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Estimating of water requirement and problems related to the application of a technique for rice irrigation based on intermittent submersion and soil matric potential scheduling

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Abstract. The paper deals with results of an experimental study carried out in north-western Po valley, aiming at the determination of the irrigation water requirement for a rice crop irrigated on level-basin, with a water saving technique (W.S.T.) using, instead of the traditional technique of continuous submersion, the intermittent submersion planned with the measure of soil matric potential in the root zone. In order to study the irrigation management problems related to the application of (W.S.T.), we have estimated by means of a mathematical model of the overland flow, the cut-off time equal to the final advance time for all the level-basins of a typical rice cultivated farm. The hydraulic parameters (infiltration and roughness) of the model were evaluated applying the continuity equation to the surface water profiles detected during the advance phase of three waterings. As shown by the results, in order to maintain the required matric potential values in the root zone, it is necessary to carry out a high number of waterings. Relief of the advancing surface water profiles made it possible to adequately determine the hydraulic parameter values useful for the application of the simulation model of the watering process. The applicatory interest of (W.S.T.) must be considered both in relation to the reduction of the seasonal irrigation water requirements and to the increase of the cost of labour, to the problems connected with the irrigation management at farm level, to the opportunity of the right-sizing of the fields and the irrigation network.

Keywords. Rice irrigation – Water saving technique – Intermittent submersion – Soil matric potential scheduling.

Estimation des besoins en eau et des problèmes liés à l'application d'une technique d'irrigation de la riziculture par la submersion intermittentte et le pilotage du potentiel matriciel

Résumé. *Cet article présente les résultats d'une recherche expérimentale conduite dans la Vallée du Pô au nord-ouest de l'Italie. L'étude vise à déterminer les besoins en eau d'une culture de riz, irriguée par une technique d'économie d'eau (W.S.T.) appliquant la submersion intermittente mesurant le potentiel matriciel de la zone racinaire, au lieu de la technique traditionnelle de submersion continue. Afin d'étudier les problèmes liés à la gestion de l'irrigation, on a calculé (avec un modèle mathématique) la durée d'arrosage correspondant au temps d'avancement final de la lame d'eau, pour tous les bassins d'une exploitation agricole typique cultivée au riz. Les paramètres hydrauliques (d'infiltration et de rugosité) ont été évalués, appliquant l'équation de continuité aux profils libres de l'eau avançant dans un bassin expérimental. Les résultats ont montré que, pour conserver dans la zone racinaire les valeurs prévues de potentiel matriciel, un nombre relativement élevé d'irrigations doit être effectué. La détermination de l'avancement des profils d'eau a permis l'évaluation des paramètres nécessaires à l'application du modèle de simulation. Afin de permettre une gestion rationnelle de l'irrigation même dans une exploitation agricole, l'intérêt applicatif de la technique doit être évalué par rapport à la réduction des besoins saisonniers en eau et à l'augmentation du coût de la main-d'œuvre et à la possibilité de redimensionner les exploitations à irriguer et le réseau de distribution.*

Mots-clés. *Irrigation – Riz – Économie d'eau – Irrigation intermittente – Pilotage du potentiel matriciel.*

I – Introduction

The research for methods to reduce water losses is an actual problem for rice irrigation in the territory delimited by Dora Baltea, Po and Ticino rivers in the north-western Po valley, where is located the greatest part of the Italian rice growing area (about 220.000 ha). The irrigation of rice in this area is traditionally operated with the continuous submersion method on level-basin throughout the entire irrigation season (from April to August); soil remain flooded to a depth of as much as 0.10 m until the final drying-out, apart from two or three periods of about five days to promote striking of the roots and to apply some nitrogen fertilizers and pesticides. The following seasonal values of irrigation water requirement can be considered in our study area for soils characterized by the probable presence of a plow soil layer (which is generally located 0.25 to 0.35 m below the field surface): 1000÷1600 mm for impermeable soils with a clayey texture; 1800÷2800 mm for normal permeable soils with a silt-loam to loam texture; 3000÷4000 mm for permeable soils with a sandy-loam texture; over 4500 mm for very permeable soils with a sandy texture where rice growing is only possible after suitable mechanical operation of clogging. Rice evapotranspiration in the growing period is estimated at 650÷750 mm (Allavena, 2001); it represents a relative small percentage of the total consumption, except in the case of clayey soils. Since the greatest part of the total consumption is constituted by the percolation and seepage losses (PS), it is obvious interest to develop irrigation techniques that enable their reduction.

The term "water-saving techniques" (W.S.T.) denominates irrigation techniques that aims at reducing (PS) losses by reducing the depth of ponded water, or keeping the root zone just saturated, or allowing the root zone to dry out to a certain extent after the submersion water vanished from the soil surface, before re-applying irrigation water (intermittent submersion). Rice irrigation with intermittent submersion is chosen because it reduces (PS) losses, while it allows for a better use of natural rains, cutting down irrigation water requirements. However, (W.S.T.) may cause the risk of yield reduction due to drought (with reference to the rice cultivation drought is defined as: situation where the water content in the root zone is below saturation) and temperature stress effects on the crop (Singh *et. al*., 2001; Bouman and Tuong, 2001; Belder *et al*., 2004; Mao *et al*., 2004). In the years 2000, 2001 and 2002, we have experienced a (W.S.T.) based on intermittent submersion and irrigation events planned with predetermined rules of watering given to the farmer (Allavena, 2004); now a (W.S.T.) based on intermittent submersion method and soil matric potential scheduling is studied. Methods to evaluate the hydraulic parameters for the use of mathematical models of the overland flow to simulate the watering process were then examined; for this study the soil water intake is described by the use of an empirical infiltration equation traditionally known as Kostiakov equation and hydraulic resistance of the irrigation run is expressed by the Manning's roughness coefficient. These parameters are evaluated from the surface water profile measured in the field during the advance phase, through the application of the continuity equation. The system parameters determined in this way, are then used with an overland flow model to calculate the cut-off times taken equal to the final advance as a function of flow rates for all the level- basins of a typical rice cultivated farm in view of a rational irrigation management.

Following the above considerations, the study focuses on the following objectives: i) determination of the number of waterings strictly necessary to maintain a matric potential greater than -35 ÷ -45 kPa in the root zone during the entire irrigation season; ii) determination of the corresponding seasonal water requirement; iii) evaluation based on the surface water profiles of appropriate parameters for infiltration and roughness; iv) application of a parameterized model of the watering process to the planning of W.S.T. in a typical rice cultivated farm and discussion of the problems related to the irrigation management.

II – Material and methods

1. Field characteristics

Field experiments on rice (*Oryza sativa*) irrigation with a (W.S.T.) technique based on intermittent submersion and soil matric potential scheduling were performed during the years 2003, 2004 and 2005 in the rice cultivated areas of north-western Po valley. The experimental site, surrounded by flooded rice fields, is located near Bianzé (Lat. N 45° 17' 50''; Long. E 08° 07' 08''; Alt. 180 m a. s. l.) in the county of Vercelli at approximately 45 km north-east of Turin.

In order to characterize climatic conditions we have reported in Figure 1 the evolution of the reference evapotranspiration calculated with the Penman-Monteith equation (five days total) and daily values of rain measured with gauges scattered in the experimental field itself; total rain of the period 1 May ÷ 31 August was: 212.1 mm in 2004; 198.8 mm in 2005.

The experimental field is composed of two level basins, one irrigated with (W.S.T.) and the other with the traditional technique of continuous submersion; the basin irrigated with the intermittent submersion during the whole cropping season has a length of 152 m and a width of 36.7 m; the adjacent basin irrigated with the continuous submersion has a surface of 1.1 ha and similar edge conditions. The slope of the surface of the experimental basins was laser leveled to zero field slope (March 22th and 23th 2003); in subsequent years no laser levelling was carried out.

The textural soil properties are quite homogeneous in the profile and classified as a silt loam following the USDA soil classification system, with an average clay fraction of 9.3 %, an average silt fraction of 61.5 % and an average sand fraction of 29.2 %. On the contrary, the hydrologic horizon show a layer with a low permeability which is typical for areas cultivated for many subsequent years with the continuous submersion method. In fact, a shallow plow layer (from soil surface to 0.25 ÷ 0.30 m) overlays a plow sole with a thickness of about 0.1 m, and a sub layer extending to the water table (situated at a depth of about 0.8 ÷ 1.0 m from the soil surface during the period May to August); this is directly reflected by the dry bulk density values ρ_d: while ρ_d equals 1250 kg · m^{-3} in the top layer of the profile, the dense horizon shows a local dry bulk density of ρ_d = 1600 kg · m^{-3}.

The rice was sown: April 2nd in 2003 (cultivar "Carnaroli"); May 8th in 2004 and April 30th in 2005 (cultivar "Gladio"); the cultural practices were similar to those adopted by farmers of this region.

During the irrigation seasons of 2003, 2004 and 2005 soil matric potentials were measured manually every two or three days at 8 ÷ 9 a.m., in two locations of the experimental field with tensiometers having the porous cup at five different depths chosen between the soil surface and the water table; it allowed exploring soil-water dynamics as related to soil texture and structure, presence of a shallow plow sole, evapotranspiration of rice plants, watering and rains. Depths of the porous cups and corresponding evolution of the mean matric potential are reported in Figure 1 for the year 2005; in this paper for purpose of concision we mainly refer to the matric potential data determined in this year.

The watering was applied when the mean matric potential in the root zone was about -35 to -45 kPa; even though this threshold value may perhaps slightly reduce rice grain yield as compared to the optimal value of -10 or -20 kPa (Kukal *et al.,* 2005), it allows increasing time intervals between two consecutive watering and hence reducing labor costs.

2. Infiltration and hydraulic resistance evaluation for modelling shallow overland flow in a rice cultivated level-basin

The flow in a level-basin is an example of unsteady, non-uniform and gradually varied flow with free surface over a porous bed (Khanna and Malano, 2006). The full description of one-dimensional shallow water flow is based on the numerical solution of the continuity and the momentum Saint-Venant equations (Strelkoff, 1969). The models where all terms of the Saint-Venant equation are retained, are called "full hydrodynamic" or simply "hydrodynamic" models. Since in surface irrigation the overland flow velocities are small, a reasonable simplification consists in assuming the inertia terms in the momentum equation to be negligible ("zero-inertia models").

Based on the above quoted equations, various detailed simulation models have been developed to help in the evaluation of the level-basin irrigation, some of which have now come to a stage where they can be called "user-friendly" computer programs (e. g.: BASIN 2.0, Clemmens *et al.*, 1995; SIRMOD III, Walker, 2003; SURDEV, Jurriens *et al.*, 2001); among these, for calculations we have chosen the last (SURDEV). The use of design software is often hindered by the lack of appropriate field values for the parameters required as input, particularly: infiltration and hydraulic resistance.

Infiltration is difficult to determine or predict with reliability and accuracy, because in a surface irrigation unit it can vary temporally and spatially. Point infiltration measurements are normally made by infiltrometers (single or double rings; furrow, sprinkler, tension, infiltrometers), but it is laborious to account for the above said variations by these traditional point methods. To overcome these difficulties, irrigation engineering research has focused on the evaluation of infiltration over the whole irrigation unit by means of water advance data collected during an irrigation event (e. g.: Maheshwari and McMahon, 1992). Field data are often matched by empirical equations; the most widely adopted, particularly in "user-friendly" programs, is the power form infiltration equation (Kostiakov equation):

$$Z = u \cdot T^{v}$$

where, Z is the cumulative infiltrated depth (volume infiltrated per unit area of infiltrating surface); T is the infiltration opportunity time; (u) and (v) are empirical coefficients. Hydraulic resistance is also difficult to estimate reliably since its value varies with the condition of the soil surface, the type and density of vegetation, and the depth of flow relative to the height of vegetation. In the user-friendly programs the estimation of the hydraulic resistance is based on Manning's roughness coefficient:

$$n = (y^{5/3} \cdot S_f^{\,1/2}) / q$$

where (y) is the surface water depth; S_f is the friction slope and (q) is the flow rate per unit width; nevertheless the suitability of the Manning equation to represent shallow flow in surface irrigation is questioned (Maheshwari and McMahon, 1992).

Surface water profiles determined in the experimental level-basin at advance times t_1 ; t_2 ; t_3 ; t_4 when the tip of the water front was at $x_1 = L/4$; $x_2 = L/2$; $x_3 = 3L/4$ and $x_4 = L$; (L = basin length), has been used to evaluate the Kostiakov infiltration equation and the Manning's roughness coefficient through the application of the continuity principle (Radhey and Pandya, 1972; Harun-Ur-Rashid, 1990; Hume, 1993; Strelkoff *et al*., 1999).

3. Evaluation of Kostiakov infiltration equation

Neglecting evapotranspiration, the volume balance principle, during the advance phase of water in a level-basin, can be expressed mathematically as:

$$V = q \cdot t = S + I$$

where V is the volume of inflow per unit width of level basin for a specified time (t); (q) is the constant rate of inflow of irrigation water per unit width; (t) is the elapsed time since the irrigation event began; (S) is the volume of water on the ground surface per unit width (surface storage) at time (t) and (I) is the volume of water infiltrated into the soil per unit width during the time (t). In the analysis it is assumed that the infiltration characteristics of soil are uniform over the length of the test level basin.

The application of the method requires the knowledge of the relationship describing the advance of the water front in the basin as a function of time since irrigation started (advance function); a power function relationship was used (Elliot and Walker, 1982):

$$x = a \cdot t^{b}$$

where (x) is the advance distance from the field lateral at the upper end of the basin at time (t); (t) is the advance time to (x); (a) and (b) are empirical constants determined fitting experimental pairs of data with the least squares regression method. Also required is the relationship between the total volume of infiltration when the water front is at (x) and the correspondent advance time (total volume of infiltration function); the total volume of water infiltrated per unit width at selected values of the advance time was computed from the volume balance equation; the surface storage (S) was evaluated using the surface water profiles obtained from the measures of the depths of flowing water in points located down the length of the basin. We used a power function relationship:

$$I = c \cdot t^{d}$$

where (I) is the total volume of water infiltrated per unit width of the test basin at time (t); (t) is the advance time; (c) and (d) are empirical constants determined fitting the computed pairs of data with the last squares regression method.

The volume balance method was applied as follows to calculate the coefficients of the Kostiakov infiltration equation based on advance times measured in the field at: x = L/4; x = L/2; x = 3L/4; x = L.

The final advance time t_L (advance time for x = L, where L = basin length) was divided into five equal time intervals (Δt). Using the advance function we calculated the advance distance x_i for the advance time: $t_i = i \cdot \Delta t$ with (i = 1,2, …, 5), and the incremental advance: $\Delta x_i = x_i - x_{i-1}$ during each time interval. By the total volume of infiltration function we calculated the total volume of water infiltrated (I_i) at time t_i.

During $t_i = i \cdot \Delta t$ water advances to point $x = x_i$; assuming: that the average height of infiltration in Δx_i is Z^*_1 ; that the average height of infiltration in $\Delta x_{(i-1)}$ is Z^*_2 , and so on; the average height of infiltration Z^*_i at time t_i in Δx_1 will be:

$$Z^*_i = (I_i - Z^*_1 \cdot \Delta x_i - Z^*_2 \cdot \Delta x_{(i-1)} - \ldots\ldots - Z^*_{(i-1)} \cdot \Delta x_2) / \Delta x_1$$

Applying the above equation to all five time intervals we calculated the average height of infiltration (Z^*_i) in Δx_1 at corresponding times (t_i) from the start of irrigation. By fitting to above calculated pairs of data the power form of the average height of infiltration equation with least squares regression method, we calculate:

$$Z^* = m \cdot T^{n}$$

The coefficients (u) and (v) of the Kostiakov infiltration equation were obtained from the relationships:

$$Z^* = Z/T = (1/T) \int_0^T (u\, T^{v})\, dT = (u / v+1)\, T^{v}$$

where:

$$(u / v+1) = m \; ; \quad v = n$$

4. Evaluation of Mannig's roughness coefficient

Referring to a trapezoidal cells (e. g. the cells marked: n_A, n_B, n_C in Figure 2) the Manning's roughness coefficient (n) can be expressed as:

$$n = [2 / (q_e + q_u)] \cdot [(y_{m,s} + y_{m,i} + y_{v,s} + y_{v,i}) / 4]^{5/3} \cdot [(y_{m,s} + y_{m,i}) - (y_{v,s} + y_{v,i}) / 2\Delta x]^{1/2}$$

where q_e is the unit flow rate entering the cell; q_u is the unit flow rate flowing out from the cell; $y_{m,s}$; $y_{m,i}$; $y_{v,s}$; $y_{v,i}$ are the surface water depths at the vertices of the trapezoidal cell; Δx is the cell length.

The unit flow rate q_u is calculated as:

$$q_u = q_e - q_s - q_z$$

q_s being the unit flow rate corresponding to the volume of water in the cell between water surface profiles at t_{i+1} and t_i :

$$q_s = [(y_{m,s} - y_{m,i}) + (y_{v,s} - y_{v,i})] \cdot (\Delta x / 2) \cdot (1 / \Delta t)$$

where $\Delta x = L/4$ and $\Delta t = t_{i+1} - t_i$;

q_z is the unit flow rate corresponding to the volume of water infiltrated in Δx during Δt :

$$q_z = [(Z_{t+1} - Z_t) + (Z_{(t+1)^*} - Z_{t^*})] \cdot (\Delta x / 2) \cdot (1 / \Delta t)$$

where Z_{t+1} ; Z_t ; $Z_{(t+1)^*}$; Z_{t^*} are the cumulated infiltration depths calculated with the previous Kostiakov infiltration equation for the infiltration opportunity times at left and right vertices of the cell.

5. Determination of the surface water profiles for hydraulic parameters evaluation

Surface water profiles to evaluate hydraulic parameters as previously reported, were determined during the irrigation season of the year 2003. The measurement of flow to obtain the inflow hydrograph was done with a full-width rectangular weir; upstream was constructed a control structure with a spillway to maintain a constant water level in the supply channel. Advance times were measured when water front arrived at: ¼ L ; ½ L ; ¾ L ; and L starting from the beginning of the diversion of water from the field channel at the upper end of the basin.

Water-depth measurements was taken at stations along the basin using gauges consisting of a steel tube 200 mm in diameter and 0.2 m high, with holes of 10 mm near the base; in the inner surface a steel scale with the zero at the soil surface is fixed. The gauges were placed at: (0.5 m); (¼ L – 10 m); (¼ L) ; (1/2 L –10 m); (½ L) ; (3/4 L – 10 m); (¾ L) ; (L –10 m); (L) from the distribution channel; depth gauge readings were taken by men. The water-depth at ten meters before the points of advance time measurements was recorded because near the advancing front the shape of the surface profile is highly non linear. In the basin were realized two parallel lines of probes at a distance of 1/3 of the basin width from longitudinal bunds; when the advance front arrived at a measurement point, levels were measured in the upstream probes.

III – Results and discussion

1. Determination of the number of waterings and corresponding water requirements

In the irrigation season 2005, applying irrigation when the mean matric potential in the root zone was about -35 kPa, we have carried out six waterings in the level-basin irrigated by intermittent submersion (Figure 1).

The seasonal irrigation water requirement was 739 mm . Values of flow rate, cutoff time and height of watering for each irrigation event operated in this year are reported in Table 1. Likewise during the irrigation season 2004 we have carried out six waterings applying irrigation when the mean matric potential in the root zone was about - 45 kPa; the seasonal irrigation water requirement was 692 mm .

In the two years the time interval between two successive waterings without consistent rainfall and in the period of maximum ETrice, was about 10 days.

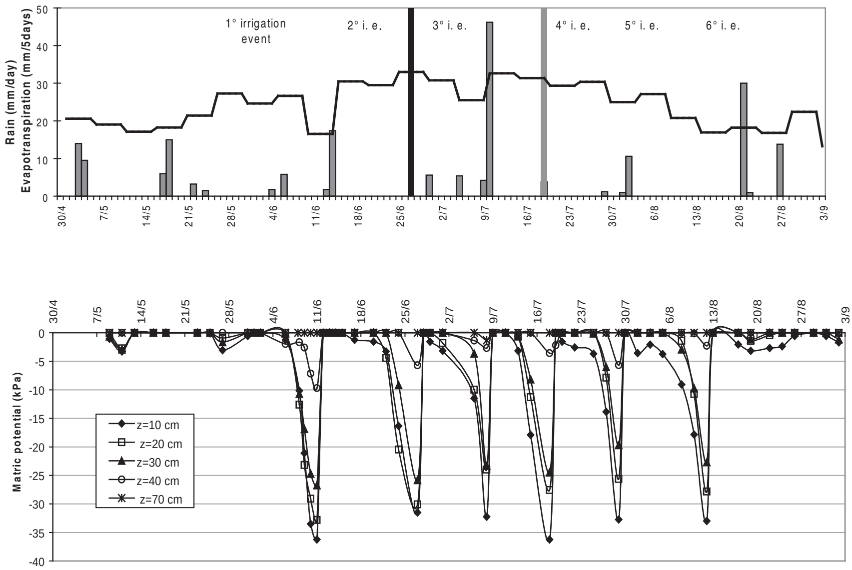

Figure 1. Depths fro m the soil surface of porous cup of the tensiometers (z) and corresponding values of the matric potential during the irrigation season 2005.

Table 1. Values of flow rate, cut-off time, height of watering (year 2005).

Date of the irrigation event	Average height of rice plants (m)	Irrigation flow rate ($m^3 \cdot s^{-1}$)	Experimental cutoff time (min)	Correspondent height of watering (mm)
11-06-05	0.10	0.094	118	119
27-06-05	0.25	0.091	122	119
08-07-05	0.50	0.096	110	114
19-07-05	0.60	0.094	115	116
30-07-05	0.60	0.092	130	129
13-08-05	0.75	0.093	142	142

For comparison, a water balance was applied to the basin irrigated with the continuous submersion method for successive periods of twenty days from the sowing date of the year 2005. The (PS) losses were directly determined in the field on the basis of the decrease of the surface ponded layer minus rice evapotraspiration and the volumes of submersion (operated after the three periods of about five days to promote striking of the roots and to apply some nitrogen fertilizers and pesticides) were calculated with the parameterized simulation model. The value of the seasonal irrigation water requirement for rice was calculated as 1800 mm; using the soil matric potential scheduling and the intermittent submersion a reduction at field scale of 60 % was realized. Rice yield at 14% moisture content was determined for the whole two basins, ranging to 7.3 Mg · ha^{-1} for the basin irrigated with the intermittent submersion, and to 7.9 Mg · ha^{-1} for the basin irrigated with continuous submersion.

2. Evaluation of the hydraulic parameters for the simulation of the watering process

In Figure 2 are reported, for example, the surface water profiles relatives to the watering of the day 25 – 06 – 2003, determined when the tip of the water was at a distance from the water inlet of x = 38 m; x =76 m; x = 114 m; x = 152 m; the correspondent advance times were: tad,38 = 30 min; tad,76 = 70 min; tad,114 = 125 min; tad,152 = 203 min .

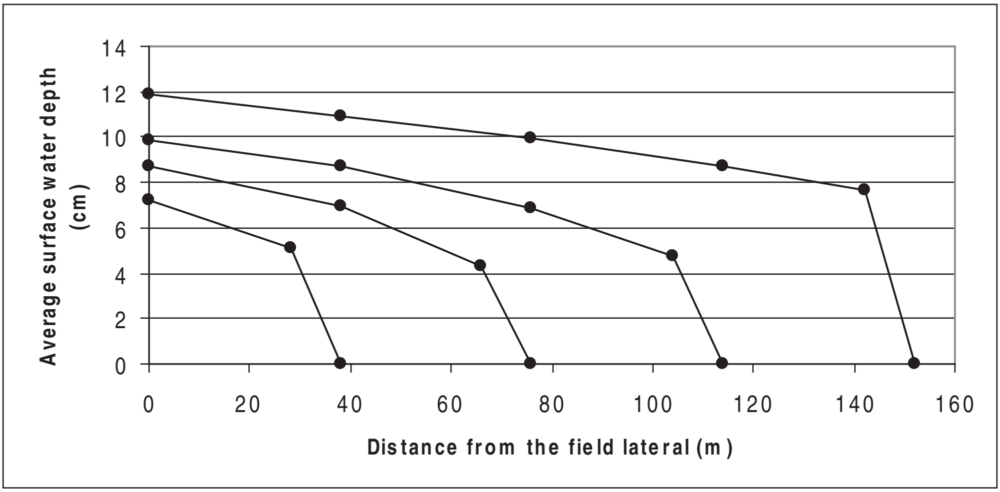

Figure 2. Water surface profiles determined in the experimental level-basin at different advance times for the irrigation event of the day 25-0 6-2003 (flow rate Q = 0.058 $m^3 \cdot s^{-1}$).

The examination of advance velocity during the watering did not highlight sudden variations, suggesting that the soil infiltration properties and the characteristic of the culture within the test basin were quite homogeneous as assumed for application of the volume balance method.

Applying the volume balance method to the three irrigation events monitored during the growing season of the year 2003 (for details refer to: Allavena, 2008) we obtained the averaged Kostiakov infiltration equation for the year 2003:

$$Z = 6.47\, T^{0.423}$$

In the above reported equations [F] is in [mm] and [T] in [min].

The computed infiltration equations generally involve cumulative infiltrated depths fairly elevated in the first twenty-thirty minutes, which follows a drastic reduction of the infiltration heights.

The Manning's roughness coefficient (n) estimate was done using the previously outlined method applied to the water surface profiles such as these shown in Figure 2.

The method was applied to each of the three cells of trapezium form marked n_A, n_B, n_C; these cells were chosen because the values of water depth at vertices has been measured directly in the field. The results of the calculations are presented in Table 4.

The mean value of Manning' s roughness coefficient is:

$$n = 0.19 \quad m^{-1/3} \cdot s$$

Recent determinations for crops such as rice, wheat, corn, cotton, irrigated on level-basin have given values of (n) around 0.1÷ 0.15 $m^{-1/3} \cdot s$ (Clemmens *et al.,* 1999; Fabiao *et al.,* 2003). The averaged Kostiakov infiltration equation and the mean value of the Manning's roughness coefficient calculated on the basis of the three watering monitored in the year 2003 were used to calculate the final advance time of the waterings effectuated in the year 2004 and 2005 with acceptable results, and then used for the computation of the final advance time of each level basin of a representative rice cultivated farm.

Table 2. Manning's roughness coefficients calculated on the basis of the water depth profiles determined in the field in the year 2003 (n_A, n_B, n_C = values calculated with reference to corresponding cells of Fig. 5).

Date of the irrigation event	Average height of the rice plants (m)	Irrigation flow rates ($m^3 \cdot s^{-1}$)	Manning's roughness coefficient ($m^{-1/3} \cdot s$)			Mean value ($m^{-1/3} \cdot s$)
			n_A	n_B	n_C	
24-05-03	0.15	0.049	0.177	0.176	0.250	0.201
07-06-03	0.30	0.083	0.160	0.181	0.202	0.181
25-06-03	0.60	0.058	0.198	0.202	0.200	0.200

3. Problems related to the application of W. S. T. at farm level

As concerning the problems related to the practical application at farm level of the (W.S.T.), we refer to the layout of a typical rice cultivated farm reported in Figure 3.

The farm, having a surface of about 50 ha, is irrigated with the traditional continuous submersion method. Water from the irrigation network reaches the head of a distribution channel running along the superior side of the unit and supplies it via an inlet; the surface of the farm is divided into diked rice fields with the bottom flat; the irrigation water flow from a level basin to another ("plot to plot" system) before arriving at the surface drainage canal. The irrigation stream is 100 ÷ 150 $l \cdot s^{-1}$ and canals are dimensioned for this flow. Today, level-basins are usually rectangular and may extend over several hectares; this is done in order to promote a regularly distribution of irrigation water, to allow the irrigation water has the same small height over the entire field, to promote farming techniques and mechanical operations, to reduce the amount of unproductive land represented by the dikes. The issues in question are reviewed below, together with some possible solutions.

First, the application of the intermittent submersion method in which the whole irrigation stream is delivered to a single level-basin does not permit the application of the "plot to plot" system; it is therefore necessary to change the irrigation distribution network to the basins by introducing new watering canals.

Secondly, the high number of waterings that need to be conducted during the irrigation season involves a substantial increase in the labor required for operating the irrigation of the farm. This may be reduced by: reducing the number of level-basins through the unification of the smaller ones and/or increasing the time interval between two successive irrigation events. To achieve the last goal: from the viewpoint of irrigation technique, it is possible to augment the height of submersion layer developed at the end of the watering and from an agronomic viewpoint the research must determine the minimum intervention threshold value of the matric potential in relation to sensitiveness of the rice culture, to the saturation deficit and to the specific agronomic techniques (manuring, weeding) adopted to obtain an acceptable production.

Thirdly, the calculation program SURDEV, with the introduction of the hydraulic parameters evaluated on the basis of the continuity equation and with reference to the case of cut off time equal to final advance time, was used to calculate for each basin of the farm, the cut-off time for the following values of the irrigation stream (Q) = 100; 150; 200; 300 $l \cdot s^{-1}$. Thereafter for each of the above values of the irrigation stream we calculated the total number of hours (O) necessary for irrigating all the basins of the farm, obtaining: for Q = 100 $l \cdot s^{-1}$, O = 155.2 h; for Q = 150 $l \cdot s^{-1}$, O = 104 h; for Q = 200 $l \cdot s^{-1}$, O = 80 h; for Q = 300 $l \cdot s^{-1}$, O = 56.8 h . The reported values must be increased of the total number of hours for the operations of waterings of the whole farm (e.g., 12 h); so, it was found that with the irrigation stream normally used (100 ÷ 150 $l \cdot s^{-1}$) it is not possible to irrigate the farm in the time interval of 10 ÷ 12 days previously identified: it is therefore necessary to use irrigation stream of 200 ÷ 300 $l \cdot s^{-1}$ and in consequence to resize the sections of the watering canals.

Fourthly it is appropriate to consider that so high irrigation streams directly runned in a single point of the level-basin can cause local erosion; it will be necessary to implement appropriate tournout structures to prevent erosion and possibly a head watering canal to allow a regular supply of the level-basins. In the case of more permeable soils the reduction of seasonal irrigation water requirement is more substantial (Allavena, 2004), but the problems associated with the transition to intermittent submersion are exacerbating.

Adopting (W.S.T.) on large scale in a territory where the widespread culture is rice irrigated with continuous submersion (e. g., the “Agro Vercellese” district) will have consequences for water use at larger spatial scale levels. Water lost from level-basins by percolation and seepage will enter the subsurface system through shallow water table and the surface system through drainage network; both the subsurface and surface systems can be exploited downstream by water reuse; less groundwater recharge may lead to a sensible drop in the groundwater table. This may reduce the possibilities of the re-employment of subsurface waters and can increase the percolation rates, offsetting the gains in water saving introduced at field level.

IV – Conclusions

From experimental data collected and from their elaboration, several conclusions and some suggestions for further studies can be drown:

i) to maintain in the root zone the required values of matric potential, a relatively elevated number of watering is necessary; for raising time interval between two successive irrigation events in order to reduce the amount of labor needed to carry out the waterings, from the viewpoint of (W.S.T.), it is possible to increase the height of the submersion layer (this height can be calculated using the parameterized model) and from an agronomic viewpoint the research must determine the minimum intervention threshold value of the matric potential in relation to sensitiveness of the rice culture to the saturation deficit and to the specific agronomic techniques (manuring, weeding) adopted to obtain an acceptable production;

ii) the evaluation of the advancing surface water profiles experimentally determined made it possible to adequately calculate, using the methods based on the continuity equation, the values of the hydraulic parameters required for the application of the user-friendly programs;

iii) the applicatory interest of (W.S.T.) at farm level must be valued in relation to: the reduction of the seasonal irrigation water requirements; the increase of the cost of labour; the problems connected with the irrigation management at farm level; the opportunity of the right-sizing of the fields and the irrigation network.

The values obtained in the experiments are crearly related to the case study examined; for their generalization it is necessary to extend the investigation to other hydropedological contexts.

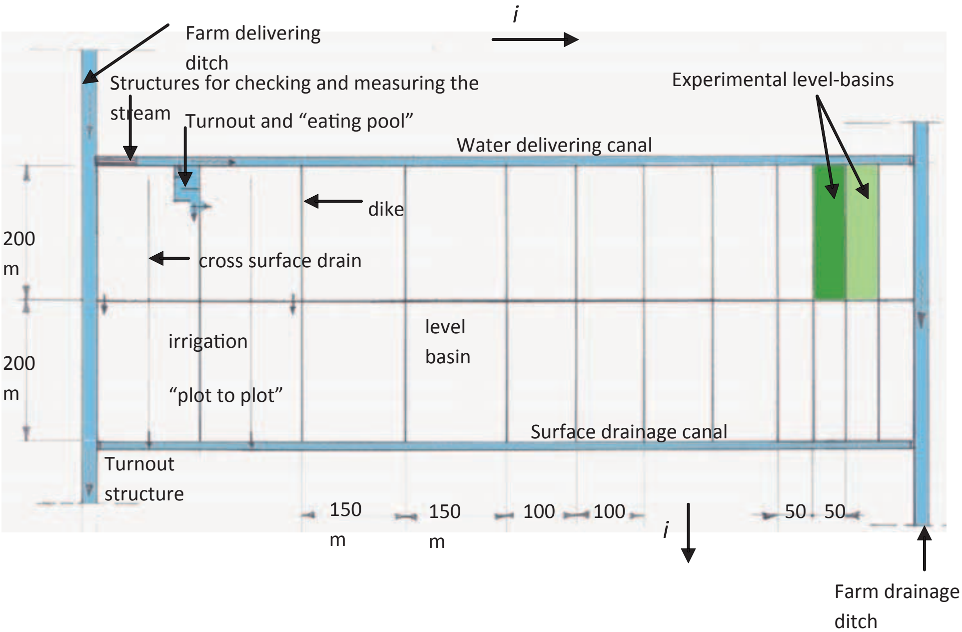

Figure 3. Schematic layout of a rice cultivated farm in north-western Po valley.

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