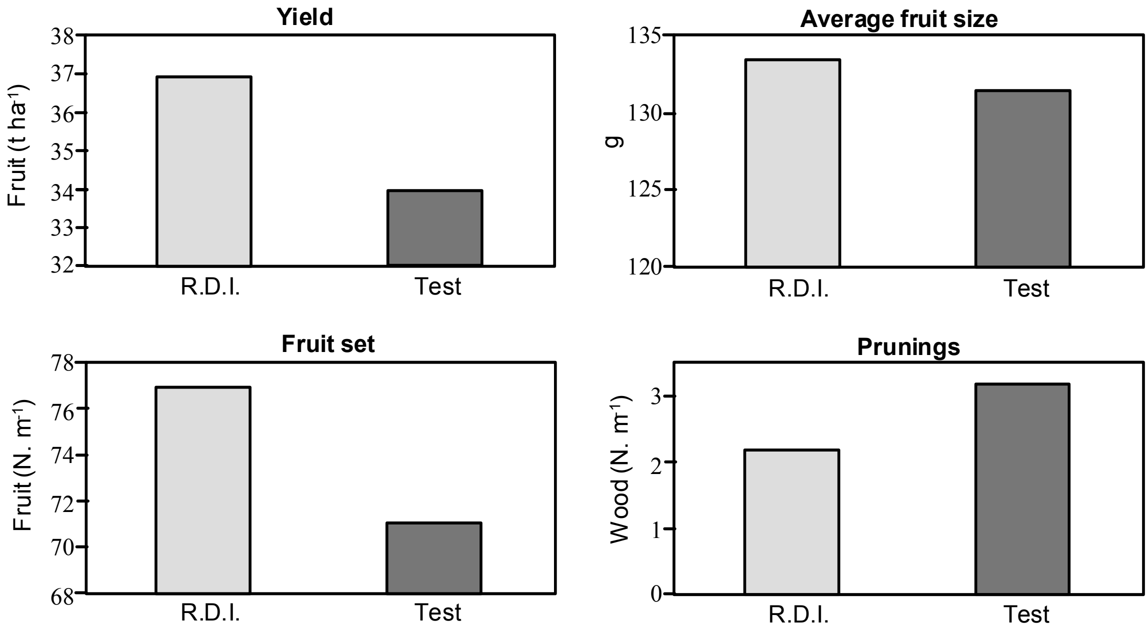

Fig. 16. Productive and vegetative effects of water stress on peach tree grown as an espalier (by Chalmers) (adapted after Mannini, 2004).

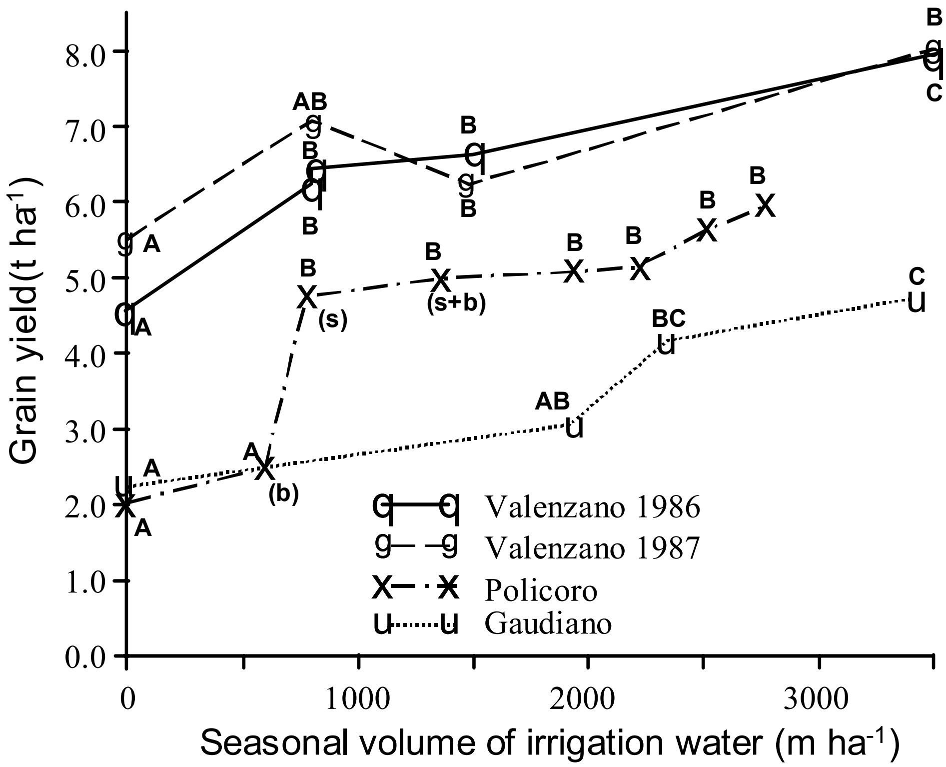

Fig. 17. Variations of wheat production under different irrigation treatments. The values assigned with the same letter are not significantly different at 0.01 P according to the Newman-Keuls method. (s) – irrigation only at the sowing; (b) – irrigation only at the booting phase; (s+b) – irrigation at sowing and booting phase.

Finally, in the Southern Italy environments, characterized with high precipitation variability which contributes to the instability of agricultural production even of non-irrigated autumn-spring crops (e.g. wheat), there is a frequent application of supplemental irrigation strategies. This helps in stabilizing agricultural production and improving the water use efficiency of precipitation. Several experiments were carried out in Southern Italy on different wheat cultivars grown in deep soils with water availability of 8.4% of dry soil weight (Gaudiano di Lavello – Basilicata) and of 16.6% of dry soil weight (Policoro – Basilicata) and on shallow soil with water availability of 13.0% of dry soil weight (Valenzano – Puglia). The irrigation strategies included the application of water only during the critical phenological stages (at sowing, at the booting phase and at both sowing and booting phase) and during the whole growing cycle with different levels of limitations. The results of these investigations, shown in Fig. 17, indicated that in particularly dry years one irrigation immediately after sowing (example of Policoro in 1986) with water volume of 770 m^3 ha^{-1} can be sufficient to increase production from 2.0 t ha^{-1} to 4.7 t ha^{-1}, while any additional irrigation did not contribute to further augment of grain yield.

STUDIES ON CROP WATER REQUIREMENTS

The researches on crop yield response to irrigation water required the intensification of the studies on the adaptability of empirical methods for the estimation of reference evapotranspiration to different Italian agro-climatic conditions. These studies were necessary in order to estimate and/or foreseen better crop water requirements for both the irrigation management purposes and the realization of irrigation projects. A particular attention has been given to the methods indicated in both the FAO Irrigation and Drainage paper n°24 (Dorenboos and Pruit, 1977, 1987) and in n°56 (Allen et al., 1998).

For the implementation of studies on crop water requirements, in many Italian regions have been constructed the lysimeters of different characteristics by means of both functionality and size. Type, dimensions and number of lysimeters used in various Italian locations are reported in Table 7, while the spatial distribution of the lysimetric stations is indicated in Fig. 18.

Table 7. Type, dimensions and number of lysimeters used in various Italian locations

Type	Surface area (m^2)	Depth (m)	Presence of guard	Underground(U) or Aboveground (A)	Location and number
I) DRAINAGE					
a) groundwater (70-110)	2x2 = 4	1,30	yes	U	Policoro (6) Metaponto (2) Foggia (4) S. Prospero (4) Guiglia (4) Gela (2) Roma
	2x2 = 4.	2,20	yes	U	Cadriano (2)
	2x2 = 4	1,00	yes	U	Polignano (2) Cadriano (2)
	1,25x1,25 = 1,56	1,40	no	A	Pisa (6)
	1x1 = 1	1,50	yes	U	Legnaro (20)
b) free percolation	2x2 = 4	0,50	no	U	Vitulazio (16)
	2,75 m*; 5,94	1,50	yes	U	Sassari (4) **
2) WEIGHING					
a) mechanical	2x2 = 4	1,30	yes	U	Policoro (2) Rutigliano (1) Gaudiano (1) Villa d'Agri (1)
b) with loading cells	3 m**; 7,07	2,15	yes	U	Campo Volturno (4)

* circular
** for tree crops

Water consumption have been valued with drainage lysimeters by using the water balance equation weekly or 10-days period, whereas it was measured with weighing lysimeters as a difference in weight at the beginning and the end of the period under consideration, generally on a daily basis, taking into account natural hydrological inputs, irrigation, and the quantities of drained water (Tarantino and Onofrii, 1991).

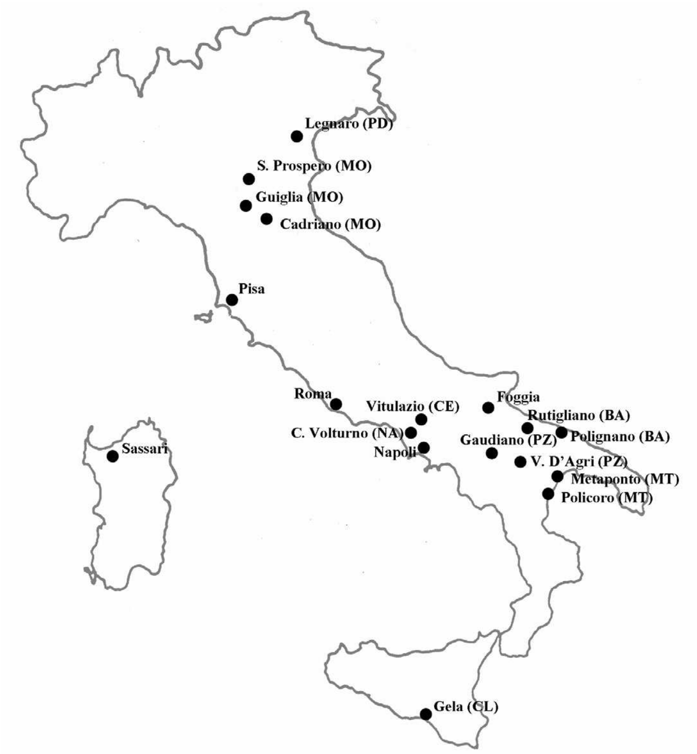

Fig. 18. Location of some lysimeter stations in Italy

Lysimeters have not been used only for the research on the adaptability of different methods for reference evapotranspiration estimates under various Italian climatic conditions, but also for the studies on crop water requirements, or maximum crop evapotranspiration (ETc), during the growing cycle of numerous herbaceous crops and some tree-crop species. Daily values of ETc measured for various species have been rationed with the equivalent values of class "A" pan evaporation (E) and/or reference evapotranspiration (ETo), calculated with different methods, in order to obtain corresponding crop coefficients:

$$Kc' = \frac{ETc}{E}$$

$$Kc = \frac{ETc}{ETo}$$

The research locations, corresponding cultivars, years of experiments and some growing and productive information are given in Table 8, the reference parameters used for the calculation of crop coefficients (Kc' and Kc) are reported in Table 9, while in Tables 10 and 11 are presented the crop coefficient values (Kc') related to the class "A" pan evaporation (E). In Figures 19, 20 21 is given the variation of Kc (derived from the ratio between the measured ETc and ETo calculated by the Penman-Monteith equation) for some vegetables (muskmelon and eggplant) cultivated under plastic mulches and without them.

Data reported in Table 10 confirmed that the lowest Kc' values, in the range between 0.1 and 0.6, were observed during the initial growing stage, about 30 days after sowing or planting, when the water losses are prevalently due to soil evaporation. The highest values, between 0.85 and 1.50, were observed when the full crop development has achieved and LAI reached the maximum values, i.e. when the water is almost exclusively consumed in the process of transpiration. The Kc' values were decreasing gradually with the approximation of the end of crop growing cycle, in relation to the vegetative state of the crops at harvesting.

Variability of Kc' values during the initial crop growing stage is related to the humidity of the superficial soil layers. In fact, the highest value (0.62) was registered for wheat, an autumnal sowing crop, when the frequency of precipitation was relatively high and ETo was limited, and, therefore, the soil water content in the superficial soil layers was pretty elevated. In fact, is well-noted that direct water losses by soil evaporation increases with the increase of humidity of superficial soil layers.

The Kc' values resulted substantially different in the Northern Italy environments, where the crop growing cycles tend to make longer, in respect to the Southern Italy, where they are shorter: evident examples are spring sowing tomato and sugar beet (Table 10). Notable differences are also observed on the values of Kc' of maize and sorghum grown under different climatic conditions: higher values were in the Northern Italy (locations of S. Prospero and Guiglia) and lower in the Southern Italy (locations of Policoro and Foggia), lower values for the early cultivars (FAO class 200-400), higher values for the hybrids with longer growing cycle (FAO class 600-700).

Table 8. Crop growing parameters of some experiments on Kc carried out in Italy

Crop	Location	Cultivar	Years of experiment	Sowing date (2)	harvesting	Plant density	Yield (t/ha)	Average ETc (mm)
On-field growing Herbaceous crops								
Sugarbeet								
	Policoro	Monohill	1975-76	March	September	10	96.5	669
	Cadriano	Monogen	1981	March	August	10	117.5	652
Artichoke	Policoro	Locale di mola	1974-75-76	August	Decem. April	1	11.4	540
	Polignano	Locale di mola	1974-75-76-77	August	Decem. April	1	29.3	557
Cabbage Broccolo								
Summer cultivar	Policoro	Green duke	1977	September	December	6	13.6	120
Winter cultivar	Policoro	Clipper	1986-87	July	Sept. November	4	16.4	374
Cetrioli	Policoro	Pioner e Bounty	1977-78-79	July	October	16	17.0	233
Alfalfa (1)	S.Prospero	Bresaola	1970-79-80-81-82	April	October	NR	20.8 (1)	939
	Guiglia	Bresaola	1970-79-00-81-82	April	October	NR	16.9 (1)	692
String bean	Policoro	LIT 551	1977-78-79	April	July	65	14.8	276
Bean (type borlotto)								
Fresh	Policoro	Lingua di fuoco	1984	June	August	44	7.5	432
Dry	Policoro	Lingua di fuoco	1984	June	September	44	3.0	479
Wheat	Policoro	Salapia	1985-86	November	June	49 ears/m^2	6.7	475
Sunflower 1st harvesting	Foggia	Luciole	1981-82	April	August	5.0	3.9	710
	S. Prospero	Luciole	1981-82	April	September	5.1	3.6	571
	Guiglia	Luciole	1981-82	April	September	5.0	3.4	605
Sunflower 2nd harvesting								
after barley	Pisa	Mirage	1986	June	October	6	3.3	537
after wheat	Pisa	Mirage	1986	July	October	6	2.9	452
maize from granella 1st harvesting								
	Policoro	Dekalb XL 304 FAO 200	1974-75-76	April	September	8	10.1	511
	Foggia	Dedalo 95 FAO 400	1976-77	April	September	6	12.0	686
	S. Prospero	Titano FAO 700	1976-77	April	October	6	13.5	589
	Guiglia	Titano FAO 700	1976-77	April	October	6	12.3	587
	Legnaro	Dekalb XL 342 FAO 606	1973-7	May	September	6	10.0	450
Maize 2nd harvesting	Pisa	Leveret 400	1986	June	October	8	13.2	582
	Pisa	Leveret 400	1986	July	October	8	8.6	457
Potato	Legnaro	Bintje	1978-79	March	August	4	50.0	600
Tomato	Policoro	Ventura	1976-77-78	April	September	6	87.0	546
	Legnaro	Roma VF	1977-78	April	September	40	80.0	451
Soya 1st harvesting	S. Prospero	Kig SOY	1983-84-85	May	October	35	3.7	861
	Legnaro	TXR 505	1975-76	May	October	30	4.0	500
	Cadriano	Hodson 78	1984	May	October	40	5.2	618
Soya 2nd harvesting	S. Prospero	Arrok	1984	June	October	35	2.9	420
Sorghum	Policoro	Dekalb XL FAO 200	1977-78	May	October	25	12.7	690
	Foggia	NK 121 FAO 200	1978-79-80	April	September	30	10.6	648
	Guiglia	54BR FAO 200	1983-84-85	May	September	50	8.2	512
	Guiglia	NK 180 FAO 400	1983-84-85	May	September	35	6.9	589
	Guiglia	Savanna 5 FAO 600	1983-84-85	May	September	35	6.2	630
	S. Prospero	Savanna 5 FAO 600	1983-84-05	April	September	35	8.9	624
	Legnaro	NK 180 FAO 400	1974- 75	May	October	16	9.0	465
Spinach	Policoro	Seven R	1978	February	April	64	31.8	153
Muskmelon mulched	Gaudiano	Nabucco	2001-2003	June	August	0.5	39.4	310
Muskmelon non-mulched							26.7	257
Muskmelon mulched	Policoro	Campero	1999	May	August	1.0	30.2	229
Muskmelon non-mulched							27.8	320
Eggplant mulched	Policoro	Tasca	2003	May	July-August	2.0	96.5	720
Eggplant non-mulched							55.6	703
Tree crops								
Orange tree	Sassari	Washington navel	1987	4° year	December	-	-	-
Apricot tree	Ponticelli	Cafona	1981-82-83-84-85	6° year	July-January	400 plants/ha	from 4 to 28	380
Olive tree	Sassari	Tondo di Cagliari	1987	5° year	January	-		
Peach tree	Livorno	-	-	-	-	1600 plants/ha		

[1] Yield of alfalfa refers to the total dry matter of 5 years of experiments obtained from 4-5 cutting per year; average annual consumptions refers to the period May-June.

[2] For tree crops it is intended as the years after planting.

Table 9. Crops and methods used for evaporation measurement and reference evapotranspiration estimates at different locations in Italy

Crops	Locations	Evaporation (E)		Reference evapotranspiration (ETo)								
		Class "A"	Wild	Grass festuca	Blaney-Criddle FAO	Radiat. FAO	Penman FAO	Epan FAO	Turc	Thornthwaite	Penman-Monteith	Other methods
Sugar beet	Policoro	X			X	X	X		X	X		
	Cadriano	X		X						X		
Artichoke	Policoro	X										
	Putignano	X			X				X	X		
Cabbage Broccolo winter	Policoro	X										
Cabbage Broccolo summer	Policoro	X		X								
String bean	Policoro	X										
Bean	Policoro	X		X	X							
Wheat	Policoro	X		X								
Sunflower	Foggia	X		X	X	X	X					
	S. Prospero	X	X	X	X	X				X		X[1]
	Guiglia	X	X	X	X	X	X			X		X[1]
	Pisa	X						X				
Maize da granella	Policoro	X			X	X	X		X	X		
	Foggia	X		X	X	X	X					
	S. Prospero	X		X	X	X	X			X		
	Guiglia	X		X	X	X	X			X		
	Legnaro	X			X				X	X		X[2]
	Pisa	X						X				
Potato	Legnaro	X			X		X			X		X[2]
Tomato	Poticoro	X			X	X	X		X			
	Legnaro	X			X	X						
Soya	Cadriano	X				X						
	S. Prospero	X		X	X							X[1]
	Legnaro	X			X		X			X		X[1]
	Pisa	X		X				X				
Sorghum da granella	Policoro	X			X				X	X		
	Foggia	X	X		X	X	X					
	Guiglia	X		X	X					X		X[1]
	S. Prospero	X		X	X					X		X[1]
	Legnaro	X			X					X		X[1]
Spinach	Policoro	X										
Eggplant												
Pepper												
Muskmelon mulched and non												
	Gaudiano										X	
	Policoro										X	
Eggplant	Policoro										X	
Apricot tree	Ponticelli	X										
Orange tree	Sassari							X				
Olive tree	Sassari							X				
Peach tree	Livorno							X				

[1] Formula of Tombesi-Lauciani.
[2] Formula of Blaney-Morin, Hannon, Hargreaves, Hedke, Ivanov, Helse, Loury-Jensen.

Table 10. Measured Kc' values (ETc/E ratio) of some crops grown under different conditions in Italy

Crop	Type of crop	Location	Days after sowing or planting																							
			10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
Sugarbeet	Spring	Policoro			0.28	0.40	0.49	0.60	0.72	0.81	0.90	0.97	1.01	1.03	1.02	1.00	0.94	0.84	0.68							
		Cadriano				0.24	0.28	0.32	0.38	0.46	0.54	0.63	0.70	0.78	0.86	0.91	0.96	1.00	1.05	1.08						
Artichoke (1)		Policoro	0.44	0.52	0.61	0.68	0.75	0.82	0.88	0.93	0.97	1.02	1.05	1.07	1.08	1.07	1.06	1.04	1.00	0.96	0.90	0.85	0.78	0.70	0.65	
		Polignano		.		0.73	0.81	0.88	0.93	0.99	1.03	1.07	1.10	1.12	1.15	1.20	1.20	1.15	1.09	1.02	0.92	0.88	0.80	0.75	0.70	0.65
Cabbage Broccolo (2)	Winter	Policoro	0.31	0.34	0.40	0.50	0.70	0.86	0.95	0.95	0.94															
	Summer	Policoro	0.37	0.42	0.45	0.67	0.71	0.84	0.87	0.86	0.82	0.80														
Cetriolo		Policoro	0.28	0.45	0.62	0.98	0.90	0.70																		
String bean		Policoro	0.36	0.54	0.70	0.82	0.94	0.88	0.84																	
Bean		Policoro	0.60	0.51	0.53	0.70	0.82	0.86	0.83	0.70	0.43	0.25														
Wheat		Policoro	0.62	0.62	0.64	0.66	0.68	0.74	0.80	0.85	0.88	0.92	0.95	0.95	0.95	0.90	0.77	0.60	0.57	0.38	0.28					
Sunflower	1st harvesting	Foggia	0.30	0.40	0.53	0.64	0.75	0.87	1.00	1.16	1.25	1.25	1.10	0.95	0.50											
		Guiglia	0.25	0.28	0.32	0.50	0.77	1.00	1.20	1.50	1.55	1.40	1.20	1.00	0.50											
		S. Prospero	0.15	0.20	0.38	0.60	0.90	1.20	1.45	1.50	1.20	0.90	0.60	0.50	0.40											
	2nd harvest. after barley	Pisa	0.48	0.64	0.86	1.08	1.36	1.46	1.46	1.38	1.30	0.92	0.72	0.68												
	2nd harvest. after wheat	Pisa	0.56	0.69	0.84	1.04	1.24	1.36	1.38	1.20	1.00	0.76	0.60													
Maize	1st harvesting	Policoro	0.38	0.42	0.51	0.70	0.87	0.98	1.03	1.00	0.93	0.82	0.71	0.56	0.45											
		Foggia	0.41	0.47	0.60	0.80	0.95	1.06	1.14	1.14	1.07	0.96	0.85	0.78	0.55											
		S. Prospero	.	.		0.40	0.70	1.00	1.20	1.27	1.28	1.25	1.20	1.18	1.05	1.00										
		Guiglia			0.15	0.36	0.60	0.85	1.02	1.20	1.30	1.35	1.34	1.26	1.10	0.80	0.48									
		Legnaro	0.40	0.43	0.48	0.57	0.67	0.80	0.91	1.00	1.05	1.07	1.01	0.90	0.75											
	2nd harvest. after barley	Pisa	0.54	0.52	0.64	0.85	1.15	1.40	1.60	1.68	1.64	1.46	1.36	1.40												
	2nd harvest. after wheat	Pisa	0.52	0.58	0.70	0.86	1.04	1.19	1.30	.1.34	1.31	1.30	1.40													
Potato		Legnaro	.			0.70	0.70	0.72	0.79	0.87	0.93	0.95	0.95	0.90	0.81	0.71										
Tomato		Policoro	0.35	0.40	0.45	0.55	0.80	0.99	1.07	1.10	1.09	1.01	0.90	0.78	0.69											
		Legnaro	.	0.41	0.42	0.45	0.50	0.55	0.62	0.71	0.82	0.91	1.00	1.08	1.13	1.14	1.14	1.10								
Soya	1st harvesting	Cadriano				0.25	0.47	0.70	0.80	1.00	1.30	1.50	1.45	1.40	1.30											
		Legnaro	0.34	0.40	0.50	0.60	0.74	0.85	0.94	1.10	1.20	1.30	1.35	1.30	1.18	0.98	0.75									
	2nd harvesting	S. Prospero	0.45	0.63	0.92	1.05	1.12	1.15	1.15	1.13	1.00	0.70														
	2nd harvest. after wheat	Pisa	0.50	0.56	0.68	0.94	1.22	1.42	1.47	1.44	1.20	0.90	0.64	.												
Sorghum	1st harvesting early	Policoro	0.46	0.49	0.59	0.71	0.85	0.97	1.04	1.07	1.00	1.00	0.88	0.72	0.55											
	1st harvesting medium	Foggia	0.43	0.47	0.56	0.65	0.77	0.95	1.00	1.00	0.99	0.96	0.92	0.86	0.78											
	1st harvesting early	Guiglia		0.30	0.34	0.45	0.60	0.75	0.85	0.90	0.90	0.85	0.75	0.50												
	1st harvesting medium	Guiglia		0.30	0.34	0.50	0.70	0.90	1.10	1.22	1.15	1.12	0.90	0.75	0.60											
	1st harvesting late	Guiglia		0.30	0.34	0.55	0.73	0.90	0.95	1.10	1.23	1.20	1.10	0.90	0.75											
	1st harvesting late	S. Prospero		0.35	0.45	0.60	0.72	0.85	0.97	1.18	1.24	1.17	0.76	0.63												
	1st harvesting medium	Legnaro	0.30	0.43	0.55	0.67	0.80	0.90	0.95	0.97	0.97	0.95	0.91	0.86	0.80											
Spinach		Policoro	0.38	0.44	0.52	0.61	0.68	0.75	0.82	0.88	0.93	0.98	1.02													

[1] for artichoke, n° of days of the vegetative recover
[2] for these crops, n° of days after planting

Table 11. Crop coefficient values of some tree crops related to the class “A” pan evaporation

Crop	Location	Month							Authors
		Apr	May	June	July	Aug	Sept	Oct	
Apricot tree (cv. Cafona)									
Drip irrigation	Ponticelli (NA)	0.70	0.33	0.55	0.64	0.68	0.73	0.81	Ruggiero, 1986
Sprinkler irrigation	Ponticelli (NA)	0.64	0.52	1.13	0.80	0.80	0.91	0.68	Ruggiero, 1986
Orange tree (cv. Washington navel; 4th year after planting, G.C.I. 20%)	Sassari	-	-	0.17	0.28	0.35	0.38	0.40	Dettori (unpublished data)
Olive tree (tondo di Cagliari; 5th year after planting, G.C.I. 30%)	Sassari	-	-	0.47	0.46	0.51	0.52	0.40	Dettori (unpublished data)
Peach tree (1)	Livorno		0.55	0.81	1.01	1.00			Natali et al., 1984

[1] On-field data.
G.C.I. – Ground Cover Index

In Table 10 is shown that the peak Kc’ values of sunflower were anticipated a) in the case of sunflower intercropping after barley and wheat in respect to the main crop and b) in the case of growing in a valley in respect to hilly area (S. Prospero in respect to Guiglia). Moreover, the Kc’ values of sunflower are higher in the case of cultivation under Northern Italy conditions (Guiglia) in respect to Southern Italy (Foggia). For soya, the peak Kc’ values resulted more anticipated and lower at the second harvesting which is related to the time of sowing and to the local environmental conditions. The peak Kc’ values of some herbaceous crops (such as spinach, potato, bean, cucumber, cabbage, broccoli, wheat and artichoke) were almost always lower than 1.0, except for the artichoke with the values around 1.1.

The Kc’ values of tree crops change slightly during the vegetative cycle, although they can vary notable between the species in relation to the density and the age of plants and applied irrigation method: the Kc’ values are greater in the case of irrigation with sprinkler method than with drip irrigation.

The Kc’ values obtained under Italian climatic conditions result higher than those recommended in the FAO Irrigation and Drainage papers, especially for the herbaceous crops during the full development phase. In fact, the Kc values reported in the FAO document represent the average data from different environmental conditions and cultivars, while the data given in this document refer to the specific environmental conditions, agricultural practices, cultivars and irrigation methods which can notable influence the Kc values.

The Kc values of crops cultivated under plastic mulches (muskmelon and eggplant) have been obtained for the Southern Italy in Lavello (Potenza) and Policoro (Matera). The data obtained for muskmelon in the location of Lavello (Fig. 19) indicate that the growing cycle of mulched crops (Fig. 19a) is shorter than of non-mulched crops (Fig. 19b) and that the Kc values at the beginning of the full development phase (10 days after planting) and immediately after the start of harvesting are greater, while during almost the whole period of harvesting are lower. On the other side, the Kc values of non-mulched crops were higher only during the first 10 days after planting. The higher Kc values of muskmelon grown under plastic mulches during almost the whole growing cycle are related to the greater vegetative development of mulched crops; it is also confirmed by the greater LAI values. However, the mulched crops as had a rapid and anticipated development manifested the symptoms of an earlier senescence of leaves which resulted in a fast reduction of Kc values. Furthermore, these data indicate how the duration of phenological phases of muskmelon is notable shorter than that reported in the FAO Irrigation and Drainage Paper n° 56 (Allen et al., 1998), independently of mulching. Moreover, as it is clearly demonstrated in Figure19, the Kc values obtained at location of Lavello are notably higher than those indicated in the FAO documents.

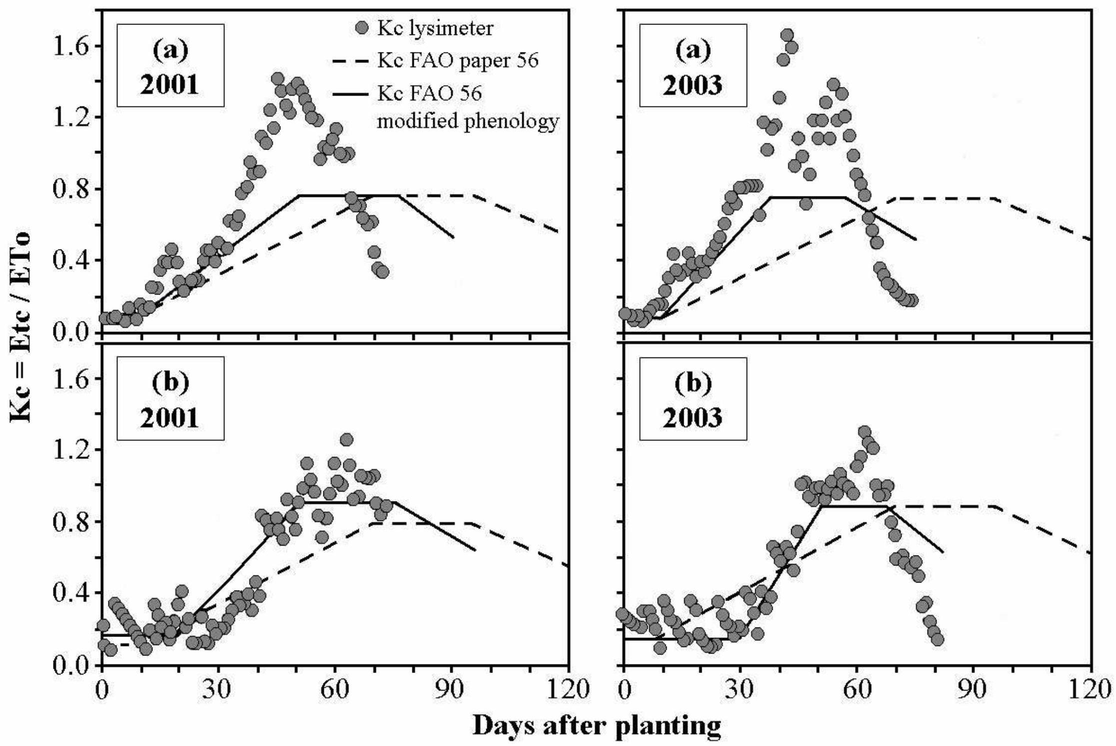

Fig. 19. Relation between estimated and measured by lysimeter crop coefficient Kc during muskmelon cycle cultivated with (a) and without mulch (b) in 2001 and 2003 in Lovello – Southern Italy (from Lovelli et al., 2004).

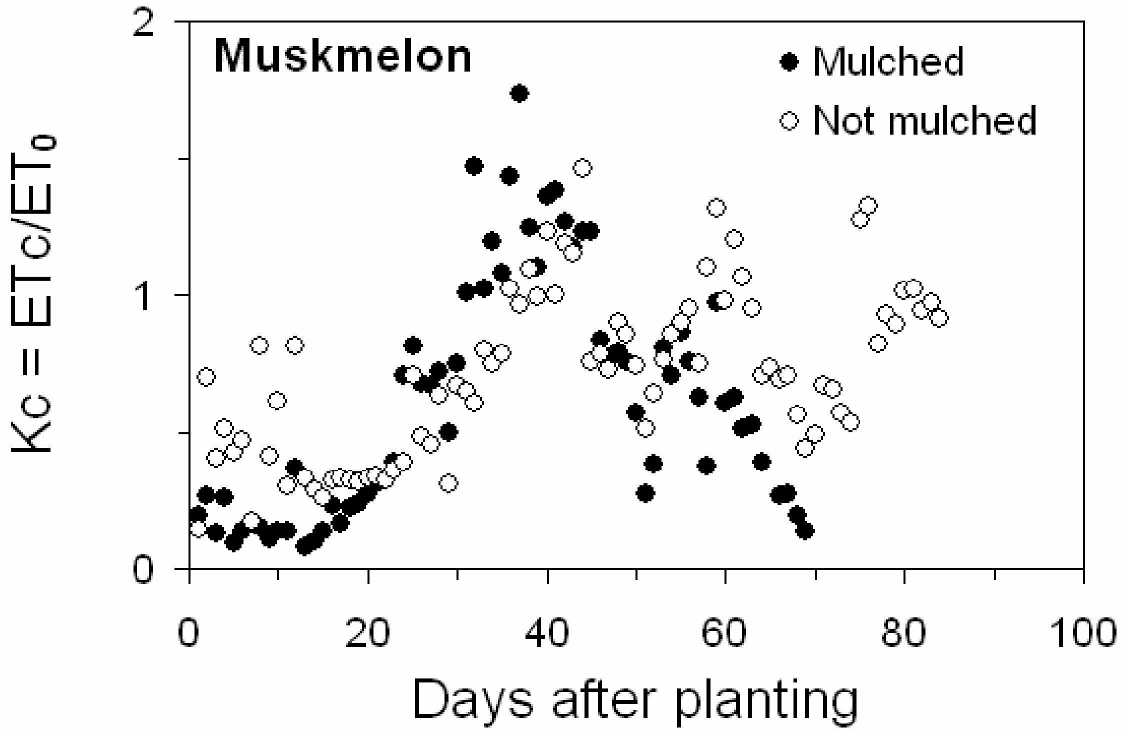

Fig. 20. Crop coefficient data (ETc/ETo ratio) of muskmelon cultivated under mulches and without mulches in Policoro – Southern Italy (from Cantore et al., 2005).

The Kc values obtained by Cantore et al. (2005) on mulched and non-mulched muskmelon (Fig. 20) grown in Policoro (Southern Italy) are very similar to those obtained in Lavello. In fact, the Kc values of muskmelon cultivated under mulches are lower during the initial development phase, in the first 10-15 days after planting, in respect to the non-mulched crops. However, the mulched muskmelon reached more rapidly the full development phase and the Kc values for mulched crops are higher than those for the non-mulched crops. Moreover, the mulched crops have demonstrated faster and more intensive development as compared to the non-mulched crops, followed by a rapid and anticipated senescence of leaves.

In Policoro, the Kc values of mulched and non-mulched eggplant (Yared Tesfagaber, 2004) were very similar to those of muskmelon, although with less remarkable differences. In fact, the Kc values of mulched crops were slightly lower during the first 20 days after the planting and they were slightly higher during the successive growing phase, with the very similar phenological phases (Fig. 21). It is interesting to emphasize that in Policoro, the yield production of both mulched eggplant and muskmelon crops resulted greater than the yield of the non-mulched crops, although the water consumption was slightly higher. In fact, in the case of the cultivars grown under mulches, the yield water use efficiency was higher. Furthermore, the Kc values of these crops grown in South Italy are higher than those reported in the FAO documents which indicates that they are influenced non only by the environment in which they are cultivated but also by the cultivars and adopted agronomic practices.

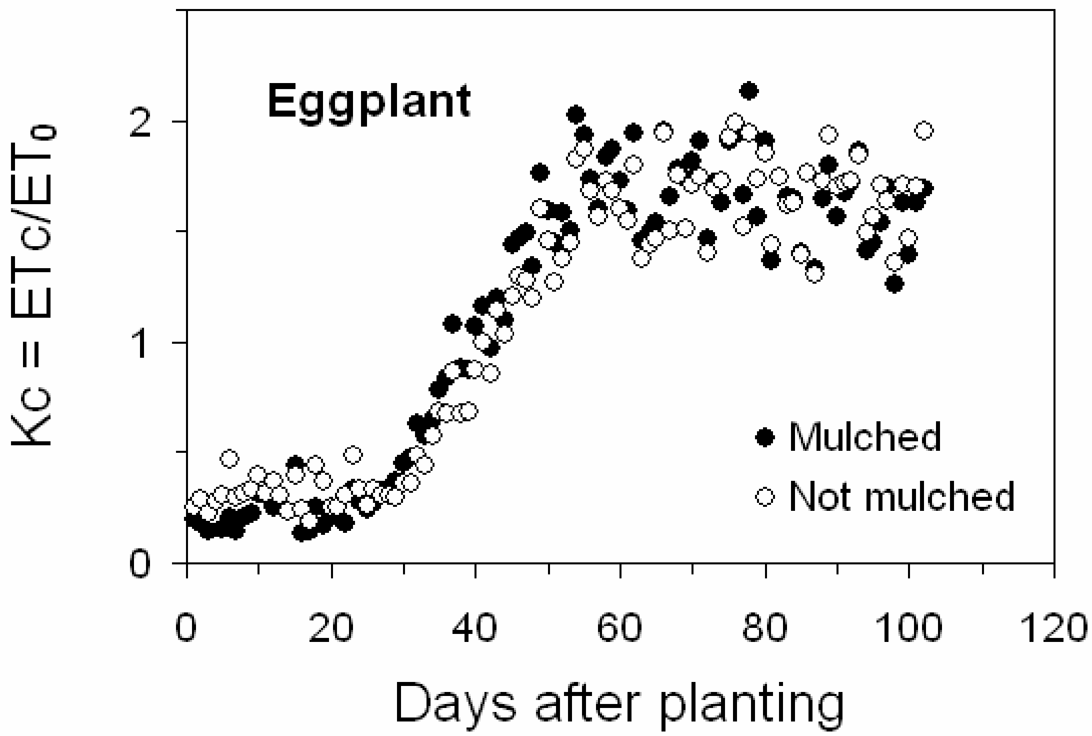

Fig. 21. Crop coefficient data (ETc/ETo ratio) of eggplant cultivated under mulches and without mulches in Policoro – Southern Italy (from Yared Tesfagaber, 2004).

WATER USE EFFICIENCY AND AGRONOMIC PRACTICES FOR IMPROVEMENT

In the agriculture field, the term "Water-Use Efficiency" (WUE) was introduced by Viets in the middle of sixties (Viets, 1962). Since that time, it has been generally used to describe the relationship between the crop growth development and the amount of water consumed, thus Stanhill (1986) called it "physiological water use efficiency". The physiological water use efficiency is more difficult to be conceived as a proper efficiency, as it is not a non-dimensional value and it does not represent an output/input ratio of only one entity. In fact, it describes a process in which water is consumed to produce new entities (e.g. biomass, yield, etc.), and a maximum value attainable by theory does not exist for reference (Monteith, 1984). The physiological efficiency is largely utilized by a wide community of scientists (plant and crop-eco-physiologists, agronomists) and it can be applied at different space- and time-scales as illustrated in Table 12.

Table 12. Major definitions of water use efficiency terms, as reported by Steduto (1996).

Term	Definition	Time scale	Space scale
Photosynthetic WUE	$\frac{A}{T}$	Minutes, hours	Leaf
Carbon Water Flux Ratio (CWFR)	$\frac{\int_{t_0}^{t_f} NCF}{\int_{t_0}^{t_f} ET}$	Hour, day, season	Canopy
Biomass WUE (BWUE)	$\frac{\int_{t_0}^{t_f} biomass}{\int_{t_0}^{t_f} ET}$	Week, season	Plant, canopy
Yield WUE (YWUE)	$biomass\, WUE \times HI$	Season	Plant, canopy

In this paragraph is given the state of art of WUE and agronomic practices to improve WUE in Italian agriculture under field conditions. It is based on the evaluation of the national scientific literature and technical reports especially focusing on the Southern Italian region. Water use efficiency values of many field crops, grown under optimal conditions (Table 13) and submitted to some agronomic techniques, such as irrigation (Table 14), fertilization (Table 15), rotations (Table 16), mulching & early sowing (Table 17) are reported. In all the tables, water use efficiency is calculated as the ratio of the above ground biomass and/or the yield over the amount of water used, determined by different methods, and expressed as kg m^{-3}.

Table 13 shows as, although all the studies refer to no-limiting environmental conditions and to environments with similar weather conditions in Southern Italy, there exist a great variability in the above-ground biomass WUE values among crops. In fact, although it is quite widely acquainted from the literature the superiority of C_4 species to use water more efficiently than C_3 species, due to the higher efficiency to fix CO_2, their values may overlap or overcome those normally found for the C_3, as it occurs in the study of Rubino et al. (1999). In this case the very high values of biomass WUE of sugarbeet (8.0 kg m-3) and rapa (14.0 kg m-3) are explained on the basis of the high net assimilation rate linked to the high translocation efficiency of yielded sucrose to the roots in the former crop and of the very low transpiration rate during the winter season in the latter crop. Nevertheless, it is important to highlight that the biomass WUE value of sugarbeet refers to the total biomass, including the heavy roots, and consequently it is difficultly comparable with the others. In the same study, very high yield WUE values are found for celery, lettuce, rapa, pepper and ascribed to the short crop cycles associated with the very elevated water content (about 85-95%) in the marketable parts of all these crops.

The results obtained in a recent work carried out by Steduto and Albrizio (2005) to compare biomass WUE among different crops (sunflower wheat, chickpea and sorghum) indicate large variability in WUE values, also within the same C_3 group. From this study it is emerged the need to normalize the amount of water evapotranspired by the climate (vapour pressure deficit and/or reference evapotranspiration), in order to compare the WUE values of crops grown in different season and/or year and climatic conditions. Similar conclusions have been reached also by Rubino et al. (1999).

The effect of irrigation practice on both BWUE and YWUE is not obvious, as it is shown in Table 13 for several crops submitted to different water regimes, including deficit irrigation (ID). Irrigation is considered among those strategies allowing to increase the water available for the crops: it may increase growth and, consequently, WUE, provided that the water supplied by irrigation is transpired and not lost as evaporation from the soil, drainage and runoff.

Tarantino et al. (1997) compared BWUE and YWUE among six crops and investigated the effect of four irrigation regimes (rainfed, restitution of 50 and 100% of the crop evapotranspiration, and deficit irrigation) on both BWUE and YWUE, showing the great variability among BWUE values of C_3 species and a different effect of irrigation regimes on the species. Concerning BWUE, it emerged that: (i) among all the treatments, the highest values have been obtained on average by sweet sorghum (a C_4) and durum wheat (a C_3); (ii) among the rainfed treatments of all the crops, the highest value was reached by durum wheat; (iii) among the most watered treatments of all the crops, the highest value was reached by sweet sorghum. Comparing the effect of water supply on YWUE, the best results have been obtained by the restoration of minimum 50% of the crop evapotranspiration in sweet sorghum, kenaf and tomato, while no significant variations have been noticed with increasing irrigation regimes in sunflower and cotton. Nevertheless, for both crops excellent results have been reached in the treatment irrigated by deficit irrigation method. Also durum wheat reached high YWUE values by applying deficit irrigation method, further than without any irrigation. The results achieved in this study are very important to highlight the importance of deficit irrigation practice for some crops grown in environments with water restrictions. In deficit irrigation strategy, in fact, "water is applied to create a certain water deficit, which results in a small yield reduction that is less than the consequent reduction in transpiration, and therefore a gain in WUE per unit water transpired, and possible lower production costs if one or more irrigations can be eliminated" (Kijne et al., 2001).

Table 13. Above-ground Biomass water use efficiency, yield water use efficiency, total water used of field-grown crops under optimal conditions. Method to determine the water used, experimental location and reference are also reported.

Crop	*Above-ground Biomass WUE ($kg\ m^{-3}$)*	*Yield WUE ($kg\ m^{-3}$)*	*Total water used (mm)*	*Determination of water used*	*Location*	*Reference*
Durum wheat	4.0	1.7	450	weighing lysimeter	Policoro, Matera, Basilicata	Rubino et al., 1999
Soybean	-	1.0	477			
Spring sugarbeet	8.0 *	11.0	862			
Artichoke	2.9 **	1.4 **	920			
Rapa	14.0	7.8	180			
Broccoli	4.8	4.2	360			
Pepper	2.0	7.4	536			
Lettuce	-	19.5	161			
Celery	2.3 **	27.4 **	316			
Kenaf	1.8 **		765	weighing lysimeter	Lavello, Potenza, Basilicata	Rivelli et al., 1998
Sunflower	2.6		891	canopy chambers	Valenzano, Bari, Puglia	Steduto & Albrizio, 2005
Grain sorghum	5.7		485			
Durum wheat	4.5		230			
Chickpea	3.0***		320***			
Sweet sorghum	4.8 **		532	pan evaporation & Kc	Metaponto, Matera, Basilicata	Losavio et al., 1999
Kenaf	2.3 **		631			
Jerusalem artichoke	2.6 **		556			

*Roots are included.
**Avg of more years.
*** Incomplete crop cycle.

Table 14. Effect of application of irrigation on above-ground biomass water use efficiency, yield water use efficiency, total water used of field-grown crops. Method to determine the water used, experimental location and reference are also reported. I_0 indicates the control; I_{33}, I_{50}, I_{66}, I_{100}, indicate irrigation treatments with 33, 50, 100 percentage of ETc restoration; I_D indicates treatment supplied by deficit irrigation method.

Crop	*Irrigation treatment*	*Above-ground Biomass WUE ($kg\ m^{-3}$)*	*Yield WUE ($kg\ m^{-3}$)*	*Total water used (mm)*	*Determination of water used*	*Location*	*Reference*
Tomato	I_0	1.0	0.9	213	water balance	Gaudiano, Potenza, Basilicata	Candido et al., 2000
	I_{33}	0.9	0.8	246			
	I_{66}	0.8	0.8	305			
	I_{100}	0.8	0.8	361			
Sweet sorghum	I_0	1.3	2.9	195	pan evaporation & Kc	Gaudiano, Potenza, Basilicata	Tarantino et al., 1997
	I_D	2.5	7.3	547			
	I_{50}	3.0	8.2	564			
	I_{100}	3.4	7.2	826			
Sunflower	I_0	1.2	0.5	217	weighing lysimeter		
	I_D	1.8	0.6	464			
	I_{50}	1.4	0.6	534			
	I_{100}	1.6	0.7	859			
Cotton	I_0	1.8	0.9	176	weight lysimeter		
	I_D	1.8	0.7	438			
	I_{50}	1.6	0.7	421			
	I_{100}	1.7	0.5	546			
Durum Wheat*	I_0	3.8	1.2	281	pan evaporation & Kc		
	I_D	3.2	1.2	339			
	I_{50}	2.6	1.0	454			
	I_{100}	2.2	0.8	641			
Kenaf	I_0	1.2	2.2	281	weighing lysimeter		
	I_D	1.3	4.0	697			
	I_{50}	1.5	4.9	570			
	I_{100}	1.5	5.0	859			
Tomato	I_0	1.6	8.1	115	pan evaporation & Kc		
	I_D	1.5	8.2	359			
	I_{50}	1.3	14.4	369			
	I_{100}	1.3	13.4	635			
Muskmelon	I_0	2.1			water balance	Matera, Basilicata	Rivelli et al., 2004
	I_D	1.7					
	I_{100}	1.1					
Pepper	I_0	1.0					
	I_D	0.9					
	I_{100}	0.6					
Sunflower**	I_0		4.9	435	Seasonal irrigation volume + rainfall	Villa d'Agri, Potenza, Basilicata	Rivelli & Perniola, 1997
	I_{33}		2.4	522			
	I_{66}		2.1	611			
	I_{100}		1.8	700			
No-flood Rice	I_{70}	3.5	0.5	501	water balance	Metaponto, Matera, Basilicata	Losavio et al., 2001
	I_{100}	3.4	0.5	594			
Sunflower***	A		5.9	446	water balance	Pozzallo, Ragusa, Sicilia	Cosentino et al., 1992
	B		8.9	202			
	C		9.1	212			
	D		8.1	276			
	E		7.4	284			
	F		8.4	306			
Cotton****	A		7.8		Seasonal irrigation volume + rainfall	Pozzallo, Ragusa, Sicilia	Foti et al., 1992
	B		9.2				
	C		10.6				
	D		11.6				
	E		9.2				

*avg of 2 years;
**avg of 3 years.

***Letters indicate 6 irrigation treatments, the same amount of water was given at different stages of crop cycle, as follow: A: full-irrigated; B: one irrigation at the head visible stage; C: one irrigation at the beginning of flowering; D: two irrigations at stage of tenth leaf and at the beginning of flowering; E: three irrigations at stage of tenth leaf, at the head visible stage and at the beginning of flowering; F: four irrigations at stages of tenth leaf, at the head visible stage, beginning and end of flowering.
****Letters indicate five irrigation treatments, different numbers of watering were given at different stages of crop cycle.

Contrasting results with respect to Tarantino et al. (1997) have been shown by Candido et al. (2000) on YWUE of tomato crop: in fact, YWUE was highest in the control and lowest in the treatment with 100% evapotranspiration restoration. It is interesting to notice that in the rainfed treatment of experiment of Candido et al. (2000) the amount of water used is about 2-fold higher than in Tarantino et al. (1997), while opposite behaviour occurred in the well-irrigated treatment, although both the studies have been carried out in the same location. It may be due to the very different cultivars used, but the method utilized to determine the amount of water used plays a crucial role too.

In a recent study of Rivelli et al. (2004) the water use efficiency response of two important vegetables (muskmelon and pepper), widely cultivated in the Southern Italy, have been compared, under three different water regimes. The findings have indicated that BWUE was much higher in muskmelon than in pepper in all the compared treatments, demonstrating a greater efficiency of the former crop in using water and its better adaptability to tolerate water deficit conditions.

Table 15. Effect of application of fertilizers on above-ground biomass water use efficiency, yield water use efficiency, total water used of field-grown crops. Method to determine the water used, experimental location and reference are also reported.

Crop		*Above-ground Biomass WUE ($kg\ m^{-3}$)*	*Yield WUE ($kg\ m^{-3}$)*	*Total water used (mm)*	*Determination of water used*	*Location*	*Reference*
Grain sorghum	-		1.6	489	water balance	Foggia, Puglia	Rizzo et al., 1990
	+		1.9	466			
Sugarbeet	-		1.3	639			
	+		1.5	655			
Soybean	-		0.4	309			
	+		0.6	322			
Wheat	-		1.2	298			
	+		0.8	283			
Sunflower	-		3.3		water balance	Viterbo, Lazio	Campiglia & Caporali, 1992
	+		4.2				
Soybean*	-	1.3	0.4	399	water balance	Foggia, Puglia	Rinaldi et al., 1996
	+	1.5	0.5	408			
Sunflower	-	2.0	0.6	538	water balance	Foggia, Puglia	Rinaldi & Rizzo, 1999
	+	2.1	0.6	549			
Sunflower	-	2.2		837	canopy chambers	Valenzano, Bari, Puglia	Steduto & Albrizio, 2005
	+	2.6		891			
Grain sorghum	-	4.4		485			
	+	5.7		510			

*Avg. of 2 years

Both the works carried out by Rivelli and Perniola (1997) and Cosentino et al. (1992) on sunflower, under different water supplies, show how much it is difficult to compare the results among experiments. The YWUE values found in these two experiments on sunflower greatly differentiated from those reported by Tarantino et al. (1997), demonstrating that, for the same crop, YWUE varies over a wide range. Similar consideration is valid for the findings of Foti et al. (1992) on cotton, as compared to those of Tarantino et al. (1997). The causes of such great variability may be ascribed to the application of different methods to determine the total “water used” and to the use of different denominators in the WUE ratio. Many times, indeed, as “water used” by the crop, which represents the denominator of WUE and/or WP ratios, is not considered the amount of water effectively lost by transpiration, but the total amount of water supplied by irrigation plus the rainfall. Of course, this amount is not all necessarily used by the crops for transpiration.

Table 16. Effect of crop rotations and intercropping on above-ground biomass water use efficiency, yield water use efficiency, total water used of field-grown crops. Method to determine the water used, experimental location and reference are also reported.

Crop	*Above-ground Biomass WUE (kg m^{-3})*	*Yield WUE (kg m^{-3})*	*Total water used (mm)*	*Determination of water used*	*Location*	*Reference*
Sorghum-Wheat		1.5	463	water balance	Foggia, Puglia	Rizzo et al., 1990
Sorghum-Wheat+Soybean		1.9	466			
Sugarbeet-Wheat		1.3	691			
Sugarbeet-Wheat+Soybean		1.5	655			
Sunflower-Wheat		0.5	466			
Sunflower-Wheat+Soybean		0.6	487			
Sugarbeet-Wheat+**Soybean**		0.5	327			
Wheat+**Soybean**		0.5	385			
Sunflower-Wheat+**Soybean**		0.5	344			
Sorghum-Wheat+**Soybean**		0.6	323			
Wheat		0.5	266			
Wheat+Soybean		1.2	286			
Wheat+Sorghum		1.2	284			
Sugarbeet-**Wheat**		0.7	242			
Sugarbeet-**Wheat**+Soybean		0.9	260			
Sunflower-**Wheat**		0.8	258			
Sunflower-**Wheat**+Soybean		0.9	267			
Sorghum-**Wheat**		0.7	275			
Sorghum-**Wheat**+Soybean		0.7	258			
Soybean* as main crop	1.0	0.4	861	drainage lysimeters	Modena, Emilia Romagna	Costantini & Melotti, 1991
Soybean* as catch crop after barley	1.3	0.7	420			
Sunflower-Wheat**	2.0	0.5	246	water balance	Foggia, Puglia	Rinaldi & Rizzo, 1999
Sunflower-Wheat+Soybean**	2.1	0.6	239			

*Avg. of 3 years
*Avg. of 12 years

Application of fertilizers may not only result in increased growth but also in increased WUE, as it is shown in Table 15. Fertilizers use may increase slightly the total amount of water used (e.g. Rinaldi et al., 1996; Rinaldi and Rizzo, 1999), but the main effect is to increase early canopy growth so that it shades the surface and therefore reduces the evaporation as a proportion of the total water that is lost (Steduto and Albrizio, 2005). However, the positive effect of fertilizer in increasing both growth and water used, and reducing the evaporation is not universal. In fact, in the study of Rizzo et al. (1990) on wheat and grain sorghum an opposite behaviour in water use was observed between treatments with either low or high application of fertilizers, despite large positive effect of fertilizers on biomass production.

A proper choice of the crop rotation is of fundamental importance for an appropriate use of water, and it affects the length of crop cycle (to be chosen), the efficiency for water uptake, the amount and the quality of crop residuals, the number and type of soil tillage practices. All these factors influence some important physical properties of the soil, such as the porosity, the water retention, the infiltration rate and the evaporation from the bare soil. Consequently, also the WUE and WP result to be strongly affected by the crop rotations, as it is shown in Table 16.

Rizzo et al. (1990) compared YWUE among rotations of wheat cultivated in monoculture, with or without catch crop of soybean or sorghum, and three two-years rotations (sugarbeet-wheat; sunflower-wheat; sorghum-wheat, with or without catch crop of soybean). For wheat the best YWUE was reached in the monoculture with the catch crop of soybean or sorghum. For both sorghum and sugarbeet as main crops, the best results were obtained with soybean as catch crop, while the YWUE of both sunflower and soybean did not significantly differentiate among rotations. Also in the experiment of Rinaldi and Rizzo (1999) all the investigated parameters (BWUE, YWUE and the water used) for sunflower did not significantly varied in the rotation sunflower-wheat as compared to the same rotation, but with soybean as catch crop.

Costantini and Melotti (1991) compared both BWUE and YWUE and the water requirement of soybean cultivated for three years as main crop (spring sowing) and as catch crop (summer sowing). From this study, it is emerged that the amount of water used by soybean as main crop was nearly double in comparison with that used by soybean as catch crop, as consequence of a longer crop cycle and the highest temperatures during the summer months. Soybean as main crop produced more biomass and yield dry matter, as compared to the catch crop, but it showed a lower BWUE and YWUE.

The effect of mulching and early sowing on BWUE, YWUE and the amount of water used is shown in Table 17. Mulching practice is a common way to reduce evaporation from the soil surface, further than decrease the soil temperature. In terms of water conservation, the main effect of mulches is to reduce the rate of evaporation when the soil surface is damp and then to extend the duration of this stage (Gregory, 2004). In a recent study of Cantore et al. (2005) the use of plastic mulches positively affected both biomass and yield WUE of muskmelon; this effect was mainly due to the reduction of about 40% of the evapotranspiration, as both the evaporation from the soil and the length of the crop cycle were strongly reduced in the mulching treatment.

Early sowing of crops is a very important mean of maximizing crop yield and WUE. In fact, increasing the early growth of the canopy when the soil surface is usually damp and the vapour pressure deficit is low has proved effective in increasing WUE. Bonari et al. (1989) found that an early sowing of ten days increased the yield of 54, 35 and 17% for maize, soybean and sunflower, respectively. Hence also biomass and yield water use efficiencies increased significantly in all the crops except of sunflower, although the water use in early sowing was higher than in the normal sowing. Differently, Rivelli and Perniola (1997) dealing with sunflower found that the increase in yield water use efficiency was strictly linked to the decrease in the amount of water used, as effect of a reduced evaporation from the soil.

Table 17. Effect of both mulching and early sowing on above-ground biomass water use efficiency, yield water use efficiency, total water used of field-grown crops. Method to determine the water used, experimental location and reference are also reported.

Crop		*Above-ground Biomass WUE (kg m^{-3})*	*Yield WUE (kg m^{-3})*	*Total water used (mm)*	*Determination of water used*	*Location*	*Reference*
Muskmelon		1.7	8.7	320	weighing lysimeter	Policoro, Matera, Basilicata	Cantore et al., 2005
Mulching Muskmelon		2.8	13.2	229			
Sunflower	Normal sowing		0.7	487	Seasonal irrigation volume + rainfall	Matera, Basilicata	Rivelli & Perniola, 1997
	Early sowing		1.0	385			
Maize	Normal sowing	4.0	1.9	457	Drainage lysimeter with variable water table	Pisa, Toscana	Bonari et al., 1989
	Early sowing	4.5	2.3	582			
Soybean	Normal sowing	2.0	1.0	457			
	Early sowing	2.3	1.2	547			
Sunflower	Normal sowing	1.8	0.6	452			
	Early sowing	1.7	0.6	537			

CONCLUSIONS

During the last 20-30 years, irrigated agriculture has been expanded over the whole Italian territory assuring a more stable agricultural production. In the same period, an important development of various irrigation techniques and agronomic practices have been occurred and followed by numerous research activities especially in two relevant agricultural regions: Puglia region in the South, and Emilia Romagna in the North – in the delta of river Po.

The research activities on water saving practices in irrigation have been conducted mainly in Southern Italy where the crop productivity is strongly influenced with limited precipitation, and irrigation represents a fundamental practice in order to increase and stabilize agricultural production over the years. Accordingly, a particular attention was given to the research related to crop water requirements (estimation of reference evapotranspiration and crop coefficients), crop production functions and application of irrigation methods and practices that improve water use efficiency. A review of published data on crop water requirements revealed that the lowest irrigation volumes were recorded for short crop-cycle crops (e.g. shell bean) while the highest volumes were observed for the long-term crops especially if their growing cycle coincides with the summer season (e.g. spring sugar beet). The presented data on the crop coefficients pointed out a large divergence between the data measured under Italian environmental conditions and those published in the FAO Technical documents. This is specially true in the cases of application of specific agronomic practices (e.g. mulching) when the length of growing season and corresponding Kc values substantially differ from those published in the literature. Therefore, further research is needed to revise the existing data and to match better the modern agricultural practices, new varieties and recently adopted standard method for reference evapotranspiration estimate (FAO Penman-Monteith approach).

This document reports the most important data related to irrigated agriculture in Italy and biomass and yield water use efficiency values found in many experiments carried out mainly in Southern Italy. Inasmuch as a large amount of data on WUE is available, there is a difficulty to compare them. In fact, it has clearly emerged how for each particular crop both BWUE and YWUE vary over a wide range. Possible reasons of it are: (i) the application of different methods to estimate the "water used"; (ii) the use of different nominators/denominators in WUE and WP ratios. In such perspective, more efforts should be done by the scientific community to make data comparable, using standardized procedures and units of measurements. Certainly, a more clear conceptualisation of WUE and WP terms is necessary at national and regional scale.

Agronomic practices to improve WUE rely on the improvement of water use efficiency (WUE) defined in terms of the yield or the biomass per unit area divided by the amount of water used (or transpired) to produce that yield or biomass. Hence, WUE can be enhanced from either crop improvement that increases yield per unit of water transpired (increased transpiration efficiency), or from crop management practices that minimize transpiration relative to other losses, or both. While transpiration efficiency is strictly linked to crop species and it varies among cultivars, there is a wide range of management practices that can reduce the loss of water by evaporation from the soil surface (such us mulching, application of fertilizers, early sowing and the choice of cultivars with rapid early growth) and/or increase the amount of water available to a crop (such as irrigation, fallowing and suitable rotations, weeds control, and the choice of cultivars having deep roots). The success of these practices at specific locations depends on soil properties, crop characteristics and climatic factors.

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