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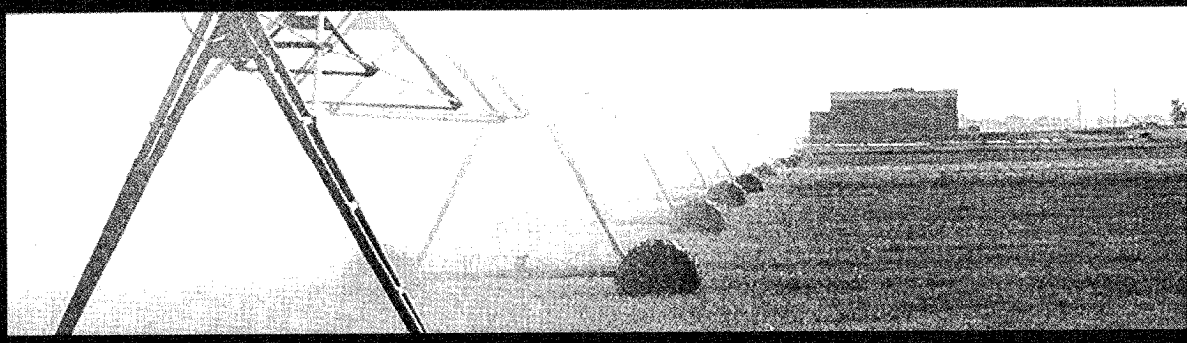

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Research on crop water requirements and water production functions in the context of the Irrigation Programme of the Southern Italy Development Fund (Cassa per lo Sviluppo del Mezzogiorno) (1950-1980)

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More than half a century had passed when the Italian State, by establishing the Southern Italy Development Fund (hereunder the "Fund"), intended to bring to an end the fragmentary policy that had in the past characterized public intervention in Southern Italy. The Fund's intervention, by a coordinated action involving an extraordinary financial commitment to overcome the centuries-old depressed economic conditions of that region, pivoted on a large scale irrigation programme. That programme, thanks mainly to the construction of works designed to gather winter orographic precipitation and to distribute it on the plains, would eliminate the condition of inferiority that agriculture in the South suffered on account of its Mediterranean summer climate (3-6 months very dry, except in the mountainous area inland). This limiting factor is much less strongly felt in Northern continental Italy, especially on the plain on the left of the Po River where the large discharge of the perennial rivers, originating from the persistent snow pack and summer rain in the Alpine arc, has since the XIIth Century made the development of very large collective irrigation systems possible (Grinovero, 1954) (Fig. 1, Tab. I).

Tab. I Geographical areas, natural discharge, and irrigated areas in 1950 (year in which the Fund began its activity). Elaborated from: Various Authors: *I problemi delle acque in Italia*; in Conferenza Nazionale delle Acque, Roma, 1972.

Regions of Italy	*Geographical Areas (thousands of km²)*	*Natural surface and underground annual discharge (billions of m³)*	*Irrigated areas in 1950 (thousands of ha)*
North[1]	120	91	1750
Center[2]	58	32	200
South[3]	123	46	350
Italy	301	169	2300

[1] Piemonte, Valle d'Aosta, Liguria, Lombardia, Trentino-Alto Adige, Veneto, Friuli Venezia Giulia, Emilia-Romagna.

[2] Toscana, Marche, Umbria, Lazio.

[3] Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria and the islands of Sicilia and Sardegna.

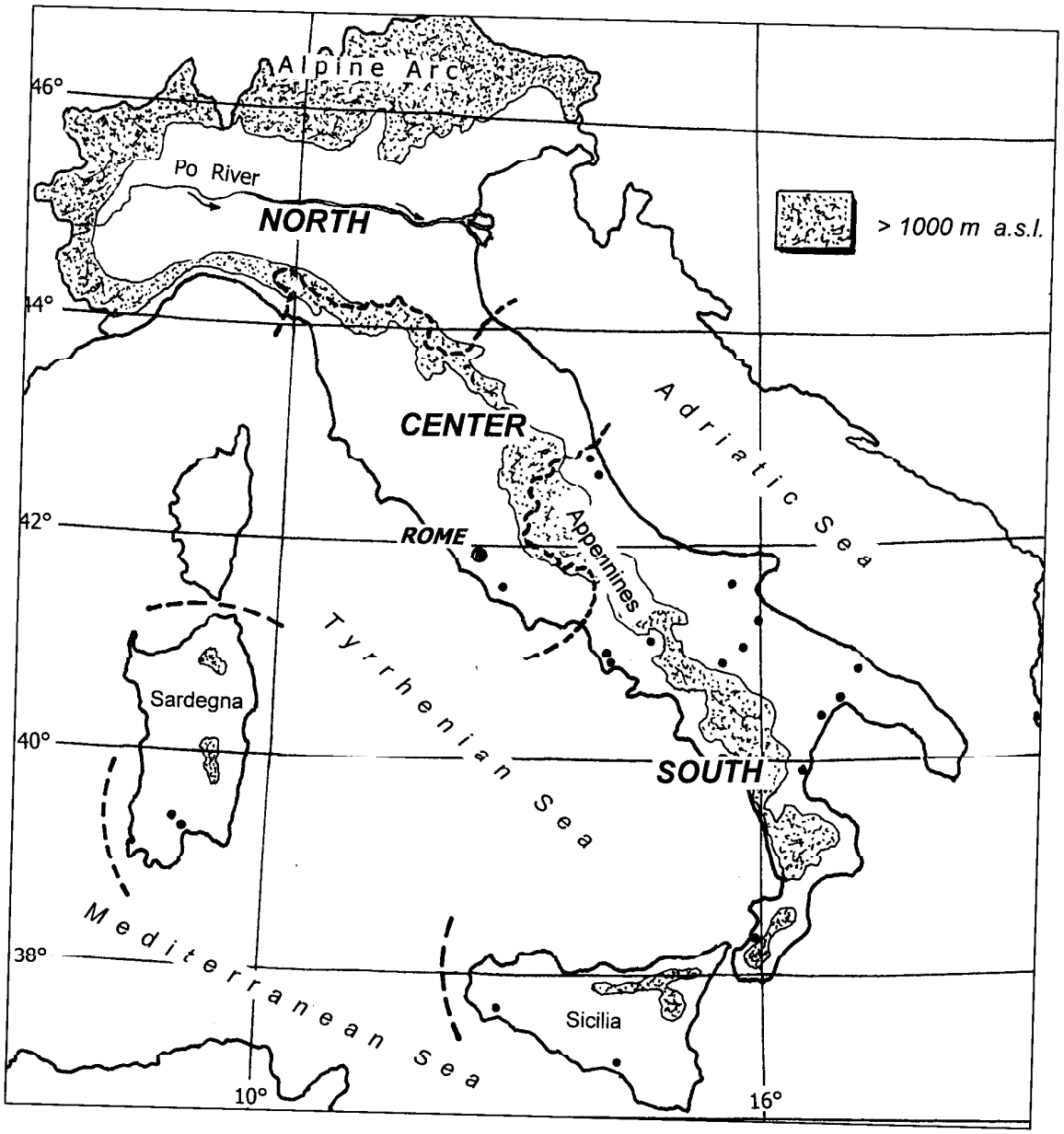

Fig. 1. Geographical areas of Italy. The perimeter of the Funds's intervention coincides roughly with the southern part of the peninsula, Sicilia and Sardegna.

In the first period (1950-1960) the Fund's intervention was concentrated on the construction of general infrastructures (aqueducts, sewers, roads, railways, etc.), on the completion of the old hydraulic reclamation and on the commencement of the irrigation programme (dams, weirs, delivery-repartition-distribution networks, equipping farms, etc.) (Fig. 2).

It should be remembered that, under the Fund's irrigation programme, the Consortiums for Land Reclamation (*Consorzi di Bonifica*) were responsible for conceiving and designing the public irrigation systems and managing them once constructed, while the Fund had first to draw up general directives and subsequently to examine, approve and finance the projects.

This is what was happening at the beginning of the 1950s in the sector of the Fund's intervention for irrigation. The Fund had to start up the most demanding programme ever undertaken in Italy in the complete absence of valid information, because what could be

obtained from the old irrigated areas in semi-arid Southern Italy (vegetable crops in Campania and in Puglia, citrus groves in Calabria and in Sicilia) could not be considered valid because it had never been analysed or supported by sufficiently extensive and rigorous study and experimentation.

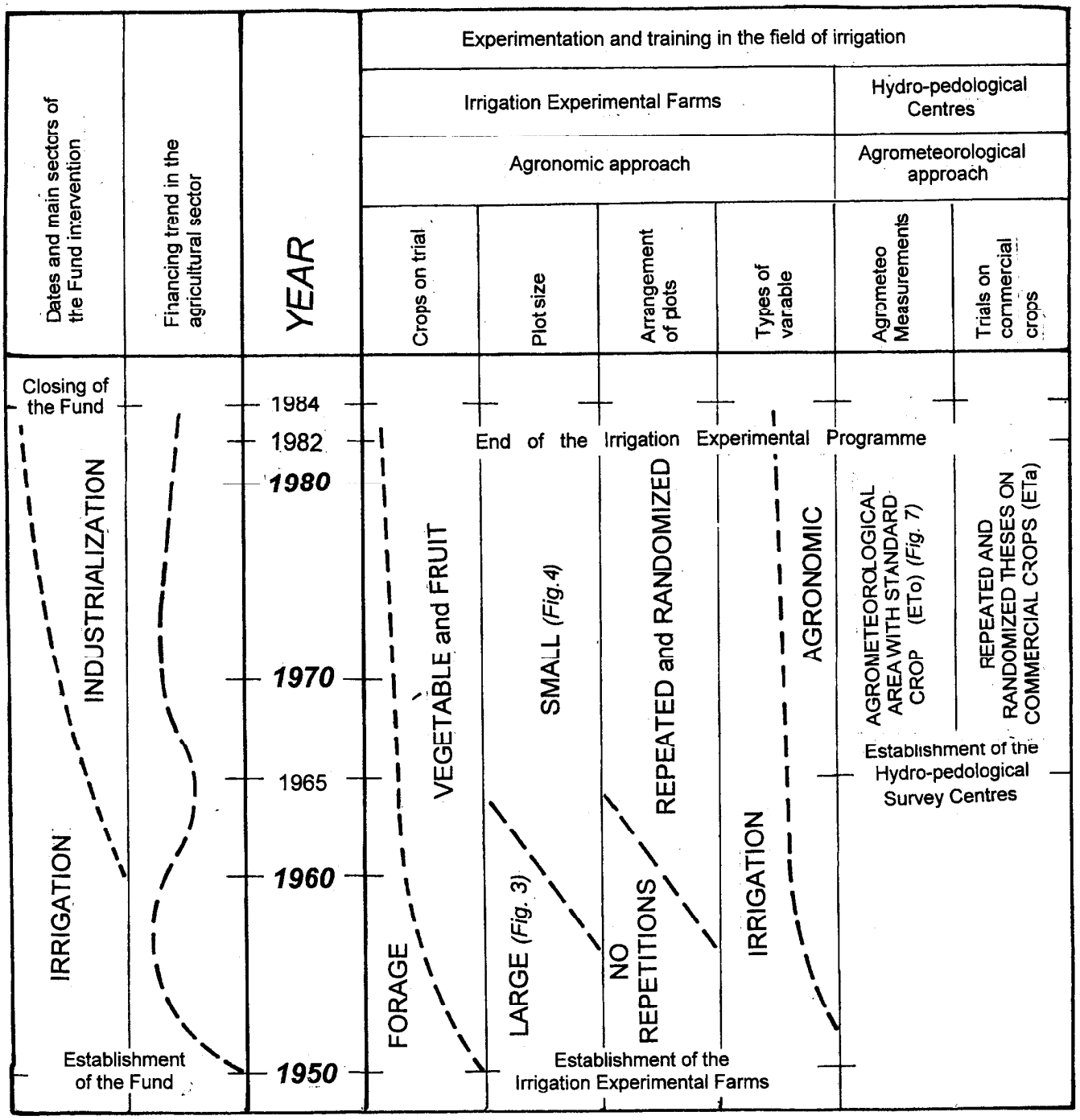

Fig. 2. Main aspects of the Funds's Irrigation Experimental Programme.

As a support to these initiatives the Fund set up a network of Irrigation Experimental Farms on which to conduct research on the crops' reaction to irrigation and on the main irrigation variables to be adopted in planning irrigation schemes and in making the economic evaluation of them.

At that time sprinkler irrigation was not as widely used as it is today (drip irrigation was practically unknown) and irrigation water was distributed at the field by gravity. Some preliminary trials had shown that the stream size and distribution methods at the field used in Northern Italy, where perennial water was abundant and a reduction of losses not absolutely necessary[1], were unsuitable for use in the South.

According to the Italian agricultural policies of that time, the Experimental Farms were set up along the lines of animal husbandry. They were therefore provided with cowsheds and silos, and the crops on trial were usually chosen from among forage crops. Trials were also given a demonstrative function for the farmers who were unaccustomed to irrigation. This demonstrative function as well as the fact that the irrigation variables on trial concerned not only the watering volume and the interval between waterings but also the irrigation methods, made it advisable to adopt experimental plots of the same size as those on normal farms (Fig. 3).

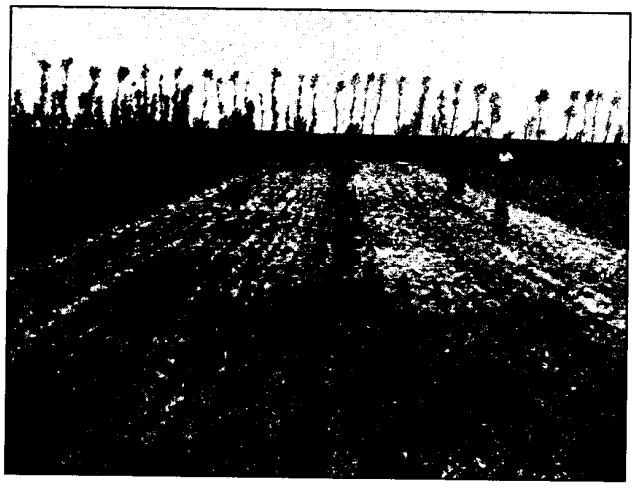

Fig. 3. Border irrigation trial on alfalfa in large plots (Metaponto Experimental Farm, Basilicata).

Trials set up in this way were carried out during almost all of the 1950s. In the final years of the decade other trials of an agronomic nature (date and density of sowing, density of plantings in orchards, varieties, fertilization, etc.) were added to the irrigation variables already on trial.

Consultancy relationships were in the meantime established with academic experts in the fields of agronomy and economics.

The first important guiding information having been acquired, the experimentation criteria were modified in the second decade of activity (1961-1970) in conformity with a more modern statistical methodology. For this purpose the irrigation and agronomic variables compared were combined in different theses repeated at random on smaller plots

[1] Irrigation of rice (a stream size of 20-40 l/sec and a watering volume of 10,000-30,000 m^3/ha) and perennial meadows (*marcite*) for thermal regulation (a stream size of 20-50 l/sec and a watering volume of 200,000-400,000 m^3/ha) is widespread in Northern Italy, particularly in Piemonte and in Lombardia. It should be noted however that the highly permeable coarse deep strata of large areas of those regions cause the large quantities of deeply percolated water to surface in other localities at lower altitude making it available again for irrigation. There has been a drastic reduction of the area under *marcite* in recent times.

(to the extent permitted by the irrigation method) in order to ensure the necessary significance of the comparisons (Fig. 4). The forage crops on trial were gradually replaced by fruit and vegetable crops as a result of the orientation agriculture in the South had been taking in the meantime. The results of the trials, submitted to significance analysis, were used to construct correlation curves between crop yields and variously combined variables (Fig. 5). The trials confirmed in quantitative terms that available water was one of the most important variables on account of its great influence on the yield and therefore on the sizing of the irrigation schemes that were being constructed and on their economic evaluation

Fig. 4. Furrow irrigation trials on vegetable crops in small repeated and randomized bordered plots (Villasor Experimental Farm, Sardegna).

On account of the complexity of the function

$Y = (M, I, P, A)$

in which

Y = crop yield

M = meteorological variables (**rain**, air temperature and humidity, solar radiation, wind velocity, etc.)

I = irrigation variables (**seasonal irrigation water**, volume of watering, interval between waterings, irrigation method, land levelling, etc.)

P = hydro-pedological variables (**capillary contribution**, etc.)

A = agronomic variables (variety, plant density, fertilization, tillage, etc.)

simplified functions were solved

$Y = \mathrm{f}\,(Q)\, M', I', P', A$

in which Q represents available water (rainfall + irrigation + capillary contribution), or the water measured at various progressive sections (diversion, district, farm, plot), the water transpired, the water evapotranspired, etc., while all the other variables - meteorological *M'*, irrigation *I'*, hydro pedological *I'*, and agronomic *A* – were combined in various sets with the characteristics and values typical of the actual situations that were to be studied (Ravelli, 1976). The shapes of the regression curves, at that time concisely defined as "yield/water volume curves", were parabolic, logarithmic, sigmoidal, etc. depending on the crop's response and the extent of the range of the values of the independent variable (for an example of a curve see Ravelli and Leone, 1977; for an analysis of the conditions which the water production curves must satisfy see Vannella and Ravelli, 1978[2]).

In order better to identify the shape of the curves, various doses of water in a wide range of values between the extremes of marked deficit and excess were compared. Such extreme values, while of no operative interest[3], were in fact useful when processing the data to quantify better their negative effect on the crop yield and to identify the type and the shape of the curve which best responded to the simulation of the phenomenon.

The results of the research conducted until 1970 were reported in numerous publications (Barbieri, Ravelli and Melas, 1975; Various Authors, 1975; Ravelli *et al.*, 1987). In commented form many data were presented in the *Giornate di Studio* of the CIGR in 1975 (Cavazza, 1975, 1975a) and, together with data provided by other institutes and universities, in n. II, 6 of *Agricoltura e Ricerca* (Cavazza and Ravelli, 1979) and in the *Atti del convegno su Irrigazione e Ricerca*, organised by the University of Bologna in 1988 (Giovannardi, 1991).

While this agronomic approach, typical of a country such as Italy having a long tradition of irrigation, satisfied on the one hand the need to provide a rapid, concise response to one of the main problems in planning, designing and managing systems, and in applying water to the fields, on the other hand prevented, on account of its empirical nature, the use of the curves in agronomic and meteorological situations different from those in which the trials had been carried out.

At the beginning of the Fund's intervention the area already irrigated amounted to 350,000 ha (see Tab. I). By the end of the 1950s, the Fund's action had made it possible to enlarge some areas that had long since been irrigated and to extend the benefit of water to new users served by the public network for a total area of 80,000 hectares, while the delivery and primary repartition public networks served 220,000 hectares. To this area should be added 120,000 hectares irrigable by water from private sources on autonomous farms (Fig. 6, Tab. II).

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[2] It should be noted that, for a given amount of available water, the yield may vary on account of:
- the different degrees of efficiency of rainfall and water supplied,
- the different yield efficacy of irrigation water on account of the different relationships between volumes and intervals of waterings,
- whether or not waterings correspond to the sensitive growth periods.

Moreover the types of curves adopted must:
- be adaptable to experimental data,
- respect some general requisites of the phenomenon, e.g. no unjustified maximum and minimum, intermediate asymptotes,
- not have too many parameters,
- have parameters which have an agronomic and biological significance,
- accurately estimate certain particularly interesting single points.

[3] Irrigation for thermal regulation and leaching excluded.

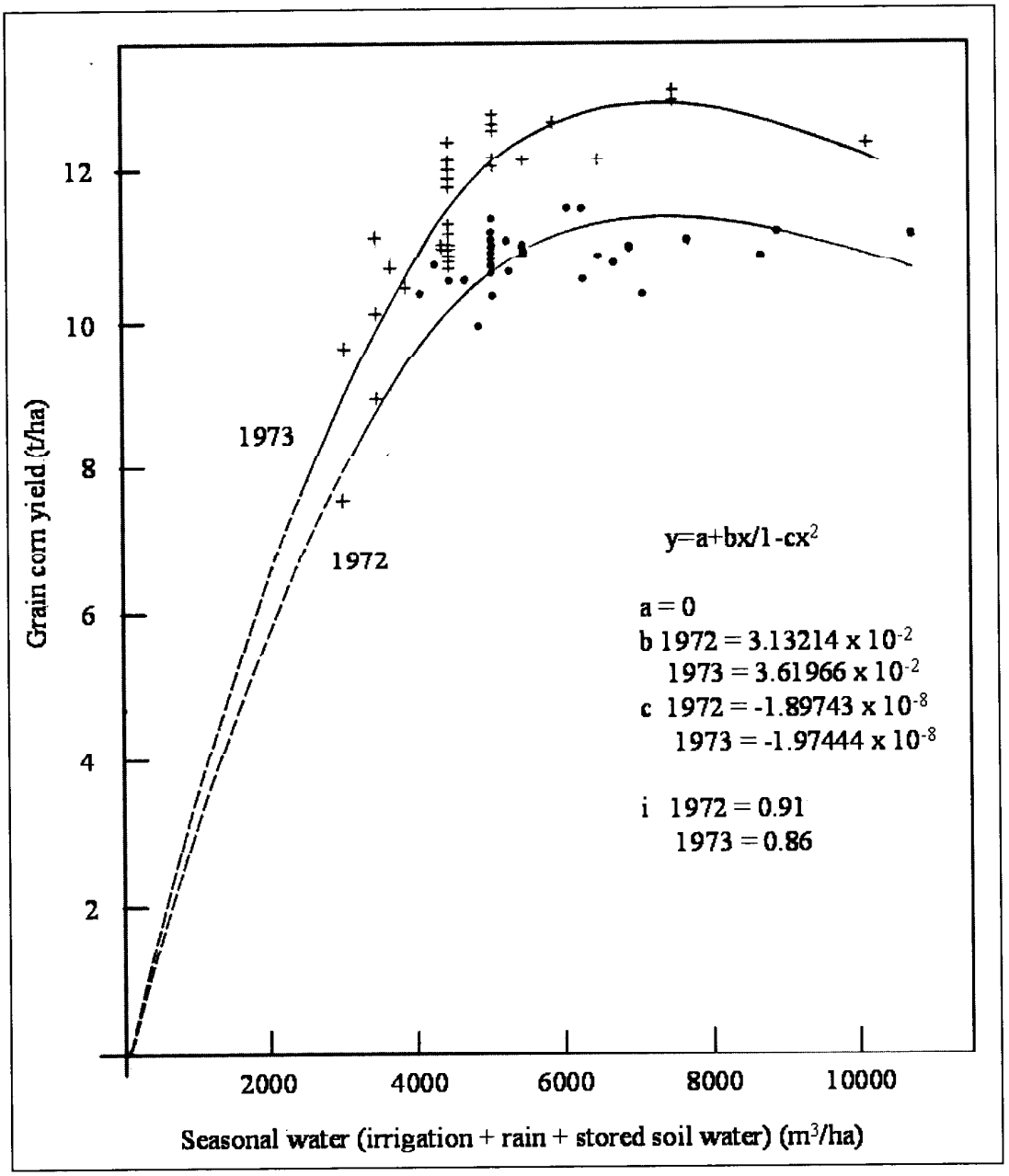

Fig. 5. Yield response curve for corn (grain) to seasonal available water (irrigation + rain + soil water stored) (Volturno Experimental Farm, Campania). Levels of waterings based on: Thesis 1-9 = watering at various combinations of sensitive growth periods; Thesis 10-12 = watering at various soil moisture tensions; Thesis 13-21 = watering at various combinations of cumulated "A" pan evaporation and watering volumes; Thesis 22-30 = watering at various combinations of intervals and volumes; Thesis 31 = no irrigation. From: Ravelli F., Leone A.: *Irrigazione del mais in Agro di Villa Literno (Caserta). Influenza della dotazione idrica stagionale e dei criteri di pilotaggio irriguo sulla produzione di granella;* in Irrigazione, Bologna, 5, 1974. For an example of the use of the function: Arrighi de Casanova J.: *Note sur le rendement économique de l'eau d'irrrigation*; in Irrigazione, Bologna, 3, 1975.

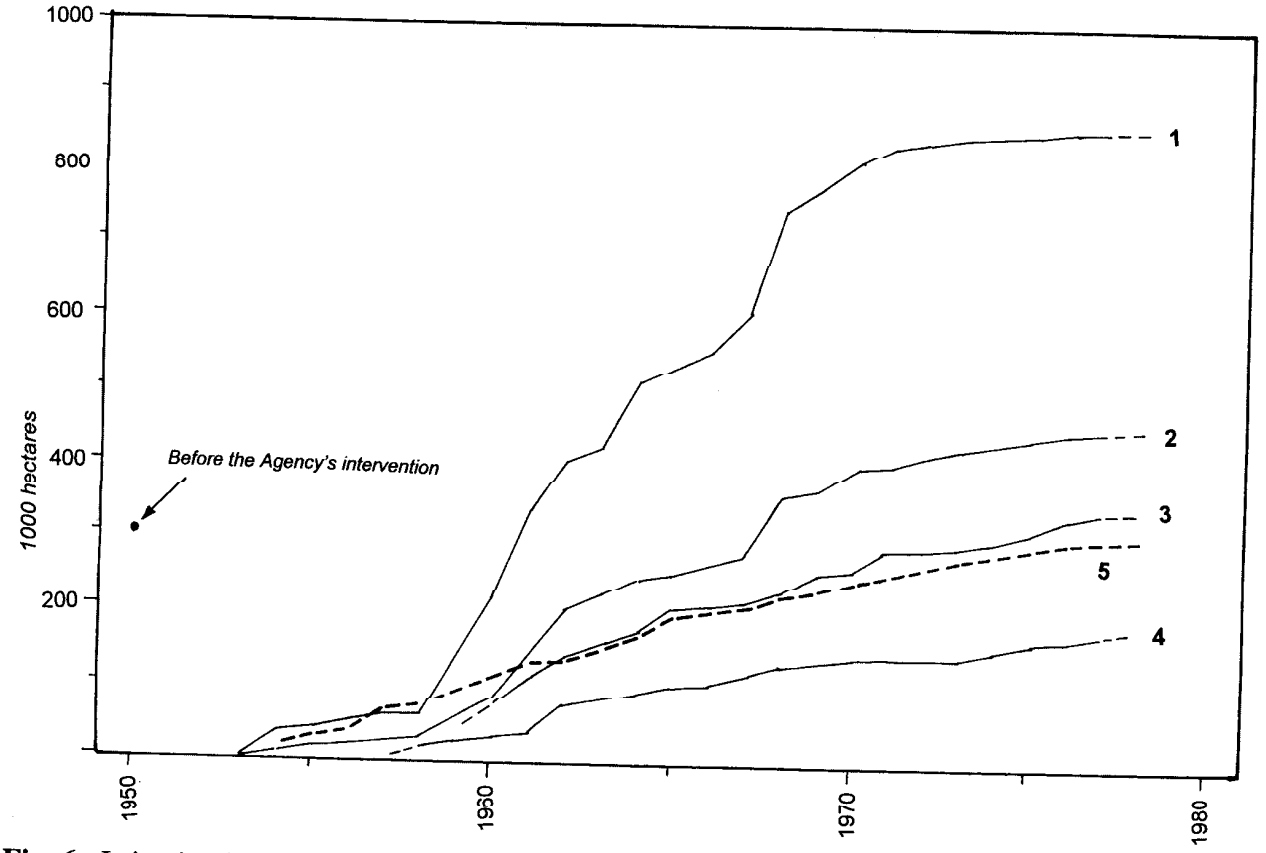

Fig. 6. Irrigation in Southern Italy as a result of the Fund's intervention (these areas were in addition to the 350,000 ha already irrigated when the Fund began its activity): Curve 1 – areas subtended by the delivery and primary repartition networks; 2 = areas subtended by the public networks up to the farm inlet; 3 = areas irrigable with water supplied by the public networks (collective farms); 4 = areas actually irrigated with water supplied by the public networks; 5 = areas irrigable (and actually irrigated) with water from private sources (see Tab. II).

At the end of this first period of intervention (roughly 1950-1960), for which about 64% of the Fund's global financial commitment had been allocated to the irrigation sector, the official policy of intervention began to change with respect to the objectives to be pursued and, as a result, greater attention was given to industrialisation and other sectors considered essential for a more balanced development of the South (aqueducts, roads, tourism, training programmes in various sectors of activity, etc.).

In the context of the Fund's training programmes, it was decided in 1965 to organize, alongside the activities of the Experimental Farms, an irrigation training programme for the technicians of the Consortiums for Land Reclamation who were responsible for extension services and the management of the irrigation systems. The programme was carried out on a network of so-called Hydro-pedological Survey Centres (*Centri di Rilevamento Pedoirriguo*), each provided with an agrometeorological station installed on a standard crop area with an adequate fetch (an aspect which had until then been neglected) (Fig. 7) and a certain number of irrigation trials on commercial crops with irrigation scheduling based on soil humidity measurements (gravimetric, tensiometric, neutronic, etc. methods compared) (Ravelli *et al.*, 1968, 1969, 1979; Tournon *et al.*, 1977).

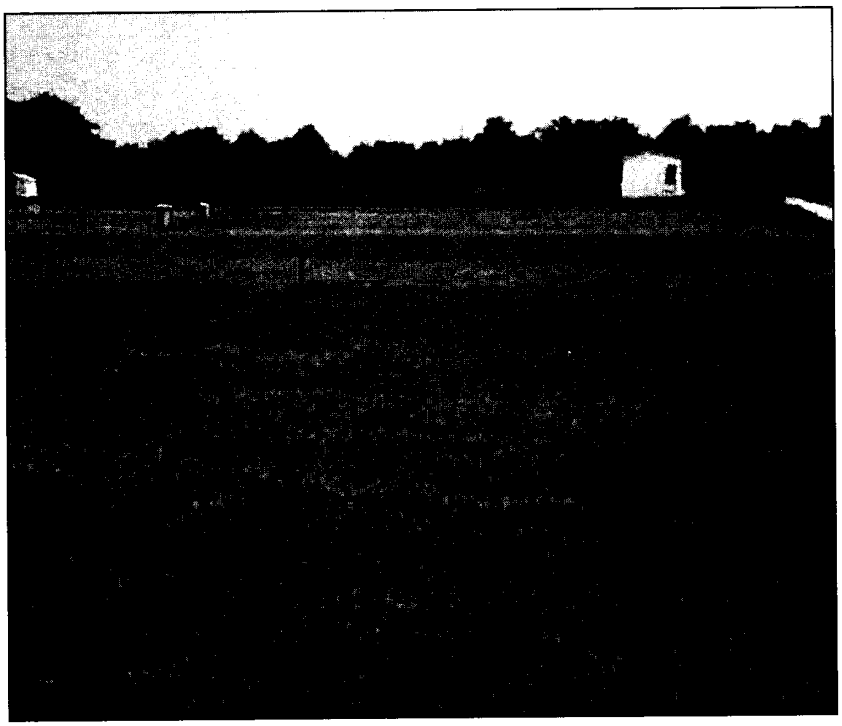

Fig. 7. Agrometeorological areas of the Volturno Experimental Farm, Campania.

Tab. II. Irrigation in Southern Italy as a result of the Fund's intervention

Curve n. in Fig. 6	*Surface areas*	*1000 hectares* [1]		
		1960	*1970*	*1980*
1	Areas subtended by the delivery and primary repartition public networks, of which (see the next line)	220	820	880
2	Areas subtended by the public networks up to the farm inlets, of which (see the next line)	80	400	450
3	Areas irrigable with water supplied by the public networks, of which (see the next line)	70	260	340[2]
4	Areas actually irrigated with water supplied by the public networks (in collective systems)	30	140	170[2]
5	Areas irrigable (and actually irrigated) with water from private sources (autonomous farms)	120	240	300

[1] Rounded off figures.

[2] For some collective systems it was preferred to choke the irrigation water supply by 50%. This made it possible to extend the benefits of irrigation to a larger number of farms, but with a proportionally reduced water supply per surface unit.

The trials conducted at those Centres constituted (i) an extremely valid didactic support to the training courses for the technicians, and at the same time made possible (ii) the analysis of the yield/water volume relationship on the basis of the agrometeorological approach

derived from Thornthwaite's climatological studies at the end of the 1950s on the concepts of *potential* and *actual evapotranspiration*, as well as (iii) the local calibration of the old and new climatic formulae for estimating evapotranspiration. The data collected made it possible to correlate yield stress and evapotranspiration stress (Doorenbos and Kassam, 1979)

$$(1-\frac{Ya}{Ym}) = ky(1-\frac{ETa}{ETm})$$

from which

$$Ya = \left[1 - Ky(1-\frac{ETa}{ETm})\right]Ym$$

in which

Ya = actual yield
Ym = maximum yield
$K\,y$ = yield response coefficient
Eta = actual evapotranspiration
Etm = maximum evapotranspiration

The function has a linear shape usually regarding a limited range of rather low evapotranspiration stress values corresponding to the upper portion of the ascending part of the yield/water volume curve (Fig. 8).

Unlike the old yield/water volume curves, these functions had a general value from a meteorological point of view. The effect of water on the yield appeared however isolated from the effects of the other irrigation, hydro-pedological and agronomic variables which had at any rate to be taken into consideration in order to conform the function to individual operative situations.

In the early 1970s the agrometeorological approach was also adopted in the experimentation activities carried out on the Experimental Farms.

In the second period of intervention (roughly 1960-1970), the Fund's activity in the agricultural sector was considerably reduced (36% of total financial commitment), while the benefits of the massive investments previously made began to be felt and the greatest increase in the irrigated areas occurred. At the end of that period the area served by delivery and primary repartition public networks had increased to 820,000 hectares, 400,000 of which were served up to the farm inlet. The irrigable area in collective systems was 260,000 hectares, of which 140,000 were actually irrigated. An additional 240,000 hectares were actually irrigated on autonomous private farms served by private water sources.

At the beginning of the third period of intervention (roughly 1970-1980) the effects of the drop in the percentage of the Fund's financial commitment to irrigation became evident. As early as 1969 the increase of the areas served by public irrigation schemes began to diminish. Moreover it was a matter of irrigating areas less ready to make profitable use of water than those which had benefited from the first interventions and this certainly did not serve to favour the acceleration of planning, constructing and activating new irrigation

schemes which could have appeared easier to carry out on account of the experience gained in the meantime.

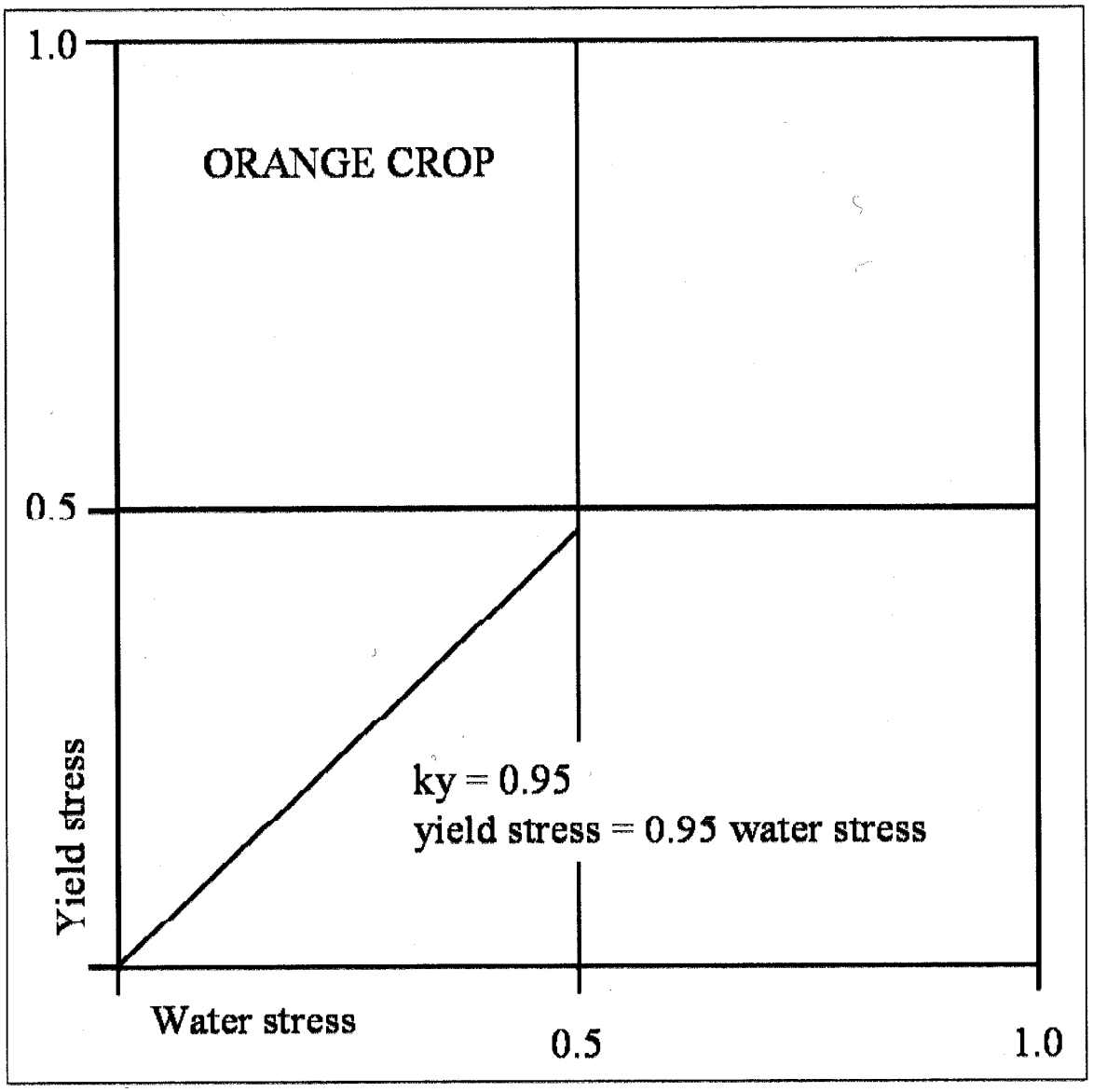

Fig. 8. Relationship between water stress and yield stress (ky = 0.95) for orange crop on Villasor Experimental Farm, Sardegna. From: Ravelli F., D'Orazio L., Vannella S., Andiloro F., Andreozzi M., Leone A., Melas F.: *La sperimentazione irrigua della Cassa per il Mezzogiorno. Primo rapporto riepilogativo sulle prove sperimentali condotte nel periodo 1970-1980 nei Campi Volturno, Villasor I e II, Gioia Tauro.* Agenzia per il Mezzogiorno, vol. I, quad. 13, 1987.

A boost to the operative programme came from the Fund's new Special Irrigation Project in 1974. This Project, drawn up on the basis of proposals made by the southern Regions, involved two lines of action: the first, similar to the one taken in previous years on which greatest financial efforts had been concentrated, was to provide the water needed to irrigate the new areas; the second was to stress all the promotional activities and incentives to facilitate the spread of irrigation on the land served. Nevertheless, expenditure on agriculture dropped to 7% of total expenditure (in the period 1968-1977). A survey made at the end of the 1970s showed that the increase in the area served had slowed down with

respect to the previous decade of intervention. While the irrigable area rose from 260,000 to 340,000 hectares, the area actually irrigated rose from 140,000 to 170,000 hectares, increasing only by 30,000 hectares. This demonstrated that, as if it were necessary, the arrival of irrigation water was a fundamental factor but not enough to guarantee on its own the successful transformation of an economically depressed territory. To the 170,000 hectares irrigated by public collective systems should be added 300,000 hectares irrigated by private autonomous systems. The latter were constructed by individuals (with the Fund's financial support) who evidently intended to use them, so that the area actually irrigated was almost equal to the irrigable area. Towards the end of the 1980s the total area actually irrigated by the Fund's intervention had reached 470,000 hectares.

A new political and administrative orientation led to a new approach to intervention according to which the Ministry for the South (*Ministero per il Mezzogiorno*) together with the Regions of the South were entrusted with the planning of works, while the Fund (which had been transformed into an Agency in 1986) continued to be responsible for only the technical examination of the projects. The closing of the Agency in 1993 marked the end of the extraordinary intervention in the South and definitively brought back the initiatives within the competence of the ordinary administrative and technical organs of the State. The reasons for this were the improved economic conditions in Southern Italy and the European Economic Community's policy to limit intervention to only particularly depressed areas where incomes were decidedly lower than average incomes in the rest of the Community.

The Experimental Irrigation Programme, which was gradually being reduced up to the mid 1970s, was practically terminated in 1982. The closing of the Agency hindered the completion of the processing of the large quantity of experimental data collected. Some processing was done on the personal initiative of the Authors of this paper, in particular for the preparation of the frequency map of monthly reference crop evapotranspiration in Southern Italy (Ravelli and Rota, 1994) and the monthly frequency maps of reference crop evapotranspiration and crop water deficits in Southern Italy (Ravelli and Rota, 1999). **The latter (posted in 1999 on the Internet site <http://www.francoravelli.it>) has been included in the CD-ROM annexed to these proceedings.**

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