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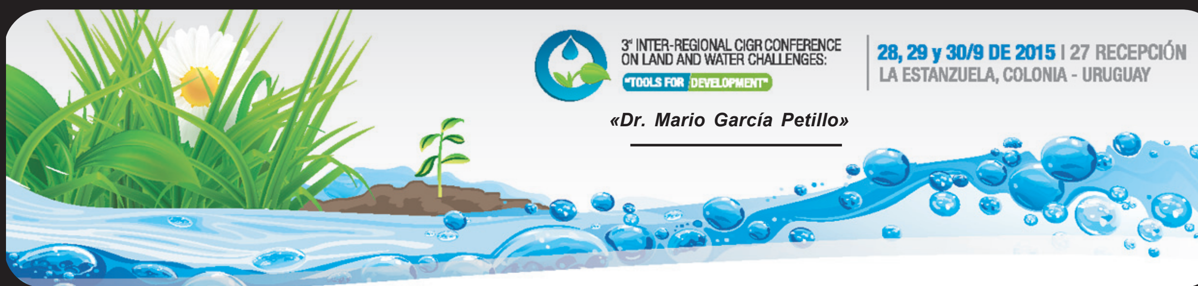
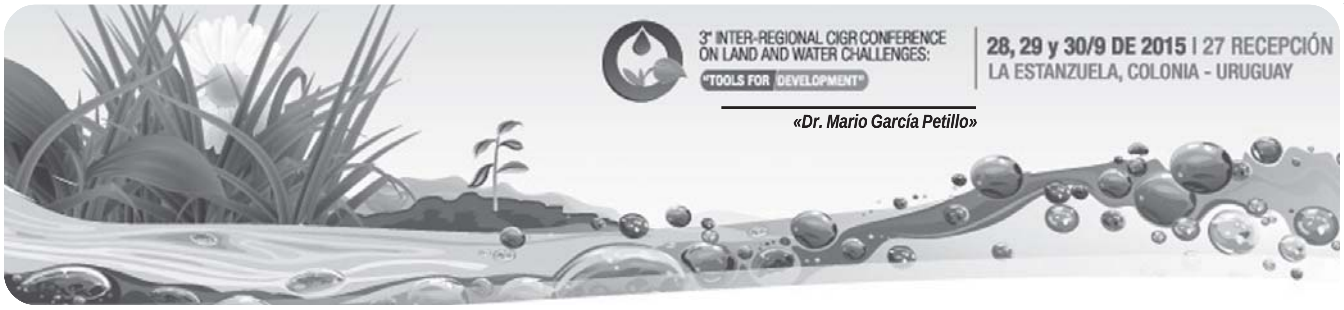


3rd Inter-Regional CIGR Conference on Land and Water Challenges: Tools for developing

«Dr. Mario García Petillo»

Revista científica de la Facultad de Agronomía, Universidad de la República, y del Instituto Nacional de Investigación Agropecuaria



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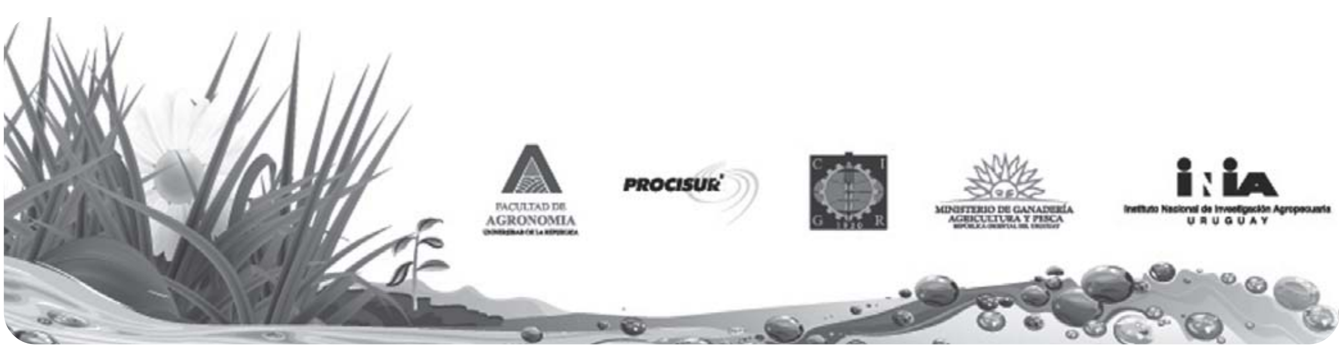
SETIEMBRE 2015



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Special Issue

Organizers of the 3rd Inter-Regional CIGR Conference on Land and Water Challenges: Tools for developing «Dr. Mario García Petillo»

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TELEDETECTION AND CROP

PREFACE

Uruguayan agriculture has undergone dramatic changes since the beginning of the XXI century. The cropped area increased by a factor of 3, with soybean as the leading crop. Moreover, there was a switch from rotation soil use systems of crops with seeded grass and legume pastures, towards no-till continuous cropping systems.

Uruguay climate determines, on average, annual precipitation from 1200 mm in the south up to 1500 mm in the north. During late spring and summer, some soil water deficits are to be expected, but inter annual rainfall amount variability determines that in some years this deficit arrives to be severe drought and in others arrives to be negligible. However, in some years not only irrigation could arrive to be not needed, but also to have water excess instead of deficit. There is agreement about that this inter annual variation has been magnified as a consequence of the global climate change. Irrigation development is one way of adaptation to these effects, and to stabilize higher vegetal production.

Water erosion is a serious risk under Uruguayan climate, if soils are unprotected. Soil water content has proven to be an important factor of soil erosion, because runoff reduces significantly when soils are relatively dry. As irrigation aims to maintain high soil water contents, increased erosion risk should be considered. Efficient soil erosion control is reached using no or reduced tillage systems, when high surface soil cover with residues is obtained. This conditions irrigation water application systems to be used. Also, because of the rolling landscape predominant in the areas with agricultural soil capabilities, there should be limitations to the use of big central pivots irrigation equipments in all the cases.

These were between others, the main reasons to proposing Uruguay to be host the 3rd Inter-Regional CIGR Conference, trying the irrigation as one of the «Tools for Developing» in the agricultural sector.

This name was not chosen randomly, it was thought out and proposed by Dr. Mario García Petillo, who dedicated his life to teaching and research in this discipline.He has been an active Professor, Researcher and past Vicepresident and President of the National Research Institute of Agriculture. In all cases, his professional career has been very much dedicated to the similar scientific topics on which the CIGR Conference focuses. Mario García Petillo started this whole process to bring the CIGR to Uruguay in early 2012, and today we are very lucky to have a conference of the highest technical and scientific level in our country. Therefore for the colleague, professor, father, grandfather, friend, go a tribute and dedication of the 3rd Inter-Regional Conference of CIGR.

We are grateful to the authors, from various countries, who have contributed their specific ideas, experiences and talents to this Conference.

This Special Issue of AGROCIENCIA Uruguay contains the conferences and a selection of papers presented during the 3rd Inter-Regional CIGR Conference that was held in La Estanzuela, Colonia, Uruguay, on September of 2015. We hope that it will contribute to improve our knowledge about the water management, soil conservation, and good irrigation practices and the subsequent effects on yields and input requirements.

Local Organizing Committee
September, 2015

Evapotranspiration and Crop

The Importance of Land and Water Engineering and Management for Food Security

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Abstract

The continued population growth associated with an increased demand for food constitute a great challenge for land and water engineers, managers and policy makers since food security is a main issue in the XXI century. In fact, land availability is likely decreasing and soils are degrading, which call for new, innovative measures of land protection and soil conservation and preservation. In association, water scarcity is increasing at same time that there is an increased demand for water, particularly for irrigated agriculture. However, land and water productivity under irrigation are increasing and there is potential for its sustainable growth. Issues required for sustainability of food production need to be well known and related policies must be considered. Issues include those referring to the sustainability of family farming vs. capital intensive farming, questions relative to the sustainability of surface irrigation vs. pressurized, energy demanding methods, and to the adequate mix of knowledge and practice when looking for land and water productivity. A few examples are given.

Keywords: economic return, land productivity, land protection, sustainable land and water use, water conservation and saving, water productivity, water scarcity

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Assessment of AquaCrop Model on Potato Crop in Uruguay

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Abstract

The potato crop (*Solanum tuberosum* L.) is a high important crop in Uruguay. The Southern region is the most important production area of potato there. It is considered that in this region, irrigation should be supplementary since summer rainfall rarely reach crop requirements. Irrigation management is a very important tool in order to produce high quantity and quality products, efficiently. The decision support system, such as AquaCrop, helps technicians to decide when and how much irrigation to apply Nevertheless, this model needs to be calibrated and validated with local data. The objective of the present work was to evaluate AquaCrop model through two potato irrigation trials. The experiments were conducted in Southern Uruguay. Two irrigation treatments were evaluated for potato crop (cv. Chieftain) in 2010-11 and four treatments in 2011-12 growing seasons (three irrigation treatments plus rainfed - without irrigation application). The maximum crop evapotranspiration was estimated by the Penman-Monteith equation (FAO-56) using meteorological data from an automatic weather station (Campbell Scientific). The soil site was a loam soil (Albolls soil). A completely randomized block design was used with four replications. Measurements of soil water content were taken once a week using TDR probes and the soil water potential was measured using tensiometers (0.15, 0.30, 0.45 and 0.60 soil depth). To evaluate AquaCrop model,actual yield crops vs simulated yields were used. Data from other experiments were used to parameterize AquaCrop, whose stress coefficient (for excess of water) was changed to reach successful simulations. Normalized root mean square error and index of agreement between simulated and observed yield was 11.8% and 0.96, respectively. Results of this study suggest that the use of AquaCrop model is possible in vegetable crops of Uruguay allowing to characterize required supplemental irrigation in this production systems.

Keywords: water productivity, yield, cultivar, supplemental irrigation, decision support system

Reference Crop Evapotranspiration (ETo) for Irrigation Equipments design in Uruguay

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Abstract

During the last decade, national irrigation systems have expanded to summer field crops and grass, in adition to intensive traditionally irrigated crops. The maximum reference crop evapotranspiration (ETo) is the starting point for their design. Nowadays the value widely used among designers, is the maximum monthly averaged ETo, usually January. This could lead to under-sized equipments which could generate water-deficits during the critical growth stages. The maximum ETo is not a single value as would be the absolute maximum, it varies according to the period considered (daily, weekly, decadic, monthly) and the probability of non-exceedence. In this study daily ETo time series, between 28 and 35 years, recorded in January at the five experimental stations of National Institute of Agricultural Research (INIA) were analyzed. Daily ETo values with 80% probability of non-exeedence were significantly higher than those calculated based on decadic or monthly data. The latter two were quite similar, ranging from 0.1 to 0.3 mm d-1 in the different experimental stations. The aim of this paper is to recommend ETo values to design irrigation systems in Uruguay allowing maximum productive response. The maximum yield does not necessarily correspond with the maximum economic return. Thus is necessary to continue research to evaluate the productive response to different maximum irrigation doses for the different design flows. As a result, a map of Uruguay with ETo isolines based on decadic data with 80% probability of non-exeedence is presented. The equipments designed with this method meet the crop water requirements with a 80% non-exceedence probability (four over five yeas), irrigating 20 hours a day. However, if watering times are increased to 24 hours a day the historical maximum of crop water requirements is covered, except in Salto and Tacuarembó, in which crop demand is covered with a 96 and 97% non-exceedence probability respectively.

Keywords: atmospheric demand, design flow, probability of occurrence, ETo isolines

Actual Evapotranspiration Measurement Trough Eddy Covariance in Uruguay

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Abstract

Tough there have been great advances in estimating actual evapotranspiration, achieving accurate estimates at the field level is still a challenge. The characterization of site specific characteristics influencing evapotranspiration like soil properties impose a great challenge to the use of modeling, and the accurate characterization of the variability within a field of crop status may bias estimates. Using remote sensing to estimate crop status and energy balance at a fine scale overcome some of these issues. Nevertheless there is a need to have accurate and precise measurements of evapotranspiration that can serve as validation sites. The eddy covariance method provides the accuracy and footprint necessary to be used as a reference. Two towers were installed between 2010 and 2015 at two contrasting locations each year in the south-west of Uruguay at agricultural fields with wheat-soybean crop rotation. The sites were maintained at the same location during wheat and soybean, and were moved when other crops were planted at the site. Each tower had instruments to measure in parallel the energy balance (radiometers, flux plates and soil temperature probes), and evapotranspiration directly from eddy covariance (sonic anemometer, IRGA). All locations met fetch requirements, were representative of agricultural fields and were situated in an area dominated by agricultural land. Season long totals showed large variability depending on crop status and seasonal precipitation regime that determined crop growth and leaf area development. Even after full canopy cover was reached (maximum Kc) there was large variation in evapotranspiration reflecting periods of severe stress in some years. This study provides reference values for a significant number of growing conditions and years and highlights the need for considering the variability among years and crops when making estimates of demand for supplemental irrigation. It also provides reference values for methods based on remote sensing of evapotranspiration.

Keywords: Eddy covariance, eta, water use efficiency, soybean

Estimation of the Water Evaporation Intercepted by an Adult Plantation of *Eucalyptus globulus* in Uruguay

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Abstract

The interception of rainfall by vegetation cover is one of the main components of the water balance in forest systems. Forest usually have an increased evaporation of water from the canopy compared to short vegetation or annual crops, in the local conditions of wet climate this is mainly due to the high rate of evaporation from the wet canopy (interception) given by a greater storage capacity and the increased aerodynamic roughness of forests. According to results of the monitoring program on forest plantations carried out by the Universidad de la República, interception loss represents between 20 and 30% of the daily incident rainfall of medium events (40-20 mm/day), and between 10 and 18% of the daily incident rainfall of extreme events (90-60 mm/day). Rainfall interception modelling, based on the rainfall redistribution process in forest plantations, is very sensitive to the estimation of the evaporation of water retained in the canopy and thus, to the estimation of the aerodynamic resistance. In most interception models the aerodynamic resistance is determined from the roughness length for momentum transfer; Lankreijer *et al.* (1993) suggest a more general formulation considering heat transfer.

In this study the Gash interception model was implemented with the objective to analyse the model sensitivity to the roughness length for momentum and heat transfer. The modified version of Gash model was calibrated and validated using field measures of interception from a Eucaliptus globulus experimental plot located in the northwestern region of Uruguay. The simulation period was from August 2006 to April 2014. Over 400 rainfall events with complete meteorological measurements were compared with the simulated values. The results show improvements of the interception model by the introduction of the general formulation tested, which is considered most appropriate in the local climate conditions.

Keywords: evapotranspiration, rainfall interception, Eucalyptus forest

Comparison of Different ET0 Formula in Tibetan Pasturing Area

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Abstract

It is difficult to calculate ET0 by FA056 PM by the shortage of meteorological data in Tibetan pasturing area. A simple?accurate and less of meteorological data formula is very important to calculate water demand of crop in Tibet. In this paper?FAO17 Penman formula?Priestley-Taylor formula?Hargreaves-Samani formula, Irmark-Allen(I-A) fitting formula were used to calculate the ET0 in three typical meteorological stations?Dangxiong county?Gaize county?Naqu county? in Tibetan pasturing area from 1983-2012. At the same time, taking FAO56 PM formula as the standard method. The results show that? (1) The calculation results of FAO17 PM?PT formula?HS formula, I-A fitting formula are higher than the value calculated by FAO56 PM formula because of the intense radiation, great difference in temperature and strong wind on highaltitudelocalities; (2) The calculation results by I-A fitting formula was the most closest to FAO56 PM formula and the error was relatively small(relative error?20%?coefficient of determination?0.94); (3) Because of less of meteorological data and relative accuracy, I-A fitting formula can be considered to instead of the FAO56 PM formula to calculate the ET0 in Tibetan pasturing area where the meteorological data is lack.

Keywords: Tibetan pasturing area, high altitude region, reference crop evapotranspiration, suitable ET0 formula

Predicting Malt Barley Yields and Water use in Two Contrasting Rainfall Years to Improve Supplemental Irrigation Schedules Under Water Scarcity Conditions

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Abstract

Barley is usually cropped during the Winter-Spring season and may require supplemental irrigation in dry years. When malt barley is cropped for the industry, irrigation is used to achieve high commercial yields taking into consideration that irrigation should be ceased about one month prior to harvesting in order to achieve high malt quality. Data from two crop seasons of *Hordeum vulgare* L. cv. Publican, one dry and the second wet, cropped in a farmer's field located in the Ribatejo region, Portugal, were used for calibrating and validating the SIMDualKc soil water balance model, to assess the ability of a simplified approach (SIMDualKc model coupled with the Stewart's global model) for grain yield predictions and to parameterize and test the AquaCrop crop growth and yield model. The SIMDualKc model calibration consisted in deriving the basal crop coefficients (Kcb) and depletion fractions for no stress (p) along the crop growth stages using available soil water (ASW) observations throughout the season. Validation of the model consisted in using the calibrated parameters for the wet season. Results have shown a good agreement between observed and predicted ASW, with low errors of estimate (RMSE < 9% of the total available water) and high modelling efficiency (EF > 0.85). The AquaCrop model was parameterized for the canopy cover curve using data derived from LAI observation with good results (RMSE < 5.2% and EF > 0.97). It was also tested using the referred observed ASW data, however showing lower accuracy than SIMDualKc and a bias in ASW estimations. Good yields predictions were obtained with both the simplified approach and with AquaCrop, with deviations not exceeding 17% of observed grain yields. Under dry climatic conditions and using two sowing dates, several supplemental irrigation strategies were designed and evaluated using both models. The feasibility assessment of those alternatives was performed analysing the water-yield impacts and various water productivity indicators. Results have shown that there could be advantageous to adopt early sowing and supplemental deficit irrigation. Furthermore, results showed that rainfed malt barley may not be economically feasible under dry climatic conditions, thus indicating that this strategy should be adopted with caution by farmers. This study shows that SIMDualKc model is more adequate than AquaCrop for irrigation scheduling proposes and that both modelling approaches herein applied can be used for yield predictions and to support farmers' advice.

Keywords: dual crop coefficients, crop transpiration and soil evaporation, soil water balance model, Stewart's model, AquaCrop model, simulation modelling

Eddy Covariance Estimates of Evapotranspiration in Irrigated and Rainfed Soybean in Uruguay

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Abstract

Estimating total crop water use and the associated variability are critical for planning, for the design of supplementary irrigation strategies and for subsequent management. Tough there have been great advances in estimating actual evapotranspiration, achieving accurate estimates at the field level is still a challenge. The characterization of site specific characteristics influencing evapotranspiration like soil properties impose a great challenge to the use of modeling, and the accurate characterization of the variability within a field of crop status may bias estimates. Using remote sensing to estimate crop status and energy balance at a fine scale overcome some of these issues. Nevertheless there is a need to have accurate and precise measurements of evapotranspiration that can serve as validation sites. The eddy covariance method provides the accuracy and footprint necessary to be used as a reference. Two towers were installed between 2010 and 2015 at two contrasting locations each year in the south-west of Uruguay at agricultural fields with wheat-soybean crop rotation. The sites were maintained at the same location during wheat and soybean. Sites were managed with supplementary irrigation at full demand or without irrigation. Each tower had instruments to measure in parallel the energy balance (radiometers, flux plates and soil temperature probes), and evapotranspiration directly from eddy covariance (sonic anemometer, IRGA). All locations met fetch requirements, were representative of agricultural fields and were situated in an area dominated by agricultural land. Season long totals showed large variability depending on crop status and seasonal precipitation regime that determined crop growth and leaf area development. Totals for irrigated fields in the north (Salto, 650-800mm) were higher than in the south (Colonia-Soriano, 600-750), and higher than standard requirements for the region. This study provides reference values for a significant number of growing conditions and years for irrigated or rain-fed soybean crops.

Keywords: Eddy covariance, eta, water use efficiency, soybean

Simulating Maize and Black Bean Yield under Different Water Management Strategies in Southern Brazil

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Abstract

The relationship between crop production and the water involved has been a object of study by soil, plants, meteorological conditions and irrigation management scientists Agriculture is the largest user of water, which requires an increase on crop water productivity (WP), which can be achieved through the adoption of an efficient irrigation water management as well as techniques that focus on the conservation of water resources. The WP is an index typically used to develop and assess the irrigation water management strategies that aim to improve the efficiency in utilizing water resources. Models of WP and f crop yield can be helpful for estimating crop response to water when associated to irrigation scheduling with and without water deficit imposition. The main objective of this study was to assess the impact of water deficit on maize and black beans yield and use the empirical Stewart's model (1977) to predict yield under different water management strategies. The SIMDualKc model was calibrated and validated using observed soil water content data during three growing seasons (2010-2012), and four irrigation strategies: fully satisfy water requirements, while deficit t irrigation were for increasing controlled soil deficit, difined as mild deficit, moderate and severe deficit during both crop growth stages. The estimated data from the actual crop evapotranspiration relating to the four irrigation strategies were used at different phases in Stewart's model in order to predict crop yields. The maximum yield (Ym) for both crops in the present study was obtained from the highest yields achieved for the full irrigation treatment and compared with those estimated with the Wageningen method. Statistical indicators were used to assess the models' effectiveness, including a linear regression through the origin, having the regression coefficient (b0), and the determination coefficient (R2).and the Root Mean Square Error (RMSE). Results should contribute for assessing the economic impacts of soil water deficits in crop yield, as well as for evaluating irrigation management strategies.

Keywords: soil water balance, Stewarts' yield model, evapotranspiration, SimDualKc model

Soil Conservation Management

How Irrigation Affects Soil Erosion Estimates of RUSLE2

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Abstract

RUSLE2 is a robust and computationally efficient conservation planning tool that estimates soil, climate, and land management effects on sheet and rill erosion and sediment delivery from hillslopes, and also estimates the size distribution and clay enrichment of sediment delivered to the channel system. In the U.S.A., RUSLE2 is supported by extensive databases maintained by the USDA-Natural Resources Conservation Service. Examples are presented of how input climate, soil and management descriptions might be built outside the U.S.A. using data from Uruguay. In addition to average annual erosion and sediment delivery, recent enhancements give RUSLE2 the ability to predict a representative runoff event sequence for a particular location, soil, management, and user-specified return period that can be coupled with a channel erosion and routing model.

Keywords: runoff, soil erosion, irrigation

Introduction

Since 2000, there has been an increase cropping intensity in Uruguay. Cropped area has increased by a factor of three, largely accounted by increasing area cropped to soybean. The growth of soybean area has come at the expense of rotations of cropland with grass/legume pastures. Current cropping systems are largely conducted with no tillage (direct seeding) and often winter cover crops are employed. Although Uruguay receives 1 to 1.5 m of rainfall annually, available soil water is not always adequate to support optimal crop growth so irrigated cropland area has also been increasing. Concern has been expressed that the wetter soil conditions under irrigation could increase the risk of soil erosion by rainfall. The purpose of this study was apply the RUSLE2 model to Uruguayan conditions to estimate the impact of irrigation on the risk of soil erosion by water.

Materials and Methods

The influence of irrigation on erosion estimated by RUSLE2 occurs through changes to the K factor and the C factor. In RUSLE2, there is no representation of any direct erosion caused by added irrigation water. Rather irrigation increases the water content of the soil, which increases the likelihood of runoff, and this is reflected through changes in the K factor. In the USLE/RUSLE/RUSLE2 family of models, soil erosion is assumed to be linearly related to the rainfall erosivity. There is no separate runoff term in the erosion equation. Rather, the likelihood of runoff and associated sediment transport is one of the factors that influences the K factor.

In RUSLE2, erosion and the state variables that control it are calculated on a daily basis. Whereas in USLE, K was taken as a constant, in RUSLE2 the default behavior is to have K vary daily based on monthly temperature and rainfall information contained in the input climate description (USDA-ARS, 2013, section 4.5). The local monthly temperature and rainfall values are compared to those from the center of the U.S.A. (Columbia, MO). Generally, the K factor is higher where and when runoff is more likely to occur due to wetter and cooler conditions. Conversely, the K factor is greatly reduced when the soil is likely to be frozen. This time varying K factor is affected by added irrigation water, resulting in a higher likelihood of runoff and therefore erosion and sediment delivery.

Added irrigation water also influences the breakdown of plant residue biomass. In RUSLE2, each sort of plant residue is characterized by a decay constant that describes that residue type's potential rate of decomposition under optimum conditions. A separate residue pool is created on each day that residue is added to the system. Each pool's decomposition is simulated with an exponential decay equation. The actual rate of decomposition on a given day may be limited by sub-optimal water or temperature conditions (USDA-ARS, 2013, section 10.3). Adding irrigation water may overcome water limitations to residue decomposition where the natural climate limits residue decomposition rates due to inadequate water. Increased decomposition will lower crop residue biomass, which will increase several of the RUSLE2 C sub-factors. Thus, irrigation could increase RUSLE2 soil loss estimates through C factor effects. However, to the extent that irrigation increases crop yield, it will also increase residue returned to the field. In RUSLE2, crop yield increases due to irrigation must be specified by the user since, unlike the residue decomposition process, RUSLE2 does not include a crop growth model that automatically increases crop yield in response to available water. If the user-specified increase in crop yield results in residue additions that exceed the increased decomposition losses caused by added irrigation water, then the net C factor in RUSLE2 may be reduced, and may offset the increased K factor associated with the wetter soil.

RUSLE2 Application to Uruguay

To illustrate the effects of irrigation on RUSLE2 erosion estimates, it is necessary to consider a RUSLE2 «profile,» which is a representative hillslope described by climate, soil, topography, and management information. Each of these are «objects» in RUSLE2 that must be specified. Below is a brief description of how these objects were described in this study.

Climate: RUSLE2 climates consist of monthly inputs of temperature, rainfall, and erosivity density (the ratio between the R factor and the rainfall depth), plus the depth of the 10-y 14-h precipitation depth (Dabney *et al.*, 2012). Zhu and Yu (2015) proposed that the following equation could be used to estimate monthly rainfall erosivity, E_j, from daily rainfall data:

$$\hat{E}_j = \alpha\left[1+\eta\cos\left(2\pi f\, j-\omega\right)\right]\sum_{d=1}^{N} R_d^{\beta} \quad (1)$$

where:

R_d is daily rainfall (mm), N is the number of days in month j, f=1/12, and α, β, η, and ω are parameters to be estimated. Generally, for the Southern Hemisphere, ω is set to π/6, indicating rainfall intensity would be highest in January, and to 7ð/6 in the Northern Hemisphere, indicating rainfall intensity would be highest in July. To find parameter estimates that would approximate monthly erosivity values from average monthly rainfall values, we replaced R_d with R_j and fitted the equation to monthly rainfall and erosivity pairs contained within in the official RUSLE2 database (USDA-NRCS, 2015) at selected sites in the southeastern U.S.A. Based on inspection of results, we used parameter values of α=0.4, β=1.5, η=0.5 to estimate RUSLE2 monthly erosivity values for Uruguay based on average monthly rainfall values for the period 1990 to 2009 (World Bank, 2015). These parameter values are not considered optimal and more testing could refine them, but the resulting estimated monthly erosivity values appeared reasonable for the purposes of this paper. The result was an average annual R=6060 MJ mm ha^{-1} h^{-1} for annual rainfall of 1344 mm. We also specified a latitude of -33 degrees and assigned a value of 140 mm to the 10-yr 24-hr rainfall depth, similar to events at similar northern latitude in the southeastern U.S.A.

Soil: A base K factor of 0.023 Mg h MJ^{-1} mm^{-1} was adopted as reported by Hill *et al.* (2008) for the la Estación Experimental La Estanzuela (LE, Colonia, Uruguay). This user-specified base value was allowed to vary on a daily basis referenced to Columbia, MO, U.S.A. Additionally, the soil hydrologic group was set to «A,» the clay was set to 32 %, and the sand was set to 25 %.

Topography: The LS factor was calculated for conditions equivalent to unit plot conditions (22.1 m long, 0.03 gradient), which is similar to the plot condition described in Hill *et al.* (2008).

Land management: Several crop management conditions were simulated. First, a continuous soybean disk/field cultivator tillage system is explored with and without irrigation. Rainfed yield level was set at 2.3 Mg ha^{-1} y^{-1}. Irrigation was represented as four 5.1 cm applications between 15 Dec and 4 Feb. RUSLE2 response to irrigation was estimated for two cases: (1) using the base soybean yield and (2) with a 30 % greater soybean yield of 3.0 Mg ha^{-1} y^{-1}. Second, a corn soybean rotation simulated under direct seeding (no-till) with grass cover crops between each grain crop, with and without irrigation. Planting dates, growth periods, and yields were varied in these simulations (Mario Pérez Bidegain, personal communications).

Results

The effect of adding ~20 cm of irrigation water during the December through February period on the RUSLE2 K factor is illustrated in Fig. 1. It should be noted that even without irrigation, the effective K factor in Uruguay is higher than the

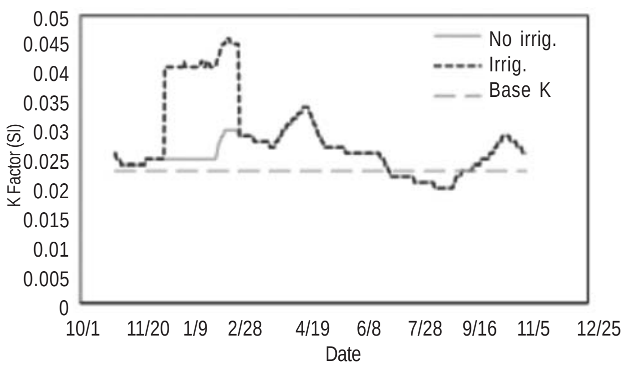

Figure 1. Daily RUSLE2 estimated K factor in Uruguay for a user-entered base K=0.023 for rainfed and irrigated conditions.

base K factor specified because Uruguay receives more rainfall than does the reference location (Columbia, MO, 987 mm). Addition of irrigation nearly doubles the K factor during the irrigation season.

Figure 2 illustrates how RUSLE2 estimates the C factor, the K Factor, the standing above ground biomass, the surface residue biomass, and the runoff and erosion for a representative series of runoff events calculated according to procedures described by Dabney *et al*. (2011, 2012) for rainfed conditions. The sum of the estimated erosion events resulted in an estimated annual soil loss of 19 Mg ha^{-1} y^{-1}. Addition of irrigation without any increase in crop yield increased the annual erosion estimate to 21 Mg ha^{-1} y^{-1}. Increasing the soybean yield to 130 % of the base yield with irrigation resul-

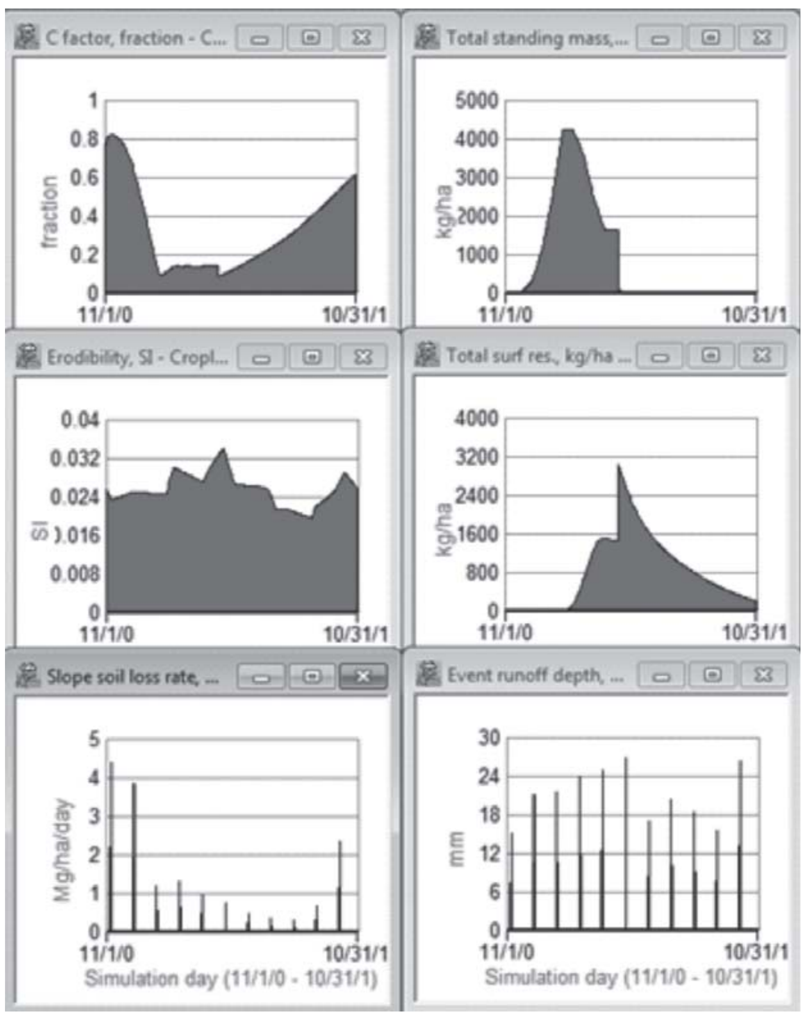

Figure 2. Plots generated by the RUSLE2 graphical user interface display daily estimated C and K factors, above ground and surface residue biomass, and representative event runoff and erosion for disk-till soybean grown on a 22.1 m 0.03 gradient plot with base K = 0.023 in Uruguay.

Table 1. RUSLE2 individual event runoff and erosion estimated on December 11 for runoff events with varying return periods for disk-tillage soybean grown on 22.1 m long, 3 % slope plots in Uruguay on a soil with K=0.023.

Scenario	Irrigation	Yield (Mg ha^{-1})	Return Period	Runoff (mm)	Erosion (Mg ha^{-1})
1	no	2.3	unspecified	21	3.8
2	no	2.3	1	55	3.8
3	no	2.3	10	99	7.7
4	no	2.3	100	150	12
5	yes	3.0	100	150	12

ted in an annual average erosion estimate of 18 Mg ha^{-1} y^{-1}, lower than the base rainfed estimate, but still much too high to be sustainable.

The user can use RUSLE2 to explore the risk of extreme events by specifying a return period for any single event in the runoff event sequence. Table 1 illustrates the effect of varying the return period on estimated individual event runoff and soil loss for extreme events occurring on 11 December, a date when the RUSLE2 C factor was equal to 0.71. The results show that both runoff and soil loss increase with extreme events. However, as implemented in RUSLE2, irrigation had only a slight effect on runoff and erosion of associated with an extreme event. This may be because the extreme event overwhelms the impact of antecedent conditions or because RUSLE2 does not account for all forms of erosion. For example, RUSLE2 erosion estimates do not account for soil loss associated with concentrated flow and ephemeral gullies, which are likely to be important during extreme events. Dabney *et al.* (2015) have discussed technology that can extend RUSLE2 erosion estimates to include ephemeral gully estimates.

To estimate the likely effect of irrigation on land managed with direct drilling and cover crops, two corn-soybean cropping systems described in Table 2 were compared on the

Table 2. Management descriptions (operations and vegetations) of direct seeded corn soybean rotations under rainfed and irrigated conditions.

Date, m/d/y	Operation	Vegetation	Yield Mg ha^{-1}	Resid. added Mg ha^{-1}	Cover added %
Rainfed					
1/1/00	no operation				
5/15/00	harvest killing crop			3.91	73
5/25/00	begin growth	grass cover	4.6		
11/1/00	kill vegetation				
11/10/00	drill, double disk	soybean	2.6		
5/15/01	harvest killing crop			1.39	51
6/1/01	begin growth	grass cover	4.6		
11/25/01	kill vegetation				
12/10/01	planter, double disk opnr	corn	6.0		
Irrigated					
1/1/00	no operation				
3/20/00	harvest killing crop			5.64	85
4/1/00	begin growth	grass cover	4.6		
11/1/00	kill vegetation				
11/10/00	drill, double disk	soybean	3.3		
4/15/01	harvest killing crop			1.72	59
5/1/01	begin growth	grass cover	4.6		
8/25/01	kill vegetation				
9/10/01	planter, double disk opnr	corn	8.0		

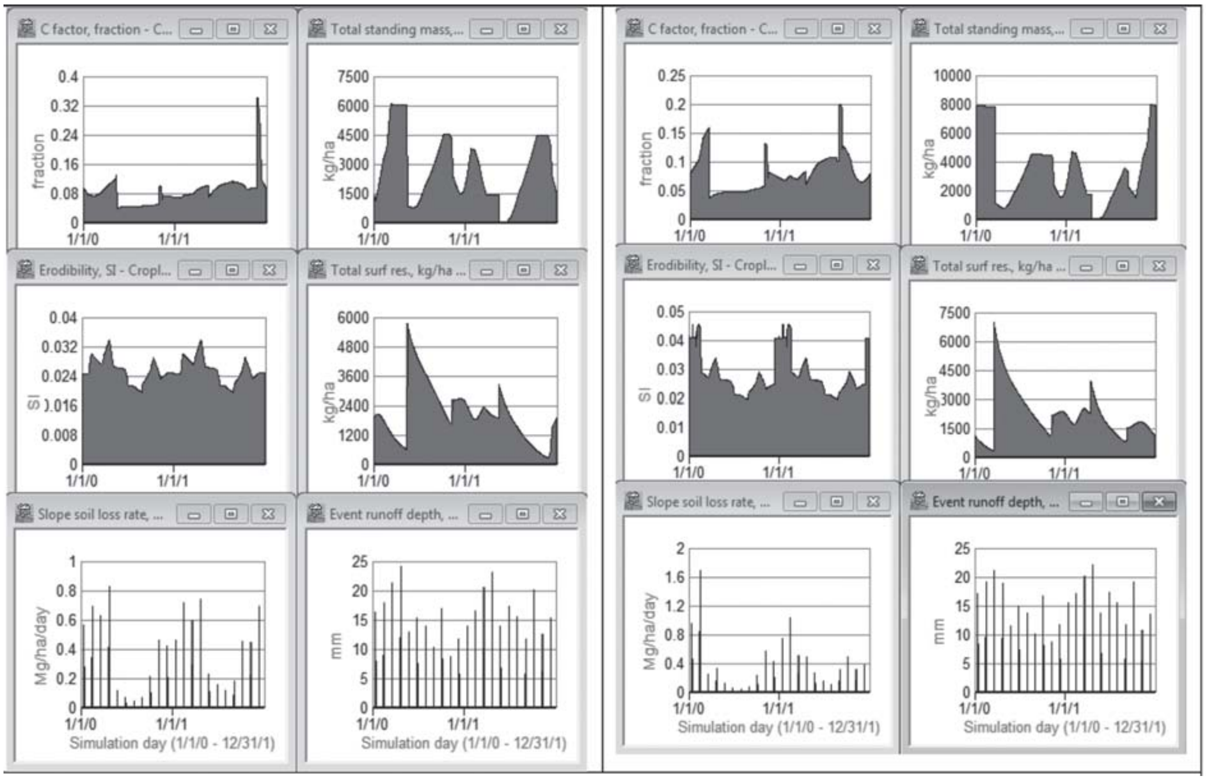

Figure 3. Daily RUSLE2 estimated C and K factors, above ground and surface residue biomass, and representative event runoff and erosion for direct seeded soybean-corn rotations described in Table 2 (A) rainfed and (B) irrigated on a 22.1 m 0.03 gradient plot with base K = 0.023 in Uruguay.

same hillslope described above. In this case, in order to have RUSLE2 generated plots begin on January 1, a null operation on that date was added to each management description.

Figure 3 illustrates the RUSLE2 estimated runoff and soil loss for the land management systems described in Table 2. In this case irrigation increased estimated average annual soil loss about 10%, from 4.5 to 4.9 Mg ha^{-1} y^{-1}. The largest soil loss events occurred during the irrigated corn growing season (mid-February of the first year) when surface residue cover was close to a minimum value. Under both rainfed and irrigated conditions, RUSLE2 sheet and rill erosion estimates were much lower than under the disk-tillage continuous soybean simulation, but are still significantly higher that would be expected from well-managed pasture (Dabney *et al.* 2012).

Discussion

RUSLE2 is a conservation planning tool whose primary objective is to lead to sound conservation planning decisions. The increased RUSLE2 K factor estimated by RUSLE2 in Uruguay is consistent with the observations by Hill et al. (2008) that erosion was increased when antecedent soil water content was higher. In this case, no water balance was conducted. Rather, the added irrigation water was disaggregated into daily values whose effect on the K factor was estimated. When used for conservation planning, the exact amount and timing of future rainfall and irrigation events is not known so simplified procedures are justified.

An option exists with RUSLE2 to use historical rainfall event data rather than the representative

runoff storm sequence approach illustrated herein. This alternative uses a «rain-data» object that accepts as input: rain event date, event depth, event erosivity, rainfall duration, maximum 30-minute intensity, rainfall start time and rainfall end time. If multiple rainfall events occur within a single day, RUSLE2 combines all the events on a day into a composite event. When this option is selected, estimated erosion will vary from year to year and not just season to season. In this retrospective case, accuracy of predicted daily runoff would be improved by a daily water balance accounting.

While an increased risk of erosion associated with wetter soil is estimated by RUSLE2, the increased yield associated with irrigation compensates for this through increased canopy and crop residue cover. For the Uruguayan conditions studied, these two influences largely offset so RUSLE2 predicts only minor impacts of irrigation on water erosion. A more comprehensive analysis would consider the effects of extreme events on ephemeral gully erosion. Certainly, field validation of erosion estimates is needed.

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Supplemental Irrigation: Improving Sustainability or Risking Our Soil Resource

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Abstract

Soils of Uruguay are economically and socially critical to this country. These soils, while highly variable, have high clay content, reside on a sloping topography, and experience periodic rainfall events with high erosive energy; these soils are very fragile and susceptible to degradation. These soils are very well suited for grassland based agriculture. Traditional crop and pasture rotations have made major contributions to the Uruguayan economy while minimizing soil degradation. However, new agricultural technologies, especially GMO soybeans, and increased foreign investment in Uruguayan agricultural land have resulted in more continuous row cropping – dominantly soybeans – and loss of grass base agricultural farming systems. Investments in irrigation systems offering supplemental water to buffer against periodic drought will likely be most economically supported for row crop enterprises designed to maximize short term profits. This technology, like GMO soybeans, could further incentivize expansion of row crop production to capitalize on short term profits and result in less agricultural area devoted to grass based rotations, creating more soil sustainability challenges than currently exist. Additionally, irrigation on row cropped soils increases the risk of accelerated soil structure degradation, surface crusting or sealing, water runoff, soil erosion, and compaction. To help counter this challenge, development of efficient and economically favorable irrigation systems for pastureland should be a research priority for long range sustainability goals of Uruguay agriculture in the face of climate change. Agriculture resilience to climate change will be better accommodated by maintaining or improving soils than by expansion of supplemental irrigation for row crop production.

Keywords: supplemental irrigation, soil degradation, soil resilience

Wheat Fertilization Opportunity (*Triticum aestivum* L.) with Localized Irrigation

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Abstract

In Argentina, the moment of application of agrochemicals on extensive crop dryland farming is reduced by the development of the vegetative phases. Although it is hardly implemented by producers, sprinkler irrigation extends the time period for the application of fertilizers. Localized irrigation, which has been incorporated into these production systems, increases the fertilization opportunity thus reducing the doses if compared to other irrigation methods. The aim of this paper was to assess the fertilization opportunity of the wheat yield (*Triticum aestivum* L.) by using localized irrigation in the city of Luján, Buenos Aires. The yield with traditional fertilizers was compared to other methods where fertilizers were fractioned. Klein Tauro wheat was planted on August 6th 2014. The field received the following treatments: dryland farming fertilization to the crop, fertilizer irrigation to the crop, irrigation through fractionation of fertilizers to the crop including the poaceae stage, irrigation though fractionation of fertilizers to the crop and pod filling, and irrigation through fractionation of fertilizers, poaceae stage and pod filling. Upon harvest, the yield and its components were assessed as well as the efficiency of water used as regards to the dry weight of the grain. Statistically, there were no significant differences (Tukey test, p-value < 0. 05) except for the dry weight of 1000 grains, taking into account the dryland farming fertilization and the irrigation through fractionation of fertilizers and pod filling 42, 70 g and 37, 36 g respectively. Mid-levels were: dry weight of 1000 grains, 39, 74 g, crop yield, dry weight yield 3665, 75 kg ha^{-1}. Mid efficiency in the production of matter considering the water used during the crop cycle was 7. 99 g mm^{-1} ha^{-1}.

Keywords: extensive crops, nitrogen fertigation, water use efficiency, yield components

Crop Yield and Determination of Kc Tomato Crop (*Lycopersicum escultentum* Mill.) in Passive and Heated Greenhouse on Northwest of Uruguay

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Abstract

Northwest of Uruguay produces 68% of tomato in counter-season conditions using passive greenhouses. A two years trial evaluating ET0, Kc, yield, quality and precocity of crop, in passive (TSC) and heated greenhouse (TCC) was carried out. Energy source for heated greenhouse was hot water from Guaraní Aquifer. Drip irrigation with fresh water was used. Hourly records of global solar radiation, wind speed, air temperature and humidity at 1.5m high, were obtained from automatic meteorological stations in both greenhouses and outdoor. Evapotranspiration was estimated by drainage lysimeters. Crop yield was weighted and calibrated at each harvest date. ET0 was calculated using FAO-Penman-Monteith method. Kc was calculated as the ratio between water consumption and ET0. ET0 calculated within greenhouses was about 70% of the calculated outdoor. Although the temperatures in TCC were slightly above unheated greenhouse no significant differences were found. With regard to outdoor temperatures, minimum did not differ significantly from those recorded in the greenhouses; not the maximum, which were higher in the protected area in first crop cycles. In the second crop cycle minimum and maximum temperatures were consistently higher ($P < 0.05$) in the TCC than in TSC. In the first crop cycle total yield was greater in TCC than in TSC ($P<0.05$) and showed precocity probably due to the lower number of hours below 10°C (critical level for flowering), early in the culture. Yield was greater in TCC in the first month of harvest. The evaluated period corresponds to flowering and fruiting, cultivar used is an indeterminate one. The Kc obtained for the whole period were 1.06 for TSC and 1.25 for TCC varying between 0.4 and 1.2 for the first and between 0.8 and 1.5 for TCC.

Keywords: evapotranspiration, water requirements, protected crop

Modelling the Soil Water Balance of Maize under No-tillage and Conventional Tillage Systems in Southern Brazil

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Abstract

No-tillage and crop residue practices could help improving water productivity (WP) in irrigated areas. Mulches increase the crop yield and WP by favouring the water status in the root zone and reducing soil evaporation. However, scientific knowledge tells that no-till systems change the soil physical properties by increasing the soil bulk density and reducing soil porosity, which can lead to alterations in soil water fluxes as well as the soil water dynamics in the soil-plant-atmosphere system. Thus, water balance models combined with field experiments can favour a better understanding of the soil water dynamics under different tillage systems and irrigation management. The present study aimed at assessing the performance of the soil water balance model SIMDualKc which applies the dual crop coefficient approach to partition crop evapotranspiration into crop transpiration and evaporation components of a maize crop cultivated under no-tillage and conventional tillage systems, and under different irrigation managements. Two experiments were carried out in the 1999/2000 and 2000/2001 growing seasons in an experimental field of the Agricultural Engineering Department of the Federal University of Santa Maria, Southern Brazil. Treatments consisted of a 2 x 2 factorial scheme, in a completely randomized design, with four replications. The tested treatments were: Factor A - irrigation management (irrigation and terminal water stress, irrigation was ceased after V7) and, Factor B - tillage system (no-tillage and conventional tillage). Soil water content was measured three times a week along crop seasons using a neutron probe until 1.10 m of soil depth. Irrigation was scheduled using as threshold a cumulative crop evapotranspiration of 25 mm and an irrigation depth that allowed raised the soil water content to field capacity was used. The SIMDualKc model was calibrated for each tillage and irrigation management using data from the first season and validated against data of the 2000/2001 season. Goodness of fit indicators were used to assess model performance and included a linear regression through the origin and an ordinary least-squares regression between observed and simulated soil water content, having respectively as indicators the regression coefficient (b0) and the determination coefficient (R2), the Root Mean Square Error (RMSE) and the Nash and Sutcliff model efficiency (EF). Results show the ability of the model to be further explored to support farm irrigation scheduling and tillage practices in southern Brazil.

Keywords: tillage systems, soil water balance, soil and water conservation, evapotranspiration partition, SIMDualKc model

Nitrogen fertilization in Maize under Irrigated and Rainfed Conditions

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Abstract

Crop production in Uruguay has changed significantly in recent years, not only in terms of expansion of cultivated area but in its main features. These changes came along with significant increase in land prices and agricultural inputs causing intensification on land use. In order to get high profits the traditional crop-pasture rotations should be strongly oriented to a continuous cropping system and strengthened on grain crops. The potential of agricultural systems is highly dependent on rainfall, therefore, the adoption of irrigation represents an attractive alternative to increase productivity and reduce vulnerability of productive systems. Maize performance and its C4 metabolism enhancing water use efficiency represent an excellent choice for farmers. Nitrogen (N) is one of the main nutrients affecting plant growth and maize grain yield response to N application is well known. In order to reduce N losses, increase uptakes and improve N use efficiency, optimum amount of water and N should be applied. The objective of this study was to assess the interaction between irrigation and N application rates and its effect upon yield. A three year field experiment was carried out in Colonia, Uruguay (34º25´S, 58º0´W), at the Experimental Station of the National Agricultural Research Institute (INIA) "La Estanzuela", in three growing seasons (2011-2014), under a Vertic Argiudoll soil. The experimental treatments consisted in eight urea treatments with four levels of N application (0, 50, 100, 150 and 200 KgN/ha) at three different phenological moments (V6, V10 and V14) under rainfed and supplementary irrigated conditions. The study showed that the average grain yield on irrigated conditions was 12.060 ± 2282 kg/ha for all treatments and 7.089 ± 1615 kg/ha under rainfed conditions. Results indicated that due to the strategies of N application and irrigation water application, yields increased as N rate application increased. Furthermore, results showed that under rainfed conditions N treatments did not translated in significantly increased grain yields, indicating that when water is scarce, the effect of nutrients are scattered, and the achievable grain yields are not reached. The maximum grain yield was obtained for 200 kgN/ha application treatments, showing an increase of 5.337 kg/ha under irrigated conditions, while on rainfed conditions was only 1.500 kg/ha. However, in order to avoid N losses and improve N use efficiency, the amount of N fertilizer should not be applied at one time. It can be concluded that supplementary irrigation is a fundamental technology not only to maximize and stabilize grain yields but to enhance N use efficiency.

Keywords: urea, supplementary irrigation, N use efficiency

Soils Degradation and Kind of Producer for Sustainable Cultivation of Quinoa in the InterSalar of Oruro'S Department, Bolivia

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Abstract

The last decade it's distinguished by a growing demand of quinoa grain, extending the cultivated surface; a cattle breeding of camelidos has reduced, accelerating the soils degradation and the appearance of different kinds of producers. From the year 2013 to 2014 this research has been developed and the principal target was to evaluate soils degradation, identify the kinds of producers and the sustainable cultivation of quinoa. The soils degradation has been evaluated through soils analysis of the 2007 and 2014 years and microbiological activity too. For the kinds of producers, was done survey and interview in 63 producers to evaluate the biophysics and economics, the information was evaluated through descriptive statistics and the multivariate analysis. Also the sustainability of cultivation quinoa was evaluated using indexes of soils quality and culture health with a rate of 0 to 5. The results show that in the period of 7 years these soils has been reduced organic matter and total N, K^+ and Mg^{++} interchangeable, variations that are statistical significant, microbiological activity it's reduced to long time production plot. Depending of land tenancy were identified three kind of producers: The kind I, who are the actually landowner with 21 to 50 or more hectare; the medians from six to 20.9 hectare and the small who have less than six hectare, the monoculture sustainability depending of soil and health soil is minor when the producing land is bigger. It's quite urgent to start public politics actions to national, local government and municipality level that can regulate the seeded land not "to live good" then "to live without degrading" .

Keywords: soils degradation, kind of producers, sustainability, quinoa, culture health and intersalar

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Farm Wastewater Treatment with Microalgae. A Living-lab Experimental Unit

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Abstract

Wastewaters from farms, agro-industrial activities and urban grey waters are residues that can be valued, through their reuse for several purposes within the farm, for example, irrigation or facilities washing. This practice saves conventional water and preserves the environment from contaminations, namely the water resources. This paper presents a research project planning an experimental study to be carry out in a wine farm aiming, through the settlement of a microalgae reactor, the wastewater treatment and the microalgae production. The farm has a vineyard, a winery and a rural tourism unit. Wastewaters are mainly generated from washing the equipment and the fermentation tanks and from the house (grey waters, with low organic loads). According to their characteristics a wastewaters pre-treatment might be required. The outdoor bioreactor uses those wastewaters, solar radiation and is supplied with CO_2 conducted from wine fermentation and from the composting unit, reducing the emission of this greenhouse gas. Prokaryotic cyanobacteria, as well as mono- and oligocellular species of eukaryotic algae species will be tested and applied. The performance of the outdoor cultivation systems will be assessed with respect to their light utilization (photosynthetic efficiency), growth yields (productivity), the economic aspects for the cultivation of phototrophs and the quality of treated wastewater.The biomass produced will be used as animal feed, for example for aquaculture, or as soil fertilizer. Treated wastewater will be temporarily stored, for later use, particularly for vineyard drip irrigation.The experimental unit of this project will be set in a living-laboratory to revitalise the environmental education, benefits for knowledge extension to other farmers of the Region. It will also provide deeper knowledge of this type of units to enable its optimization for a larger scale application and extension.

Keywords: algae, bioreactor, irrigation wastewater reuse, wastewater

Phosphorus Runoff in a Non-fertilized Soybean Production System of SW Uruguay

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Abstract

Since 2001/2002 there has been a formidable expansion of annual crops in Uruguay which has determined changes in land use, with a strong expansion of soybeans (*Glycine max*) under no-tillage. Improperly managed crop production systems can be an important nonpoint source of pollution, accelerating eutrophication of surface waters resulting from nitrogen and phosphorus (P) inputs. Nutrient losses depend on many factors such as climate, soil characteristics and management practices. Thus, the objective of this work was to estimate the annual P loss on a cropping system and to determine the main factors contributing to such losses. Runoff plots were located at the Experimental Station of the National Agricultural Research Institute in Colonia (INIA "La Estanzuela"), Uruguay (34º25´S, 58º0´W) during the period 2013-2014. Plots were under a Vertic Argiudoll soil with 18.5 mg/kg P-Bray I on the first 7,5 cm, a 3% slope and available water content of 92.7 mm on the first 56 cm of soil depth. The rotation established was soybean - fallow/cover crop, non-fertilized for over 5 years. The amount of runoff water was measured for 23 rainfall events and analyzed for soluble P. During that period the soybean yield was similar to the national average yield and the annual P loss was 0.5 kg/ha. Available water, precipitation, maximum rainfall intensity and runoff explained most of the variation in P runoff losses. Rainfall events of high magnitude and intensity on soils with high available water were identified as the events that produced higher water and P runoff. On the other hand, the model that best fitted P losses was just explained by rainfall and runoff (P = - 9.99 + 0.95*rainfall +21.56*runoff; R^2=0.73). Overall, our results indicate that these soybean-cover crop systems under no-tillage, on soils with proper nutrient status and non-fertilized for a long time seem to be economically and environmentally adequate management systems.

Keywords: nutrients, eutrophication, runoff plots, annual crops

Soil Use Intensity Effects on Soil Organic Carbon in No-till Crop-pasture Rotations Systems

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Abstract

Soil organic carbon (SOC) is a key soil quality indicator for cropping systems sustainability. We evaluated 20 yrs. soil use intensity effects on SOC (0-5 cm and 5-15 cm depth) in a 72 ha no-till crop-pasture rotation experiment (33°:15'36"S, 54°:29'26"W, 60-m elevation) in Treinta y Tres, Uruguay (Abruptic Argiaquolls and Oxiaquic Vertic Argiudolls). Treatments between 1995-2005 were: Continuous cropping (CC) of ryegrass (*Lolium multiflorum* Lam. or oat *Avena sp*. in winter and sorghum (*Sorghum bicolor* L.) or foxtail millet (*Setaria italica*) in summer; 2) Short Rotation (SR): two years idem CC and two years pasture of red clover (*Trifolium pretense* L.) and *Holcus lanatus* L.; 3) Long Rotation (LR) two years idem CC and four years pasture of tall fescue (*Festuca arundinacea* L.), white clover (*Trifolium repens* L.) and birdsfoot trefoil (*Lotus corniculatus* L.); 4) Permanent Pasture (PP): natural pasture overseeded with legumes used in RL. Since 2005 until now, grain crops substituted forage crops in the «cropping phase» of all rotations (CC, SR, LR), maintaining without modifications the pasture phase of them. Grain cropping sequence was: Oat (*Avena sativa L.), Sorghum bicolor (L.),* black oat *(Avena sp.,* as a winter cover crop), soybean *(Glycine max L.)* and wheat *(Triticum aestivum).* After 20 years, significant SOC differences (0-5 cm) were found between rotations. Continuous cropping decreased SOC by 16%, 18%, 31% compared to SR (25.55 g kg^{-1}), LR (26.17 g kg^{-1}) and PP (31.32 g kg^{-1}), respectively. Although no SOC differences were found between rotations that include perennial pastures (SR and LR), both had 18% lower SOC than PP. A trend of SOC decrease (12%) was observed also in PP compared to the original situation that existed at the beginning of the experiment (natural pasture 35.25 g kg^{-1}). No SOC differences were found in the 5-15 cm depth between treatments that included pastures. However, there was an average SOC increase of 14% in these treatments (13.34 g kg^{-1}) compared to CC. The aggregate of data suggest that, even under no-till, continuous cropping reduced SOC compared with cropping systems that include some proportion of pastures in the rotation. For undisturbed fragile soils incorporated to grain production, like those prevalent in 1 million ha in Eastern Uruguay, the inclusion of perennial pastures in the rotations is critical for soil conservation and mitigation of SOC losses in cropping systems.

Keywords: soil quality, conservation systems, carbon sequestration, long-term experiments

Water Interception by Crop Mulch *Avena strigosa* in Irrigated No-Tillage System

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Abstract

One of the difficulties of the irrigation management is determining the effective rainfall, that is, the water that is indeed available to the crops, due to the influence of the climatic factors and the soil characteristics, as the surface roughness, the composition and the amount of mulch. Objectifying the quantification of the interception and the water storage through mulching in an irrigated no-tillage crop system this work was conducted on a Ultisol in Santa Maria, RS, Brazil; in the agricultural year of 2013/2014 with *Avena strigosa* crop waste. The period of the evaluations was from 60 days, numbering nine events; in which three levels of mulch, (bare soil, 2 and 4 t ha^{-1} of dry matter - DM) under three irrigation levels (4, 8 e 16 mm) in a micro sprinkler system, with a bi-factorial distribution scheme in three repetitions. The water content in the mulching were quantified before, 3; 6 and 24 h after the irrigations, collecting the mulch, randomly in the experimental units, with the assistance of a sampling board of 0.09 m^2 and the content of water in the soil, with sensors FDR installed in depths 0.00-0.10; 0.10 -0.25; 0.25-0.55 e 0.55-0.85 m. The content of water in soil from different levels of mulch, which received 4mm of irrigation, didn't diverge, suggesting a bigger specification of the soil profile when small doses of irrigation are evaluated. In relation to the water in the mulch, it is observed that three hours after the irrigation, the mulch has the same content of water it had before the irrigation, not having difference between the two mulches levels in the whole period evaluated. The water interception through the mulch drifted from 0.5 to 1 mm, in the treatments 2 and 4 t ha^{-1} of DM, tending to reduce with time, considering the collections done thereupon the irrigations. The water interception through the mulch must be offset in an irrigation crop system in irrigated no-tillage, particularly as it is worked with low irrigation volume.

Keywords: irrigation management, no-tillage, mulch

Impact of Livestock in Quality of Wastewater for Irrigation

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Abstract

Over the last decades, antibiotics have been used in human and animal therapy and livestock. In Europe, they are not allowed as growth promoters in intensive livestock, but can be used as feed additives in aquaculture and poultry production. Antibiotics are daily excreted as a mixture of unchanged and partially metabolized forms, together with resistant bacteria. The major routes of environmental contamination with antibiotics, resistant bacteria and resistance genes are the network of municipal and farm sewers. Besides chemical pollution by antibiotic, their long term permanence in water systems, pressures the selection at sub-inhibitory concentrations upon microorganisms, favouring antibiotic-resistant bacteria. The wastewaters, with high levels of organic and inorganic matter and microorganisms are especially adapted for growth and spread of antibiotic resistances. Common agricultural practices of water, nutrients and organic matter reuse for crop production, *e.g.*, soil fertilization with manure and slurry from intensive livestock farming and irrigation with effluents from intensive aquaculture systems, are responsible for agroecosystems contamination. Humans can be continually exposed to these contaminants, through the ingestion of food plants grown on that irrigated land. Conversely, agricultural systems, then can further contribute to environmental contamination of soil and water resources. Moreover, in intensive aquaculture the antibiotics are directly added to the water to treat infections, generating high concentrations in local wastewaters, resulting in serious environmental and public health problems. This paper presents a preliminary study sought to access the contribution of some livestock activities (chick rearing, hen, poultry, pigs, dairy cattle and slaughterhouse) to the spread of antibiotic resistances through the treated wastewaters, manure and slurry in the central region of Portugal. Between March and July 2015, sampling of treated wastewaters from selected livestock WWTP is being conducted. Samples are collected in 1L sterile plastic bottles, from which *Enterobacteriaceae* are isolated and phenotypically characterized, by the agar diffusion method for determination of the resistance profiles against 14 antibiotics. AMP^r bacteria are enumerated on VRBG plates ampicillin supplemented. The results will be presented in the paper. This paper will provide an insight about the real contribution of these activities to this public health problem in this Region.

Keywords: antibiotic resistance bacteria, antibiotic, irrigation wastewater reuse, wastewater, water quality, WWTP, livestock

Soil Organic Sequestration in Irrigations Farm of Black River Valley, Argentina

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Abstract

Larger water application by irrigation increases biomass productivity and consequently soil C input through residues and roots, changes mineralization rates, and alters the carbonate balance. Most irrigation is in areas with low levels of Soil Organic Matter (SOC) in the native state. Therefore, there is a large potential for carbon sequestration by the use of gravitational irrigation. Irrigated crops are grown on about 50.000 ha in the upper Valley with gravitational border and furrow irrigation system. For this work 29 farms located in Cipolletti Irrigation District, with crops pear and gravitational furrow irrigation. The edaphic variables selected: organic carbon, plantation age, soil texture, soil depth, soil drainage, pH and electrical conductivity. By using statistical programs multiple regressions equations, simulations of different scenarios allow to relate the stock of C ha^{-1} yr^{-1}, according to variations in clay, the permanents years of irrigation and soil pH. The stock of t C ha^{-1} yr^{-1} have average values ranging from 0.50 t C ha^{-1} yr^{-1} the first 15 years, to 0.17 t C ha^{-1} in the next 30 years. The average carbon stock values are 0.28 t C ha^{-1} yr^{-1}. Excessive irrigation, lack of proper drainage, and use of poor-quality irrigation water accentuate the risks of soil salinization. Use of proper irrigation methods and improved cropping systems is therefore essential to reap the benefits of irrigation in enhancing productivity and soil carbon sequestration. The gravitational irrigation border and furrow System minimizes the emission of CO_2 and enhances carbon sequestration in the fight against global warming.

Keywords: carbon storage, gravitational irrigation, climate change

Basin Management and Land Use

Challenges for Sustainable Food Systems in Metropolitan Landscapes

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Abstract

Metropolitan landscapes are facing the challenge to find a balance between urban development on the one hand and the preservation of farmland and natural resources on the other. Conventional land use planning approaches are often not up to this complex challenge and many regions are in need for innovative knowledge and approaches. This paper discusses the role of scenario methodology in the search for innovative solutions, with special emphasis on the challenges related to the sustainability of the food system. An example of application of scenario tools is presented for the Metropolitan Region Amsterdam, the Netherlands.

Keywords: sustainable food systems, future studies, land use planning, scenarios

Introduction

Landscapes are being shaped by societal activities, as human kind strives to make a living in the biophysical environment. These activities include, for example, the cultivation of land for food production, the construction of buildings, the extraction of raw materials and the consumption of services such as leisure activities. Some consequences of these activities are the translocation of nutrients, altered hydrological systems and the loss of biodiversity (Baldwin 2009; Lang *et al.*, 2009). The consequences are especially prominent in densely populated metropolitan areas, such as delta regions. Delta regions are worldwide among the areas with the most fertile soils and often accommodating important wetland areas. Many of these delta regions, such as in the coastal areas of South America and Asia, are subject to urbanization, resulting in an increasing pressure on the rural area for economical and urban development, but also an increasing need to preserve farmland and natural resources (Chen *et al.,* 2015). A key challenge is to find a balance between urban development on the one hand and the preservation of farmland and natural resources on the other. In practice this balance often turns in favor of urban development. Conventional land use planning approaches are often not up to this complex challenge and many regions are in need for innovative knowledge and approaches (Carsjens 2009, Carsjens *et al.*, 2013). This paper discusses the role of future studies in the search for innovative solutions, with special emphasis on the challenges related to the sustainability of the food system.

First, the challenges related to the sustainability of current food systems will be described. Afterward, some methodology of future studies and scenario tools will be introduced and an example of application of these tools in the Metropolitan Region Amsterdam, the Netherlands. The paper concludes with a discussion.

Toward Sustainable Food Systems

"When you consider that every day for a city the size of London, enough food for thirty million meals must be produced, imported, sold, cooked, eaten and disposed of again, and that something similar must happen every day for every city on earth, it is remarkable that those of us living in them get to eat at all" (Steel 2013, p. ix)

A food system includes all processes and its related inputs and outputs involved in feeding a population, from the production of food to the disposal of waste after consumption. The conventional, industrial-based food system has been especially successful from an economical perspective. It does not only offer cheap food but delivers a wide array of choice as well. The main characteristics of the conventional food system are standardization, centralized distribution, just-in-time principle and a-seasonality (Lang *et al.,* 2009, Pirog *et al.,* 2009, Steel 2013). Standardization is a way to increase cost-efficiency. If all the products are the same, the same treatment and distribution can be used, which cuts the costs. Standardization also gives more control on the product. This control is needed with increasing concerns about food safety and quality. When supermarkets grow larger, they centralize their distribution channels. By centralizing, less coordination is needed, which reduces the transaction costs. Although transport costs and energy usage increase when the product travels longer, the overall costs still decrease. Next to the shift towards centralized distribution, a shift towards self-distribution emerges. Supermarket chains are starting to buy their products directly from manufacturers instead of wholesalers. This centralized distribution system relies on the 'just-in-time' principle. Products should go as fast as possible to the consumer, especially when perishable. To save on the relative high costs of storage, the motorway has turned into a warehouse, in a complex logistic exercise. Moreover, customers nowadays do not know anymore when fruits and vegetables are in season and expect to find the products in the shelves all year round.

The price of food is relatively cheap because in many cases impacts are un- or underprized, making the conventional food system unsustainable (Morgan *et al.,* 2006, Baldwin 2009). The environmental impacts of intensive agriculture are well known. Too intensified farming systems in areas with limited resources lead to problems such as eutrophication, acidification, overgrazing, deforestation, loss of soil fertility, air pollution, water shortages and loss of biodiversity. We often do not realize the hidden costs of food (Pretty *et al.,* 2005). When looking at water usage, significant differences exist between products. One gram of lettuce takes 130 milliliter of water to produce, one gram of rice 3,4 liter, and one gram of lamb nearly 15 liter of water. From environmental perspective, the production and processing of meat is an inefficient way of feeding ourselves. Large areas of farmland are needed to produce fodder for animals. It takes 23 kilogram of grain to produce one kilogram of lamb, 15 kilogram to produce one kilogram of beef, 6 kilogram to produce a kilo of pork, and 2.3 kilogram to produce a kilogram of chicken. Moreover, the production of meat contributes to nearly a fifth of greenhouse gas emissions.

The pursuance of sustainable agriculture is justified considering the high environmental impacts of intensive agriculture. But defining the sustainability of the food system is even more complicated when realizing that environmental impacts are only one dimension of sustainability, as shown in Table 1. It is also important to consider the social, economic and health dimensions of food products. To avoid complexity, current product labels are often partial, they only focus on one topic like fair trade, animal welfare or local food.

Two competing paradigms can be distinguished in the transition towards a more sustainable food system: the agri-industrial paradigm and the alternative food paradigm (Morgan *et al.*, 2006). The agri-industrial paradigm aims at improving efficiency and productivity by specialized, high-yield farming systems, focusing on technical solutions for environmental problems, quality and safety assurance schemes, and nutritionally engineered functional food. The alternative food paradigm involves various types of alternative, local and ecologically produced food This paradigm focuses on closing cycles at regional scale, trust in the quality of food based on personal relations between producer and consumer, and selling fresh, whole foods (Carsjens 2015).

Although more and more sustainable initiatives and technologies are available, improvements in food systems happen slowly. An explanation can be found in the complexity of conventional food systems with an overwhelming number of actors involved, ranging from the government, the private sector to civil society (Lang *et al.,* 2009). This complexity makes it hard to find a consensus which is supported by all involved parties. Transitions cannot be pressed by governments only nowadays, as they have to share their power with the private sector and civil society. Policy and decision making takes place in a multi-level framework of governance, which also requires more time. In these processes, the involved actors use their power to influence and shape policies on food. In metropolitan landscapes the complexity is further raised, as the development of food systems has to compete with many other types of urban related land uses.

Table 1. Examples of sustainability indicators (Pirog *et al.,* 2009).

Environmental	Economic	Social
Food miles/LCA	Profitability	Distance grower - consumer
Energy consumption	Import vs. domestic products	Nutritional value of food
CO_2 emission	Waste produced per unit food	Food safety
Land use	Transport efficiency	Number of farmers' markets

These complex situations asks for planning and decision making approaches that can deal with the many uncertainties involved, including uncertainties related to value and power issues of involved actors and uncertainties related to future developments and trends, such as economic development, climate change and the energy market. Some authors argue that this asks for the ability to link strategic visions and scenarios for the future development of a region with short-term decision-making processes (e.g. Albrechts 2004, Carsjens 2009, Ratcliffe and Krawczyk 2011). The next section will introduce scenario methodology as a potential tool to support this complex challenge.

Scenario Methodology

Börjeson *et al.* (2006) distinguish three types of future scenarios: predictive, explorative and normative scenarios. Predictive scenarios aim to predict what will happen in future, based on probability analysis. Explorative scenarios analyze developments that might happen, usually resulting in sets of scenarios showing a variety of possibilities. Normative scenarios or visions have explicit normative starting points, and focus on how the future should look like. Some authors (e.g. Dreborg 2004) propose a combination of explorative and normative scenarios, also called a two-scenario approach. Such an approach has been developed at the Wageningen University, the Netherlands (Carsjens *et al.,* 2013), shown in Figure 1.

The approach combines the development of external scenarios, a type of explorative scenarios, with normative scenarios or visions. External scenarios focus on external trends that are outside the control of the actors in a region, such as sea level rise due to climate change. An important step in the development of external scenarios is the classification of trends according to their potential impact on the region and their uncertainty. The most uncertain and important trends are then used to explore opposing future conditions and to construct diverging scenarios that represent a range of future conditions that the region may have to meet. Visions are usually made using the diversity of perspectives of actors about their ideal future for the region. A SWOT analysis is then used to confront a vision with the current conditions in the area, which results in identifying strengths and weaknesses of the current situation. A confrontation between the vision and the external scenarios results in opportunities and threats, resulting from how certain trends may evolve in the future. The results of the SWOT analysis allow to arrive at policy strategies that can support the debate about current and future decision making in the region.

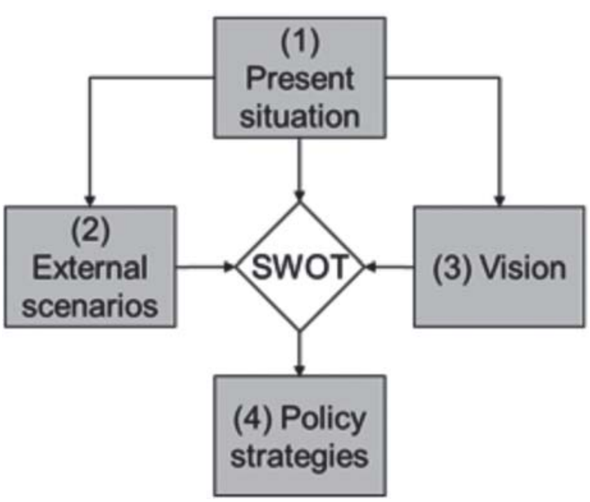

Figure 1. Scenario approach.

However, scenario studies have to deal with an important dilemma. On the one hand scenarios aim to describe possible future trends that can help policy makers to anticipate on possible future conditions. On the other hand, the future has still to unfold, so consequently there is no empirical basis to do research. Therefore, scenarios try to jump from factual developments in the past and present to possible or desirable developments in the future (Dammers, 2010). It is important to keep in mind that the results of scenario studies are not end-states of the future, but rather narratives about how future events could or should unfold. These narratives especially help to raise the debate among actors in a region, which may allow to develop a shared vision for the future, and to reflect on the potential consequences of current and future decision-making.

The next section describes the application of this scenario approach in a project for the Metropolitan Region Amsterdam (MRA), the Netherlands. The project took place in the context of a so-called regional innovation network that aims to link educational institutes with practitioners, politicians and stakeholders in a region. The aim of a regional innovation network is to stimulate the sharing of knowledge and approaches among the participants, which should support regional innovation through personal and professional development (Foorthuis and Lutz 2012, Carsjens *et al.,* 2013).

In the project a group of 12 bachelor students from the Landscape Architecture and Spatial Planning program at the Wageningen University worked for four weeks on a project assignment of the MRA. The assignment aimed at developing a vision for the long term (2045) for the region, taking into consideration trends and developments that may have an impact on the structure and the interplay between different functions in the region. The students were also asked to develop strategies for the longer term and an action-oriented program for the shorter term (4-10 years). They worked in two project teams, focusing on two themes and corresponding detailed areas within the MRA. In both themes the role of the food system in the MRA played an important role.

Project Metropolitan Region Amsterdam

The Metropolitan Region Amsterdam (MRA) is an informal cooperation between 36 municipalities and two provinces in the Netherlands (Figure 2). The region is one of the main economic and urban regions in the Netherlands and Europe. Outstanding qualities of the metropolitan landscape of the MRA are its diversity, the interweaving of city and countryside and the cultural, historical and ecological values. These qualities are important assets for the international competitiveness of the MRA as an attractive living, working, living and business climate for both (current and future) residents and visitors.
Agriculture and food are assigned as a top sector by the Dutch government, and horticulture is on top of the political and social agenda of the MRA. MRA has a highly developed agriculture, water sector, distribution and trade sector, knowledge infrastructure and a population that wants something with food. The region is exploring the building blocks for a common vision on agriculture and food, in which all parties can agree and know their role. These building blocks include, for instance, a food strategy, sustainable agriculture and alternative agriculture.
The project focused in particular on two areas that are important in the context of the food system, the Zaanse Schakel and Waterland (Figure 2). The Zaanse Schakel is a declining harbor area, in-between the cities of Amsterdam and Haarlem, with several food related companies located in and around the area. Waterland is a mainly agricultural wetland area with dairy farms and areas of special importance for wetland birds, bordering the city of Amsterdam in the northeast. The economic activities in certain parts of the metropolitan landscape, such as Waterland, are unilateral, partly caused by current policies. A new vision for this area can make a world of difference, but can also meet severe opposition due to colliding value systems of different stakeholders in the area. Therefore, the students were asked to provide new, innovative input for a renewed discussion about the future of the metropolitan landscape and the role of agriculture in it.
The results of the scenario approach of the two project teams included two sets of A0 size posters, which were presented orally during a meeting with the client and stakeholders from the region, and two 14-pages management summaries, one for each detailed area. The management summaries are intended as stand-alone products that can be used in future discussion sessions with stakeholders in the region. A collage of graphical examples from these products is shown in Figure 3.

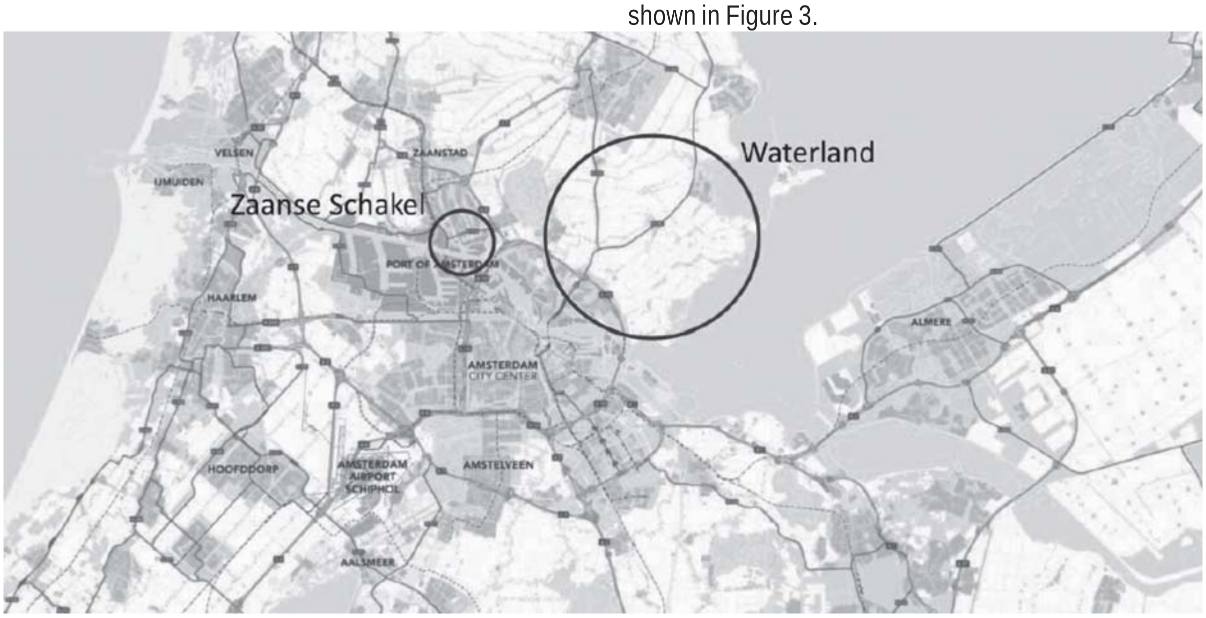

Figure 2. Metropolitan Region Amsterdam (MRA).

Figure 3. Examples of scenario products.

Discussion

During the final presentation in the region, the client and stakeholders responded with enthusiasm on the presented results as these showed some new perspectives on the future developments in the region. Moreover, the students were invited to participate in upcoming events in the region that aim to initiate the discussion between various actors in the region. From that perspective it can be concluded that the results of the scenario approach were considered relevant to stimulate this discussion. Of course, it should be realized that the results are products of four weeks work, so consequently will have deficiencies and lack sufficient detailed analyses. This also raises the question if such results can actually support regional innovation. This aspect was assessed for three similar projects in other regions in the Netherlands (Carsjens *et al.,* 2013). The assessment was carried out using semi-structured interviews with clients and stakeholders. The assessment focused on three aspects: content related results, process related results and personal and professional development. The assessment results showed that the content related results (vision, scenarios and strategies) did not contribute directly to regional innovation, but only indirectly through the process and personal and professional development. For example, the creative visions stimulated new initiatives and follow-up projects by raising awareness and enthusiasm among clients and stakeholders. The lasting effects on regional development in these projects were evident (Carsjens *et al.,* 2013). These conclusions are supported by Dammers (2010) who also found evidence that participants in scenario processes learn more from the process itself than from the resulting scenarios.

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Watershed Management: Towards Increasing Food Production with Sustainability

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Abstract

. The Brazilian agribusiness sector is one of the most dynamic in the world. Significant production and productivity gains have been made over the last two decades. Agribusiness in Brazil is responsible for 33% of the GDP, 42% of the exports and 37% of the jobs. In recent past, growth of food production in Brazil was primarily achieved through expansion of agricultural land and increase in water use. Land degradation has in many areas resulted in diminishing crop yields. The focus of attention has been on blue water with limited attention given to direct use of productive green water. Currently, Brazil is capable of increasing its agricultural production without jeopardizing the environment. In this context, irrigation is an important technology to help to achieve sustainable agriculture, but needs to improve its efficiency. The irrigated area in Brazil is currently 6 million hectares (about 9.8% of the total cropped area) and is responsible for 19% of the total agricultural production and 35% of agriculture income. Irrigation in Brazil is, however, somewhat inefficient, compared to potential levels of efficiency that could be achieved. Until the beginning of 2015, the potential area for irrigation in Brazil was estimated in 30 million hectares and now is estimated in 61 million hectare. How this will impact the environment and food production in Brazil? Currently, less than 1% of the surface water is used in the country, but water conflicts are present in some regions, especially in those regions where there has been excessive and little organized growth of irrigated agriculture, which are associated with an unequal distribution of this resource. In the São Francisco River Basin, for example, studies indicate potential conflicts in the use of water, with the main players being energy generation and agriculture. Brazil has developed important technologies to sustainable use of agricultural land. One of these technologies is known as integration crop-livestock-forest system, which are the best way to recover degraded pasture. Regarding water management, however, irrigation efficiency is low and there is much to be done. Most of the conflicts appear due to lack of data and knowledge of the withdrawals and water availability in the watersheds. In this regards, there are great opportunities to apply decision support systems, hydrologic modeling to design irrigations strategies in critical watersheds. The challenge still remains in how to increase food production with sustainability in region with lack of data and information. Study projections indicate that irrigation in Brazil, even in the most pessimistic scenario, will continue to increase. It is important, however, to manage irrigation in a sustainable manner to leave more water to downstream users. In this context, watershed management will play an important role, once it can contribute to organize the multiple uses, reduce water conflicts, increase food security and livelihoods of rural communities.

Keywords: basin management, irrigation production systems, multipredial irrigation uses

Potential Yield of Contrasting Soybean Maturity Groups in Southern Uruguayan Conditions

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Abstract

Soybean potential yield (*Glycine max* (L.) Merr.) is determined by temperature, radiation, photoperiod and genotype in every location. The variability of potential yields is strongly associated with changes in available solar radiation through years. Selection of management practices that lead to maintaining high yields are: genotype, sowing date and row spacing. Sowing date enables coupling solar radiation offer with the crop stages were yield is defined. Furthermore, potential yield for every environment depends on genotype. Selection of the maturity group (MG) defines the initiation of the reproductive period, which conditions the nod number, the maximum leaf area index (LAI) and the environmental conditions during grain filling. Additionally, growth habit of each genotype is also related to potential yield. Early sowing date allows the expression of the greatest differences among MG. A crop growth simulation study showed that the average potential productivity of early maturing cultivars (MG from III to V) achieved higher yields than later maturing cultivars (MG from V to VII) at early sowing date conditions in Uruguayan latitudes. Later maturing cultivars localize their critical period when daily radiation curve declines (late January - February) and consequently the growth rate during reproductive stage is not maximized. The objective of this study was to determine the potential crop growth and yield of different MG in two ambient crated by early and mid sowing date, at southern Uruguayan latitudes. The experiment was carried out during summer 2014-2015. Contrasting MG -from III to VII- were tested on two sowing dates: 15/10 and 15/11. Different growing variables were measured during the growing season: evolution of the intercepted solar radiation, biomass (B), soil water content, number of pods per square meter and crop yield. Results showed that early maturing cultivars expressed higher yields in both sowing dates. The yield on mid-October sowing date ranged from 5400 to 6300 kg ha^{-1} for early maturing cultivars and 4600 to 5600 kg ha^{-1} for later maturing cultivars. For mid November sowing date the yields ranged from 4600 to 5200 kg ha^{-1} for early maturing cultivars and 3800 to 5500 kg ha^{-1} for later maturing cultivars. However, evolution of LAI and B was similar among MG. The main difference showed was accumulated biomass at initial reproductive stage. Daily water uptake did not differ among MG; nevertheless, total water uptake responded positively to the increase of the crop cycle length. The highest potential yield for season 2014-2015 was reached with early maturing cultivars. Results showed that yields could be maximized with management practices as supplementary irrigation and the use of short MG sowed in October. The use of these practices lead to obtain over 6000 kg ha^{-1} crop yield combined with high water productivity.

Keywords: sowing date, intercepted solar radiation, leaf area index, biomass, supplementary irrigation, water productivity

Irrigation Water Effect In Soybean Crop In Uruguay

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Abstract

In the last 10 years, soybean crop area has increased strongly, being 309x103 ha in 2005 to over 106 ha in 2015. Uruguayan climate conditions allow the soybean sowing between October to December according to crop cycle, and its cycle is completed between March to April. However, the irregular rainfall throughout the crop cycle causes short periods droughts that may trigger an important yield decrease, depending on the stage crop. The supplemental irrigation allows to reduce the water deficit in particular crop periods, given to farmer a high and stability yield. The need to have a good farm irrigation strategy according to the different soybean cycle length is the main reason for soybean yield response studies under supplemental irrigation. The experiment was conducted at Salto (Northwest of Uruguay) during 2013-2014 crop season. Four soybean crop length cultivars (4990, 5500, 6.2i, 8000) were used. Two treatments were applied, rainfed and irrigation, with three replications randomized block design. Irrigation treatment received the 100% of maximum crop evapotranspiration according to FAO56. Crop cycle length was 140 days with a total rainfall of 575 mm. Sprinkler irrigation system was used with an average rainfall of 6.6 mm hour-1. The average water depth was 232 mm distributed in 7 irrigation events between December and January. Regardless of crop cycle, irrigation treatment showed a higher yield than rainfed treatment (differences about 80%). Long cycles soybean cultivars, irrespective of the irrigation treatments, reached a higher yield than the shorter ones (differences over 50% and 20% in rainfed and irrigation treatments, respectively). Therefore, in the North of Uruguay, soybean crop with long cycle, and under supplemental irrigation, should allow a greater yield to the farmers with the aim to reach a high profit margin.

Keywords: soybean cultivars, supplemental irrigation, sprinkler irrigation, yield

Soybean Yield Potential Under Contrasting Maturity Groups, Plant Population and Soil Water Regimes in Eastern Uruguay

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Abstract

Soybean is the main crop in Uruguayan agricultural systems. Integrated crop management practices are critical to increase productivity while reducing climatic vulnerability in soils with restricted water holding capacity. The objective was to evaluate the impact of contrasting crop management practices and water regimes on crop yield potential. We conducted a three year (2012-2013, 2013-2014 and 2014-2015) field scale study on an Abruptic Argiaquoll at INIA Treinta y Tres, Uruguay. In each season, two experiments were set under contrasting water regimes: rainfed (RF) and supplementary irrigation (SI). Each experiment evaluated 4 Maturity Groups (MG): 5.0, 5.5, 6.1 and 6.8; and 4 Plant Populations (PP): 15, 25, 35 and 45 plants m^{-2}. A RCB split plot design was used and analyzed using mixed models. The greatest productivity was obtained in 2012-2013 (4030 kg ha^{-1}), 22% higher than the average of other seasons. No water regime effect on yield was observed in the first two seasons. In 2012-2013, no yield differences were observed between MG. However, 15 plants m^{-2} had 4.4% lower yield than other PP (4067 kg ha^{-1}). In 2013-2014 no productivity differences were observed between PP, but MG 5.5 had 11 % higher yield than other MG (3271 kg ha^{-1}). In 2014-2015, SI yield (3760 kg ha^{-1}) was 1020 kg ha^{-1} higher than RF. SI received 105 mm of supplementary irrigation. In RF, 5.0 MG had a trend of higher yield (16%) compared to other MG (2608 kg ha^{-1}) and 45 plants m^{-2} decreased yield by 6% compared to other PP (2754 kg ha^{-1}). In SI, the greatest yield was obtained with MG 5.0 (3941 kg ha^{-1}). The aggregate of data suggests that yield potential without water restrictions was 4000 kg ha^{-1} for most MG, with higher yields in high PP. However, under water limiting conditions in reproductive stages, high populations decreased yield. Water productivity reached 10 kg grain mm^{-1} applied, reflecting the positive impact of supplementary irrigation.

Keywords: yield potential, supplementary irrigation, water productivity

Soil and Water Conservation Technologies for Implementing Climate Change Adaptation Measures: Local Scale Proposal of Basal Project in Cuba

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Abstract

This paper presents an actions proposal for implementing adaptation measures to variability and climate change at local scale, based on integral diagnoses developed on the framework the international collaboration project Environmental Basis for Local Food Sustainable Production (Basal for its spanish abbreviation) in three intervention municipalities in Cuba. The crop systems diagnosed were related to: rice (Los Palacios municipality in east region of the country); beans, vegetables, fruits, roots and tubers (Güira de Melena municipality in central-east region) and pasture and forage for milk production in livestock (Jimaguayú municipality in west region). The measures adopted are related to soil and water management and also include actions for introduction of sustainable management practices for conservation and soil improvement, new irrigation technologies or improve those already in use, for increasing water use efficiency. Among the most important actions are the introduction of technologies for land leveling and maintenance and rectification of channels net for increasing water application and conduction efficiency in surface irrigation systems and the modernization in demonstrative areas with the introduction of pulse or non continues surface irrigation technologies and flexible pipes for third channels. Other remarkable the actions are linked to the implementation of Use and Quality Brigade (BUCA, for its spanish abbreviation) and the Advisory Irrigation Service (SAR, for its spanish abbreviation) for monitoring water availability, quality and use efficiency for irrigation and technical training for technicians and farmers involved in the exploitation of irrigation systems. The proposal of specifics and integral indicators for monitoring effectiveness of measures in the variability and climate change adaptation and support its performance in planning and management of agricultural sector.

Keywords: basin management, water use efficiency

Biochar to Climate Change Adaptation

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Abstract

Rain-fed agriculture in the semi-arid northeast of Brazil faces stronger challenges regarding water for agriculture. Biochar is recognized to promote soil water holding capacity. Its properties vary widely with feedstock material and processing conditions, so it is recognized the importance of its characterization and performance evaluation, before use. The objective of this study was to identify best regional available biochar for soil water-holding capacity increase, based on laboratory tests and microstructural porosity evaluation. Types of biochar were compared, according to wood source. Cashew tree and two species from caatinga biome were used, jurema-preta (*Mimosa tenuiflora* (Willd.) Poir. and marmeleiro (Croton sonderianus Müll. Arg.). For water holding evaluations, both biochar were submitted to Hainnes Funel. Samples were crushed and brought to the laboratory and separated using sieves of 16 mm; 8 mm; 4 mm; 2 mm; 1 mm; 0.5 mm; 0.25 mm; 0.12 mm and <0.12 mm mesh. Samples with particle size diameters of 2 mm and 4mm were submitted to Hainnes Funel. Transversal sections of both biochars were prepared to be observed under a scanning electron microscope, identifying macropores and micropores. Caatinga wood biochar demonstrated greater water holding capacity than cashew wood one in all evaluated diameters. Greater levels are observed related to caatinga wood biochar, 1.89 g g^{-1} for to particle size diameter of 2 mm and 2,27 g g^{-1} for 4mm and cashew wood biochar demonstrated water holding capacity of 0.57 and 0.53 g g^{-1} to 2mm and 4 mm particle size diameters respectively. The fewer quantity of macropores and larger number of micropores may give caatinga wood biochar higher water holding capacity, while thickly lignified cell walls of cashew wood biochar supports the idea that a hydrophobic effect may contribute to its lower holding capacity.

Keywords: water holding capacity, adaptation strategy, climate change, biochar

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The Effect of Biochar with Different Content on Soil Hydraulic Conductivity

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Abstract

This study aims to explore the influences of biochar with different content on corresponding hydraulic conductivity and soil physical structure of sand and loam. Indoor laboratory test was conducted to measure and analysis the variation of soil accumulative infiltration amount, saturated hydraulic conductivity and soil water characteristic curve under conditions of different ratios of biochar content (0%?1%?3%?5%?8%?10%) being added to sand and loam, which revealing the correlations between biochar content and soil water dynamic parameters of two kinds of soils. Results indicate that when the bulk density remains unchanged, the effect of different ratios of biochar on sand and loam was different. Once biochar was mixed into sand soil, related infiltration rate and cumulative infiltration amount decreased with the enhanced amount of biochar, reaching to mean values of 60.3% and 48.5% separately in relation to the control group. The valid soil water holding capacity was enlarged by 66.3%, and the variation of saturated hydraulic conductivity tended to be a positive parabola. For loam, associated infiltration rate and cumulative infiltration amount were decreased by 40.4% and 32.5% comparatively to the control group, whereas the valid soil water holding capacity was increased by 23.2% when the mixed percentage of biochar was increased, the inclination of saturated hydraulic conductivity appeared to be a negative parabola. Significant differences were observed for the influences of different biochar ratios on the soil structures of these two types of soil, those impacts were more visual on sand soil structure but, been less obvious in terms of the loam soil structure. Those sandy soil involved hydraulic conductivities were more sensitive to the biochar with different content. Corresponding results are capable of providing theoretical basis in promoting the improvement effect of biochar on soil.

Keywords: biochar, soil, saturated hydraulic conductivity, specific water capacity, characteristic curve of soil moisture

The Modernization of a Large Irrigation Perimeter to Support Rural Sustainable Development - study Case of Matala (South of Angola)

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Abstract

Matala Irrigation Perimeter (MIP), located in the Cunene river basin, Huíla Province, South of Angola, is under a modernization process, managed by the Angola government. It aims a sustainable rural development, focusing on the socioeconomically aspects and the reduction of poverty of the local populations. This paper describes the MIP and presents the main results of a research study carried out to evaluate this process to establish actions for its improvement. It includes procedures for better water use at conveyance network and on-farm levels, and for higher land productivity through the improvement of crop systems. MIP has an area of 10,732 ha, being the water diverted from the Matala dam, in Cunene River. The irrigated perimeter was built in the 1960s, with a gravity canal distribution system, designed for traditional surface irrigation methods. Since 2002, the MIP was deeply rehabilitated, through the recovery of the main canal and water control structures, the enlargement of the irrigated area and the implementation of agro industrial and animal production units. MIP has several constraints, related with the maintenance of hydraulic structures, the effectiveness of water distribution, and shortage water supply. The main crops grown are potato, tomato, maize, pasture, horticultural and fruit trees, being their irrigation scheduling analysed. The development of on-farm irrigation has been set as an important priority, because the majority of the area applies low effective traditional methods. The modernization of the surface irrigation is a key crucial option, particularly in the flat soils with topographic conditions for gravity supply. The micro irrigation, particularly the drip irrigation, is applied in tomato crop and fruit tree, and the fixed or centre pivot systems used for maize and pastures. The research presented in this paper evaluated those systems, the performance indicators and the main difficulties found, including the requirements of farmer's technical support.

Keywords: Matala Irrigated Perimeter, Angola, irrigation modernization, farmer's technical support, canal distribution system, on-farm irrigation

Description and Quantification of Wet Bulbs in Soils with Contrasting Textures with Different Patterns of Water Application under Drip Irrigation

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Abstract

The objective of this work is to obtain one first approach in the determination of the size of wetted bulbs, and to analyze the effects of different ways of water application on the patterns of the size and shape of the wetted bulb. Irrigation experiment were installed on two soils with a silty clay loam superficial horizon of 0,40 m depth, followed by a clay horizon of low permeability. Measurements were taken to determine the size of the bulb, applying irrigation with dripper of different flow, different distances, with one or two lines and different applied volumes. In addition a field test was carry out using a portable device assessed different flows and irrigation times in a sandy and a clay loam soils. The gravimetric method was used to evaluate the water content of the samples to determine the dimensions of the obtained wetted bulb of in each case. The data were introduced in a computer program (SURFER8), to plot these results and obtain the different wet bulb. The first results show important differences between observed values and the models proposed in the bibliography and there are aspects of the irrigation management, for example irrigation time, that produce deep percolation of the irrigation water.

Keywords: microirrigation, soil wetted volume, stratified soils, trickle

Fitting a Numerical Model for the Analysis of the Wet Bulb Dimensions by Drip Irrigation

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Abstract

Prevision of the unsaturated zone hydrodynamics is one of the most important criteria for designing efficiently localized irrigation practices. In Uruguay the design of localized irrigation has been historically based on formulations and previsions to quantify the size of the wet bulb, using different methods (analytical and numerical simulations, empirical and field tests). These methods were based on soil conditions for light and homogeneous soils, and arid climatic conditions, which are difficult to extrapolate to local soils and crops. Nowadays, is known to be common practice over irrigation because of the lack of a more accurate prevision of the shape of the wet bulb. However, there is no knowledge about the amount of deep percolating water. This research is based on the comparison of experimental results obtained from field test under controlled drip irrigation of alfalfa with the results of a numerical model that simulates unsteady hydrodynamic processes in unsaturated zone. The used code was CODE_ BRIGHT, developed by the Department of Geotechnical Engineering UPC, Barcelona, Spain. Tests were carried out modifying both the time of water application as the emitter discharges. A 1.20 m diameter and 1.20 m tall cylindrical lysimeter was built reproducing the original soil profile of the area. Each stratum was assumed to be homogeneous and axial symmetry was used to find the most efficient way to locate measuring instrumental. Percolating water volume was also measured in the experiment, placing a drainage system at the bottom of the lysimeter. The test was set up on the INIA Las Brujas facilities, using soils of the area (silty loam and silty clay loam) typical of the center-south of the country. The comparison of measured and predicted results suggests the existence of complex phenomena more based in soil structure than in soil texture, which may explain the rapid percolation observed on the initial stages of irrigation. It is necessary to develop other numerical models that represent more accurately these behavior.

Keywords: drip irrigation, unsaturated zone, soil wetting patterns dynamic

Water Resources and Energy

Groundwater Extraction with Minimum Cost. Application to Sprinkler Irrigation Systems for Corn Crop in Spain

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Abstract

The aim of this study was to develop a DSS tool named DC-WAT, which linked with the already developed PRESUD tool, aims to optimize, in a holistic manner, the process of water extraction from an aquifer and its application in plot with a pressurized irrigation systems, obtaining the minimum total water application cost (CT) (operation (Cop) + investment (Ca)) per unit irrigated area improving water and energy management. This tool permits identifying the cost for transporting water from the source to the irrigation subunit inlet (Cws) and analyzing the irrigation system as a whole, from the water source to the emitter. An application to permanent sprinkler irrigation systems using groundwater of two types of aquifer (confined and unconfined aquifers) for corn crop in Spain is analyzed, evaluating the effects on CT of parameters such as the static water table in the aquifer (SWT), irrigated area (S), sprinklers and laterals spacing and average application rate (ARa). Results showed that Cws increased lineally with SWT and decreased exponentially with S. The timing of crops water requirements, the efficiency of the irrigation system, and the size of the irrigation subunit, among other factors, determine the optimal pumping flow rate and the cost of energy. For the aquifers studied, the Cws was mainly conditioned by the borehole investment cost, being the confined aquifer 30-60% more expensive than the unconfined for the studied cases. The Ce is the most important cost of CT (65-70 % in the studied cases). DC-WAT is a useful tool to optimize the design and sizing of water pumping facilities in irrigation systems, which considers the aquifer performance in a holistic manner.

Keywords: sprinkler irrigation design, water application cost, energy cost

Introduction

Efficient water and energy use take on greater importance in agriculture due to the widespread tendency of reduced water availability as a result of increasing water demands in other sectors, including for environmental integrity, and increasing energy costs, which determine the viability of irrigated agriculture in many areas of the world, and mainly where groundwater is the main source of water.

Throughout the history of sprinkler and drip irrigation, there has always been interest in finding those system characteristics that produce the cheapest results with irrigation (Kumar *et al.,* 1992; Lamaddalena *et al.,* 2007, Ortiz *et al.,* 2006, Montero *et al.,* 2013). The cost of the sprinkler irrigation system depends on the equipment and its design, materials and automation level. This cost is also influenced by other factors such as shape, layout and size of the plot, distance from the water source to the plot and pumping requirements (Van der Gulik, 2003).

Maize (*Zea Mays* L.) achieves high yields under semiarid conditions but with high water requirements, which in many areas around the world means an important restriction due to water scarcity (Plan, 2004; Martín de Santa Olalla *et al.,* 2007). As this crop is one of the most important cereals in terms of production (FAO, 2014), more efforts have been dedicated to both improving water use efficiency and minimizing irrigation water application costs by improving the design and management of irrigation systems.

The specific capacity (q) (flow capacity per meter of decline in the water level (m^3 day^{-1} m^{-1}), usually obtained from well capacity testing, can be used to analyze the cost of extraction of ground water. This parameter is directly related to the efficiency or performance of the well, which in turn depends on the constructive design and maintenance, as well as permeability (K, in m d^{-1}) and transmissivity (T= K Hs, in m^2 d^{-1}, where Hs is the saturated depth of the aquifer before pumping, in m) (Kalf and Woolley 2005; Srivastava *et al*. 2007). Aquifers are not isotropic, which means that the above mentioned parameters are usually variable along the aquifer.

The wide variety of parameters that influence the water application cost with a pressurized irrigation system leads to partial studies of the problem, but it is necessary to analyze the irrigation system as a whole, from the water source to the emitter, and not separately, to avoid errors that may be significant.

The optimum hydraulic design of a sprinkler irrigation system is reached by determining the sizes of pump and distribution pipes that ensure proper flow and intake pressure head in the sprinkler, with minimum annual water application cost. Thus, the aim of this study is to apply the DSS tool named DC-WAT (Design and Cost for Water) to obtain the minimum total water application cost (CT) (operation (Cop)+ investment (Ca)) per unit irrigated area in pressurized irrigation, identifying the cost for transporting water from the source to the irrigation subunit inlet (Cws), analyzing the irrigation system as a whole, from the water source to the emitter, improving the water and energy management in irrigation. An application to permanent sprinkler irrigation systems using groundwater in two types of aquifer for corn crop in Spain is analyzed, evaluating the effects on CT of parameters such the static water table in the aquifer (SWT), irrigated area (S), sprinklers and laterals spacing or average application rate (ARa). All the data assumed for the case studies can be modified in the tool to fit the requirements of any case study.

Methodology

DC-WAT tool was developed using MATLABTM. It aims to optimize the shape of the characteristic and efficiency curves of the pump and the pumping and distribution pipe of the system with a holistic approach. In order to evaluate the tool it has been applied to different case studies, considering in the design rectangular subunits of permanent sprinkler irrigation systems, with the borehole in the centre of the plot because this layout leads to lower investment costs. The optimum lateral and manifold pipes are previously calculated using the PRESUD (Pressurized Subunit Design) tool (Carrión *et al.,* 2014), which is linked to DC-WAT tool. However, any other shapes and location of the wells can be implemented in the tool.

Since the distribution pipes used are made of smooth material (polyvinylchloride (PVC)), and the diameters are small, the Veronesse-Datei head loss equations have been used for the hydraulic calculations. For pumping pipes (carbon steel), the Hazen-Williams equation has been used. Minor singular head losses (hs) are considered to comprise 15% of hf in the distribution pipe network and pumping pipe.

Types of Studied Aquifers and its Hydrogeological Properties

To analyse the cost of groundwater extraction two large aquifers of Castilla La Mancha have been considered (confined and unconfined aquifers, Fig. 1). They are the source of water for more than 430.000 ha of irrigated land. The first hydrogeological unit is the Western Mancha (HU 04-04), located in the Guadiana River basin, that covers an area of more than 5.500 km^2 and approximately 320.000 ha of irrigated land (67 and 31% of drip and sprinkler irrigation respectively). This is a not very thick unconfined aquifer (between 100 and 200 m), with transmissivity values (T)

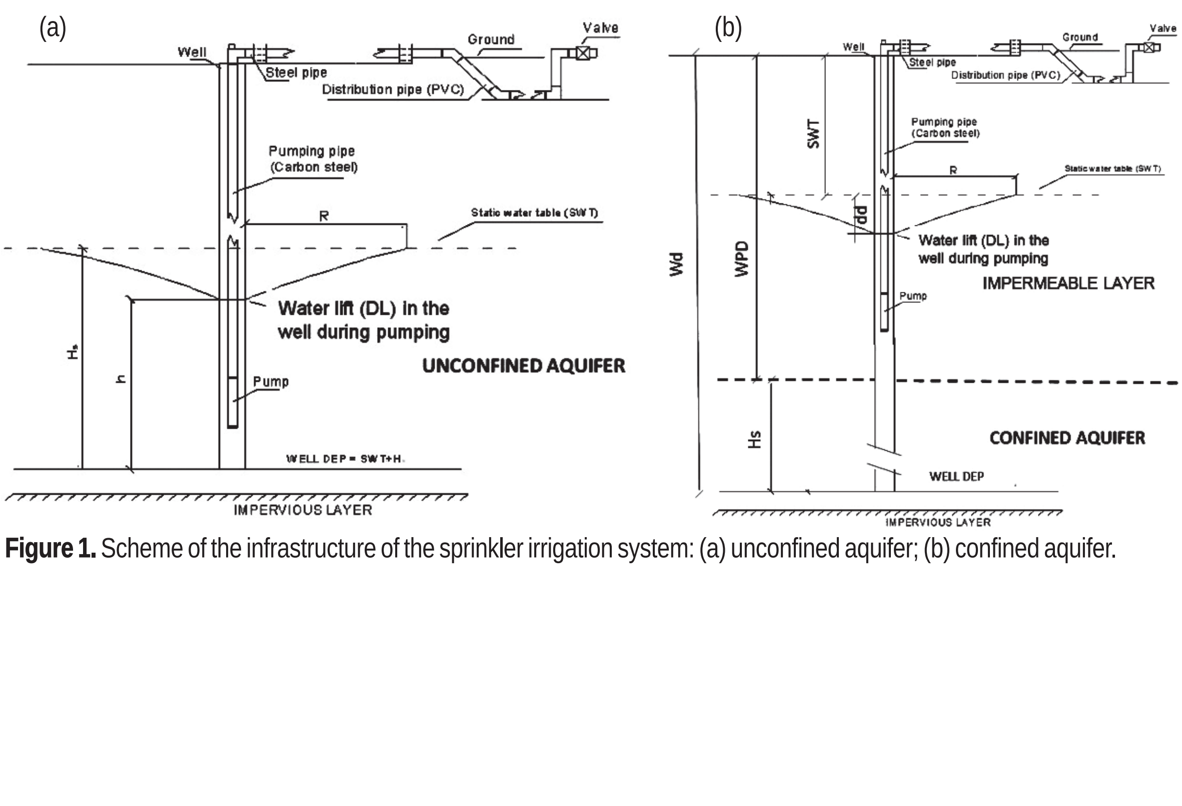


Figure 1. Scheme of the infrastructure of the sprinkler irrigation system: (a) unconfined aquifer; (b) confined aquifer.

between 300 and 700 m^2 day^{-1}. The second is the Eastern Mancha (HU 08.29), with an area of 7.260 km^2 and 110,000 ha of irrigated land (78 and 20 % of sprinkler and drip irrigation respectively). This is a confined and deep aquifer, with 300-600 m thickness, with T values that can exceed 30.000 m^2 day^{-1} (Sanz *et al.,* 2009).

Modelling the Well Performance

For permanent operating conditions, the specific discharge (q) of a borehole located in an unconfined aquifer and in steady state can be estimated in a simplified manner with Eq. 1 (Custodio and Llamas, 1983; Hamm *et al.,* 2005).

$$q = \frac{Q}{dd} = \pi \frac{T}{H_s} \frac{2H_s - dd}{\ln\left(\frac{2R}{D_{wp}}\right)} \quad (1)$$

$$h = H_s - dd = \sqrt{H_s^2 - \left(\frac{QH_s}{\pi T}\ln\left(\frac{2R}{D_{wp}}\right)\right)} \quad (2)$$

where q= specific capacity (m^3 day^{-1} m^{-1}), Q= system flow from the aquifer (m^3 day^{-1}); dd= theoretical drawdown in the well (m); T = transmissivity of the aquifer (m^2 day^{-1}), Dwp = inner diameter of well pipe (m); R = the radius of the cone of influence (m); H_s= saturated depth of aquifer before pumping (m) (with static water table (SWT)) (Fig. 1); h= the saturated depth of drilled aquifer after pumping (m).

For permanent operating conditions, the specific capacity (q) of a borehole located in a confined aquifer and in steady state was estimated with the simplified Eq. 3

$$q = \frac{Q}{dd} = \frac{2\pi T}{\ln\left(\frac{2R}{D}\right)} \quad (3)$$

The dynamic lift (DL) is the depth to the SWT plus the drawdown (DL = SWT + dd,) (Fig. 1).

According to Eqs.1 and 3, the theoretical specific capacity (q) is independent of the extracted flow rate (Q) and only depends on the characteristics of the aquifer and the inner diameter of well pipe (Dwp) (Custodio and Llamas, 1983). The actual specific capacity is always lower than the theoretical and the actual drawdown during pumping is higher than in the rest of the aquifer due to head losses in the tube-well.

In this study the theoretical equations were used, with the values of the main hydrological parameters of Table 1 for the two types of selected aquifers. However, DC-WAT tool permits to use the other approach in case required data are available.

Table 1. Summary of the average hydrogeologic data considered in the aquifers used for this study.

Concept		HU 04-04	HU 08-29
Seasonal drawdown (S_d) (m)		5	5
T (m^{-2} day^{-1})	Minimum	300	700
	Medium	500	5,000
	Maximum	700	16,000
R (m)		800	1,500
Well depth (W_d) (m)	for $Q \leq 15$ L s^{-1}	SWT + 40	WPD[(1)]+ 40
	$15<Q \leq 30$ L s^{-1}	SWT+ 50	WPD+ 50
	$30<Q \leq 60$ L s^{-1}	SWT+ 75	WPD+ 75
	$Q>60$ L s^{-1}	SWT+ 100	WPD+ 100
Saturated depth of aquifer before pumping H_s (m)		$H_s = W_d - SWT - S_d$[(2)]	$H_s = W_d - WPD$[(2)]
Pump depth (P_d) (m)		$P_d = SWT + S_d + dd + 15$[(3)]	
Inner diameter of well pipe (D_{wp}) (m)		$D_{wp} \geq$ maximum external diameter of pump and/or flanged pumping pipes + 100 mm	
Drilling diameter (D_d) (mm)		$D_d \geq D_{wp}$ + 2 x well pipe thickness + 50 mm	

(1)WPD = waterproof depth in the top of confined aquifers (m) (it is considered 350 m in this study).
(2)Sd= seasonal drawdown ((it is considered 5 m in this study).
(3)To ensure a water height above the suction of the pump.

Model Design. Objective Function and Optimization Variables

Figure 2 summarizes the optimization process implemented in DC-WAT tool. The optimization variables were: the coefficient of the characteristic curve of the pump (c) (Moreno *et al.,* 2009), the pumping pipe diameter (Dp), and the distribution pipe diameter (D). The optimal results of the in-plot subunits, which were obtained with PRESSUD tool (Carrion *et al.,* 2014) were incorporated in the total cost. The optimization process was carried out using the Downhill Simplex Method (Nelder and Mead, 1965), which aims to minimize the total cost.

$$MIN(C_a + C_m + C_e) \tag{4}$$

where C_a = annual investment cost, C_m = annual maintenance cost, and C_e = annual energy cost.

To select the optimum pump that minimizes the cost for transporting water from the source to the irrigation subunit inlet (Cws) and the total cost (CT) for feeding the irrigation system directly from the borehole, the software considers the shape of the characteristic (Q-H) and efficiency (Q-Ep) curves (Moreno *et al.,* 2009), as well as the optimum sizing of the pumping pipe and the distribution pipe for each specific type of aquifer. These variables will determine the energy efficiency of the whole system through the irrigation season, as well as fitting it to the varying conditions of the aquifer. Other characteristics of the well are derived from these variables, such as the well diameter and the pumping pipe depth being also optimized in the process.
The characteristic and efficiency curves of the pumps (H-Q and Ep-Q) can be approximated by Eqs. (5) and (6) (Moreno *et al.,* 2009).

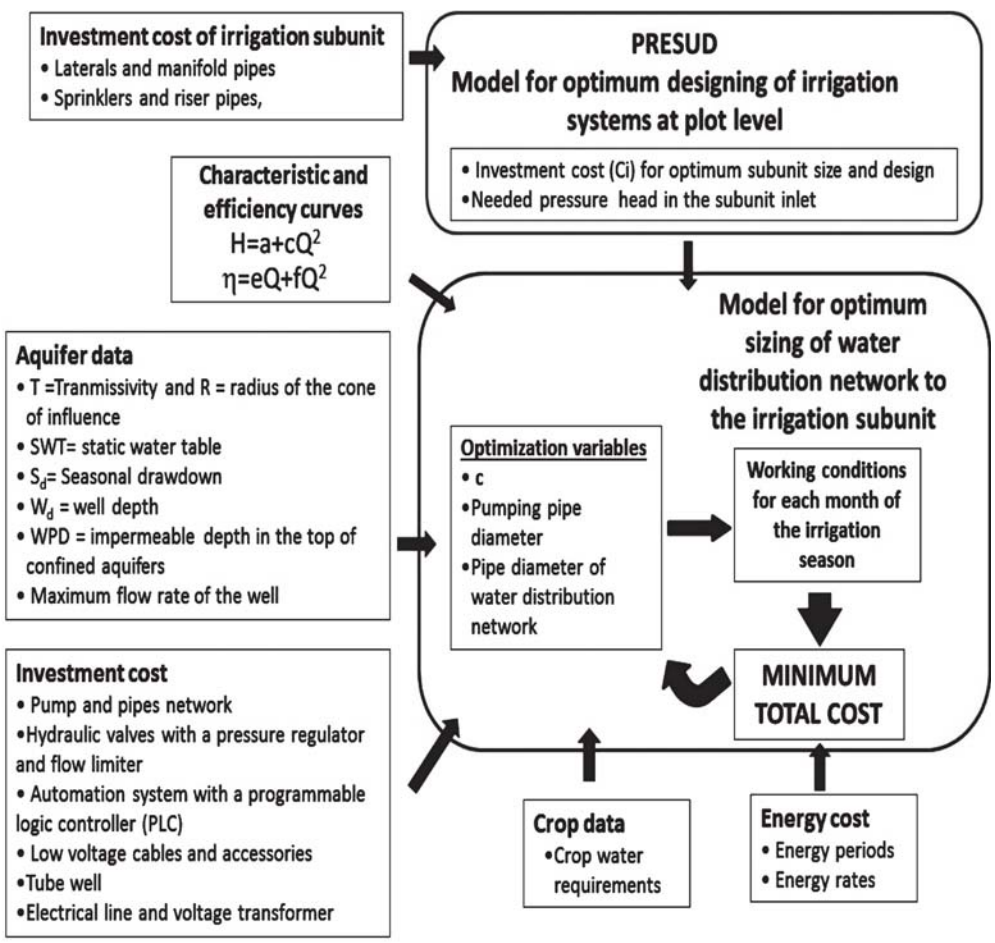


Figure 2. Diagram of the optimization process in DC-WAT tool.

$$H = a + cQ^2 \quad (5)$$

$$E_p = eQ + fQ^2 \quad (6)$$

where the coefficients a, c, e, and f determine the shape of the curves.

Moreno *et al.* (2009) propose an algorithm to obtain the desirable types of characteristic and efficiency curves considering the theoretical relation between the two curves for a specific pump as a function of the coefficient c. Thus, during the optimization process, different values of c, D and Q were obtained, obtaining also the power of the pump, which is directly related with the investment cost and energy cost. The rest of the optimization variables drive to the remaining investment and energy costs.

Investment Costs

The investment costs (C_i) considered were: well drilling and well pipe, pump, electrical line and voltage transformer for using conventional electrical energy, pipe and assembly costs (laterals, manifold and distribution (PVC), and well pumping pipes (steel), sprinkler, riser pipes, opening and closing of ditches, hydraulic valves with a pressure regulator and flow limiter for each irrigation subunit, the automation system with a programmable logic controller (PLC), the low voltage cables and accessories.

The investment annuity ($A = CRF\ C_i$, in € yr^{-1}) for the total investment cost (C_i, in €) was computed considering a useful life (N) of 12 years for the pump and 24 years for the pipes, borehole, electrical line, valves, electrical line, voltage transformer (Scherer and Weigel, 1993), and an interest rate (i) of 0.05. The capital recovery factor (CRF) and the investment annuity per unit of irrigated area (Ca, in € $ha^{-1}yr^{-1}$) were calculated using equations (7) and (8):

$$CRF = \frac{i\,(1+i)^N}{(1+i)^N - 1} \quad (7)$$

$$C_a = \frac{A}{S} = \frac{CRF\,.\,C_i}{S} \quad (8)$$

where S is the area irrigated by the irrigation system (in ha). To determine the total investment cost (C_i), the average prices of equipment from different manufacturers and distributors in Spain were considered (Table 2).

The considered cost of well drilling in the area is included in Table 3. These costs also include the costs of transportation and installation of machinery, technical documents and restoration.

Table 2. Average prices of different manufacturers and distributors in Spain.

Concept	Material	Cost (€ $unit^{-1}$)	R^2
Distribution pipe	PVC 0.6 MPa	$C = 0.001253D^{1.632397}$	0.99
Pumping pipe	Steel	$C = 0.0009D^{1.8013}$	0.99
Hydraulic valves	Cast iron	$C = 0.017385D^2 + 0.010499D - 26.648651$	0.99
Pump		$C = 0.0016\,P_p^3 + 0.924\,P_p^2 + 268.28P_p$	0.94
Electrical wire	Cooper	$C = 0.0025318P_p^2 + 0.0823262P_p + 5.7296411$	0.99
Electrical panel		$C = 224.418612P_p^{0.329085}$	0.99
Electronic starter		$C = -0.023988P_p^2 + 25.423305P_p + 758.163174$	0.98
Controller and auxiliary		C = 800 (€)	
Voltage transformer		$C = 0.012140P_t^2 + 9.699422P_t + 4051.880598$	0.97

D= inner pipe diameter (mm); Pt= power of the transformer (kVA); Pp= power of the pump (kW).

Table 3. Cost of well drilling.

Concept	Drilling type	Well depth (W_d) (m)	Drilling diameter (Dd) (mm)						
			350	400	450	500	550	600	650
Well pipe, inner diameter (D_{wp}) (mm)			250	300	350	400	450	500	550
Average cost (€ m^{-1})	P[(1)]	W_d<250	165	198	225	248	264	286	308
	RC[(2)]	250<W_d<600	205	215	223	228	232	237	245

[(1)]P = Percussion; [(2)]RC= Reverse Circulation.

The estimated cost of the electric line is included in Table 4. The electrical line length is considered 500 m plus half square side assigned to each plot size, since the borehole and the pump are located in the centre of the plot.

Carrión *et al.* (2014) reported the typical permanent sprinkler irrigation subunit design (Table 5) of minimum cost as function of the subunit size for corn crop. In this case only the identified option of lower cost (Table 6 and 7) were considered.

Table 4. Cost of electric line.

	Plot area (ha)			
	< 10	10 to 20	20 to 40	40 to 60
Cost of electric line (€ km^{-1})	4,550	6,500	7,800	8,500

Table 5. Values of the different parameter related with the sprinkler irrigation system considered in this study.

Spacing of sprinklers (m x m)	h_a (kPa)	E_a (dimensionless)	AR_a (mm h^{-1})	Diameter of nozzles (mm)	Corn gross water requirement ($m^3 ha^{-1} yr^{-1}$)
18 x 18	300	0.77	5.90	4.8 + 2.4	8.249
	350	0.79	6.33	4.8 + 2.4	8.049
15 x 15	350	0.82	8.00	4.4 + 2.4	7.766

h_a = Average sprinkler working pressure = average pressure head in the subunit (kPa); E_a= general application efficiency for the irrigation system (Keller and Bliesner, 1990); $AR_a = q_a (s_s s_l)^{-1}$ average application rate of the irrigation system (mm h^{-1}); q_a = average emitter flow in the subunit (L h^{-1}); s_s= sprinkler spacing in the lateral (m); s_l= lateral pipe spacing (m).

Table 6. Investment annuity cost (C_a) of a permanent sprinkler irrigation subunit with 18 m x 18 m spacing for minimum total cost C_T (Carrión *et al.,* 2014) as function of the subunit area, including the diameter and length of lateral and manifold pipes, H_0, EU, Δq and Δh values.

Subunit area (ha)	Lateral length (m)	Manifold length (m)		C_a (€ $ha^{-1}yr^{-1}$)	H_0 (m)	EU (%)	Δq (%)	Δh (%)
	Lateral external (inner) diameter (mm)	Manifold external (inner) diameter (mm)						
	50 (46.4)	140 (131.8)	160 (150.6)					
Sprinkler spacing 18m x 18m, h_a= 300 kPa and AR_a= 5.9 mm h^{-1}								
1.56	198	54		86.4	35	95.9	4.2	8.4
2.33	198	90		87.8	35.1	95.9	4.4	8.8
3.11	198	126		88.6	35.4	95.7	4.7	9.5
3.89	198	162		89.0	35.8	95.5	5.4	10.8
4.67	198	198		89.3	36.3	95.3	6.3	12.8
5.44	198	234		89.5	37.1	94.9	7.7	15.5
6.22	198		270	94.0	36.6	95.1	6.9	14.0
7.00	198		306	94.2	37.2	94.8	8.1	16.4
7.78	198		342	94.3	38.0	94.4	9.5	19.4
Sprinkler spacing 18m x 18m, h_a= 350 kPa and AR_a= 6.33 mm h^{-1}								
1.56	198	54		86.4	40.4	96.0	4.1	8.2
2.33	198	90		87.8	40.5	95.9	4.2	8.5
3.11	198	126		88.6	40.8	95.8	4.6	9.3
3.89	198	162		89.0	41.2	95.6	5.2	10.5
4.67	198	198		89.3	41.8	95.3	6.2	12.5
5.44	198	234		89.5	42.7	95.0	7.5	15.1
6.22	198		270	94.0	42.1	95.2	6.7	13.6
7.00	198		306	94.2	42.8	94.8	7.9	16.0
7.78	198		342	94.3	43.7	94.4	9.3	18.9

H_0 = pressure head required at the inlet of the irrigation subunit (m); EU= sprinkler emission uniformity (Keller and Bliesner 1990); Δq = difference in extreme sprinkler flow in the irrigation subunit (% of q_a); Δh = difference in extreme pressure heads in the irrigation subunit (% of h_a); h_a = average pressure head in the subunit (m).

Table 7. Investment annuity cost (C_a) of a permanent sprinkler irrigation subunit with 15 m x 15 m spacing for minimum total cost C_T (Carrión *et al.*, 2014) as function of the subunit area, including the diameter and length of lateral and manifold pipes, H_0, EU, Δq and Δh values.

Subunit area (ha)	Lateral length (m)	Manifold length (m)		C_a (€ $ha^{-1}Y^{-1}$)	H_0 (m)	EU (%)	Δq (%)	Δh (%)
	Lateral external (inner) diameter (mm)	Manifold external (inner) diameter (mm)						
	50 (46.4)	140 (131.8)	160 (150.6)					
Sprinkler spacing 15m x 15m, h_a= 350 kPa and AR_a= 8.0 mm h^{-1}								
1,26	195	45		110.9	40.3	95.9	4.3	8.6
1,89	195	75		112.4	40.5	95.9	4.4	8.9
2,52	195	105		113.2	40.7	95.8	4.7	9.6
3,15	195	135		113.6	41.1	95.6	5.3	10.7
3,78	195	165		113.9	41.6	95.4	6.1	12.3
4,41	195	195		114.1	42.3	95.0	7.3	14.8
5,04	195		225	118.8	41.9	95.3	6.6	13.3
5,67	195		255	119.0	42.5	95.0	7.6	15.4
6,3	195		285	119.1	43.3	94.6	8.8	17.9

Energy costs

The annual operation costs (Cop= Power access + Energy consumption) can be calculated with Eq.(9).

$$C_{op} = \sum_{i=1}^{12}\sum_{j=1}^{k}(N_p)Pa_{ij} + \sum_{i=1}^{12}\sum_{j=1}^{k}(N_p)Ot_{ij}P_{ij} \qquad (9)$$

where: N_p= power absorbed for irrigation water application (kW);O_t= monthly operation time of the pump (h); Pa= power access price (€ kW^{-1} $month^{-1}$); P= energy rate (€ kW^{-1} h^{-1}); *i* and *j* refer to the month and the different time-of-use energy rate periods (*k*), respectively.

The N_p was calculated according to the pressure head (H, in m) and flow rate (Q_{0s}, in m^3 s^{-1}) necessary for the proper operation of the least favourable sprinkler irrigation subunit:

$$N_p = \frac{9.81 \cdot Q_{0s} \cdot H}{E_p} \qquad (10)$$

where: E_p = efficiency of pumping system (decimal).

The pressure head (H) can be obtained with the equation (11):

$$H = DL + h_f + h_s + H_{su} \qquad (11)$$

where: H_{su} pressure head required at inlet of the valve located in the origin of subunit, equal to the H0 value of Tables 6 y 7 increased in 3 m for considering the head losses in the valve.

The number of operating hours per month (O_t) was calculated from the monthly distribution of net crop irrigation water requirement (R_n) (Table 8).

The gross crop irrigation water requirement (R_g) for the subunit can be calculated with Eq.(12):

$$R_g = \frac{R_n}{E_a} \qquad (12)$$

where: R_n = net corn crop irrigation water requirement (m^3 ha^{-1} yr^{-1}) E_a= general application efficiency for the irrigation system (Table 5).

In the case studies, located in Spain, the energy rates of this country were utilized. For these energy rates, the available hours in each period considered are described in Table 9.

Table 8. Monthly distribution of net irrigation water requirement (Rn) for corn crop in the Albacete area, Spain.

Crop	Monthly net crop irrigation water requirement (m^3 ha^{-1})						
	April	May	June	July	August	September	Annual (Rn)
Corn	113.4	580.2	1,096.4	2,112.0	2,058.0	540.0	6,500.0

Table 9. Monthly hours of each energy rate period.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High (P1)	186	168	186	180	186	180	186	186	180	186	180	186
Medium (P2)	310	280	310	300	310	300	310	310	300	310	300	310
Low (P3)	248	224	248	240	248	240	248	248	240	248	240	248

Table 10. Energy rates of power access and energy consumption.

Energy rate period	Power access (Pa) (€ $kW^{-1} yr^{-1}$)	Energy (P) (€ kWh^{-1})
High (P1)	24.49	0.13544
Medium (P2)	15.10	0.12010
Low (P3)	3.46	0.07562

The distribution of high, medium, and low energy rate times was detailed by the electrical company in a complex schedule. It can be simplified in three energy rate periods: P1) high energy rate period (6 h day^{-1}), P2) medium energy rate period (10 h day^{-1}), and P3) low energy rate period, at night (0:00 to 8:00 am). The energy rates for each period are detailed in Table 10.

The annual energy cost per irrigated area (C_e, € $ha^{-1} yr^{-1}$) was calculated by dividing the operation cost (C_{op}) by the irrigated area (S, in ha).

Maintenance costs

An additional average cost of 5% above investment costs was considered for the maintenance needs of the irrigation system (C_m), to reach a useful life (N) of 12 years for pump and 24 years for pipes, tube well, electrical line, valves, electrical line, voltage transformer.

Results

Determination of water cost (Cws).

Water cost (Cws) in this study is defined as the cost of pumping water from the source to the origin of the irrigation subunit, which includes investment and operation costs, without considering the head pressure required at the head of the irrigation subunit. Figure 3 a and b shows the relationship between Cws and SWT in an unconfined aquifer (UH 04-04) for a 20 ha plot divided into 12 subunits (1.66 ha per subunit) with sprinkler spacing 18 x 18 m, and into 15 subunits (1.33 ha per subunit) with sprinkler spacing 15 x 15 m, both with corn. Results showed that Cws increased lineally with SWT. These values were conditioned by the temporal distribution of the water requirements, which depends on the crop, the efficiency of the irrigation system, the subunit size, among other. All of these parameters influenced the discharge and energy cost.

Figure 3 c and d shows the relationship between Cws and area of the irrigated plot in an unconfined aquifer (UH 04-04). Results showed that Cws decreases exponentially with the plot area, until near 40 ha, slightly increasing for larger areas (Fig. 3c and 3d), and with slight differences caused by sprinkler spacing. The increase of Cws for the larger areas is due to the large increase in energy cost when increasing the flow rate as seen in Figure 5b. Regarding the cost per cubic meter, the differences observed due to sprinkler spacing are higher than when analyzing the cost per unit of area because for 18 x 18 with ARa = 5.9 mm h^{-1} requires a lower flow rate than the 15 x 15 with ARa = 8.0 mm h^{-1} and therefore, lower investment costs. However, energy costs are similar because 18 x 18 spacing supplied more water than 15 x 15 due to its lower application efficiency (8.249 $m^3 ha^{-1} yr^{-1}$ for 18 x 18 and 7.766 $m^3 ha^{-1} yr^{-1}$ for 15 x 15 in Table 6), which made that the difference of cost of water per unit of area were very similar.

The high effect on Cws of plot area and SWT shows that those studies that consider a fixed value for water cost can commit errors in cost analysis. This is one of the main contributions of this work, highlighting the importance of analyzing the irrigation system as a whole, from the water source to the emitter, and not separately, to avoid errors that may be significant.

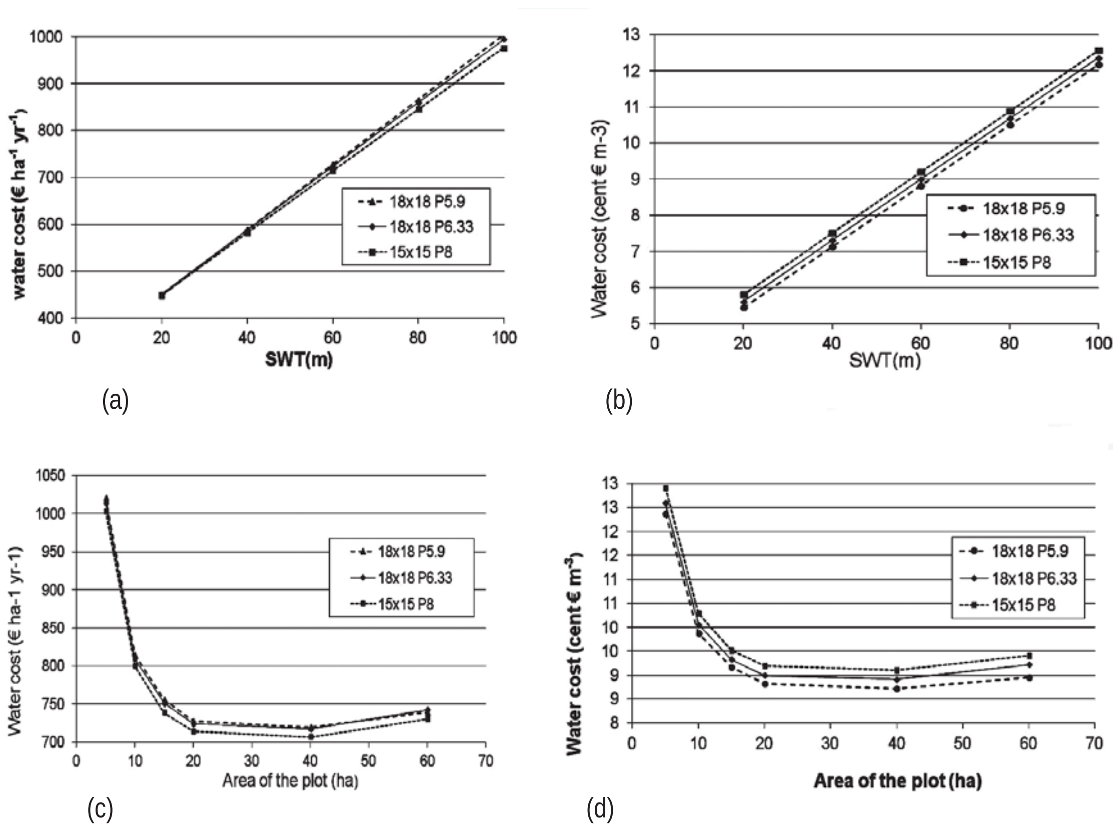


Figure 3. Cost of water transporting from the source to the subunit inlet (C_{ws}), for a corn crop in the unconfined aquifer, with different sprinkler spacing and ARa, calculated versus the SWT for a S= 20 ha (a and b) and the irrigated area, for SWT= 60m (c and d); both per unit of irrigated area (a and c), and per unit volume (b and d).

Effect of irrigated area (S) over total cost (CT)

The C_T decreased exponentially when increasing the plot area (Fig. 4), although slightly increase for areas larger than 40 ha, because the energy cost is higher as seen in Figure 5. Moreover, C_T is increased when increasing the SWT for the different sprinkler spacing and ARa considered. The C_T is very high for plots smaller than 15 ha, due to the large weight of the costs of borehole and electricity line on C_T.
Results indicated that the lowest C_T was obtained with the spacing 18 x 18 with ARa = 5.9 mm h^{-1}, although the differences were very slight, and were even shortened when the SWT increased. These results improved the results obtained by Carrión *et al.* (2014) that concluded that the solution with the lower C_T was 15 x 15 with ARa= 8.0 mm h^{-1}. This was because they analyzed the subunits of irrigation using constant C_{ws} and an average value for C_e, regardless of tariff periods. However, the slight differences could drive to farmers to install 15 x 15 systems in case of restrictions in water availability, since with less amount of water (Table 6) and a similar cost they could supply the crop water requirements and ensure a proper yield.

Regarding Figures 4 and 3c, subunit for 15 x 15 sprinkler spacing and 350 kPa, showed higher investment and energy costs than subunit for 18 x 18 with 300 kPa. It is explained because subunit for 15 x 15 reached the lowest C_{ws} (Fig. 3c) while subunit 18 x 18 showed the lowest CT (Fig. 4). The Ca and Ce increase for spacing sprinkler 15 x 15 is not compensated for the higher amount of water consumed during the irrigation season for spacing sprinkler 18 x 18, due to its less application efficiency for the irrigation system (Table 6).

Analysis of the components of the CT and its variation with NS and SWT

In all the cases analyzed, the energy cost (C_e) was the component of the CT with the highest weight (about 70%). Investment and maintenance costs (C_a+C_m) tend to decrease when increasing the NS, as the pump, the transformer and

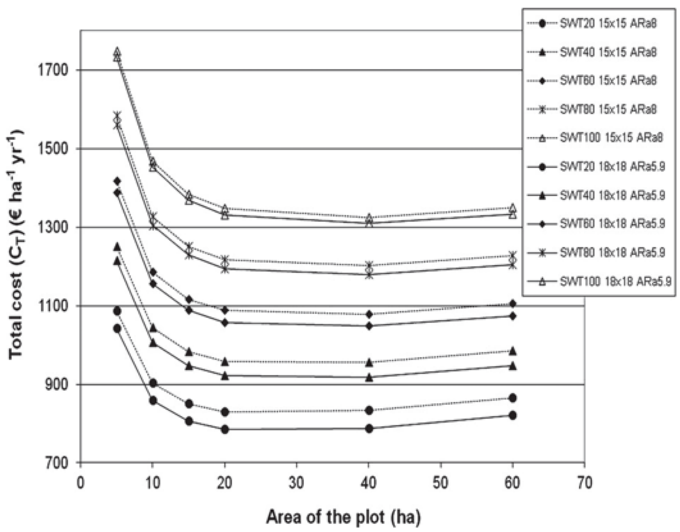


Figure 4. Pattern of C_T with the plot area for different sprinkler spacing and SWT analyzed in the unconfined aquifer, using 12 subunits in 18 x 1 8 spacing and 15 subunits in 15 x 15.

the necessary piping are smaller, being less the pumped flow rate to the subunit. The C_e usually increase with NS because increase the required number of hours of operation in the medium (P2) energy rate period.

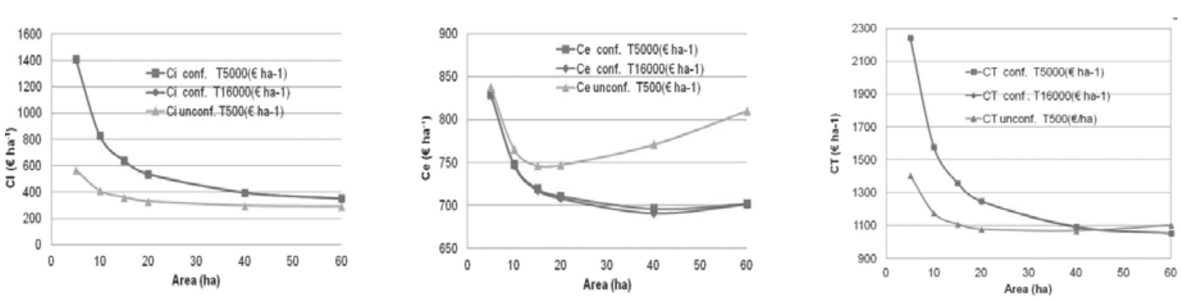
As expected, Ce increased notably with increases of SWT (mainly by the higher power necessary in the pump), and Ca also increased but to a lesser extent, thereby increasing C_T. Thus, is crucial to minimize the C_e though a proper selection of pipe diameters and pump type.

The results highlight the high participation of Cws in C_T, and its high dependence of SWT. Despite the negligible differences between spacing sprinklers, pressure heads and ARa, the 18 x 18 spacing sprinkler with ARa = 5.9 mm h^{-1} reached the lowest C_T values.

Comparative between unconfined and confined aquifer

At first it is should be highlighted that the minimum CT is highly influenced for the tube well sizing, related to the drilling diameter intervals (each 50 mm) which are available (Table 1). According to this, in some cases it might be justified the use of lower diameters of pumping pipe, for not increasing the diameter of pipe well, despite the increase of energy costs. This is and other important contribution of this work, that it is not easy to identify without a full analysis of the process. With regard to Ca, the differences are significant between both type of aquifers, being higher in confined aquifers (ranged from 20 % to 150 %)(Fig. 5a) because in this study a fixed WPD value of 350 m is considered, decreasing exponentially when the plot surface is increased, although it needs more flow rate and therefore more drilling diameter and deeper well, which depends on Q, SWT and WPD (Table 1).

C_e is higher in unconfined aquifer with differences between 1 % and 15 %, being higher when the plot surface is increased, due to the required power increase. It is explained because the drawdown in the well (dd) reaches a high value because of the low transmissivity (T) in unconfined aquifer.



(a) (b) (c)

Figure. 5. Comparative between unconfined and confined aquifer for spacing sprinkler 18 x 18, ARa=6.33 mm h^{-1} and SWL = 60 m regarding a) Ca b) Ce and c) C_T.

The differences between C_T are explained by the borehole investment costs, being in the confined aquifers much more expensive than the unconfined aquifers considered in this study. The C_T is lower in the aquifer confined in larger plots of 45 ha due to the higher value of Ce in unconfined aquifers by the low T value (results norshow).

The transmissivity (T) increase in unconfined aquifers, from 5.000 to 16.000 m^{-2} day^{-1} did not cause relevant differences between Ce and, therefore, of C_T (results norshow).

The drawdown in the well (dd) increase with the plot size, reaching 22 m for S = 60 ha in an unconfined aquifer with T= 500 m^{-2} day^{-1}, but only 2 m for a confined aquifer with T= 5.000 m^{-2} day^{-1}, and 0.7m with T= 16,000 m^{-2} day^{-1}. This highlights the important role of T in the water extraction cost.

Conclusions

Water cost (C_{ws}), including extraction and transport from the source to the point where is used, increase lineally with static water table (S_{WT}) in the aquifer and decrease exponentially with the irrigated plot size (S), having lower influence on C_T the remainder factor as number of subunit, the sprinkler spacing or the average application rate for the studied cases. Thus, the studies that consider a constant Cws to analyze different scenarios of relationships between parameters involved in the process irrigation water application can have errors. This is one of the main contributions of this work, highlighting the importance of analyze the irrigation system as a whole, from the water source to the emitter, and not separately, to avoid errors that may be significant.

For the studied aquifers, the Cws is mainly conditioned by the borehole investment cost, being the confined aquifer 20-150% more expensive than the unconfined in the studied cases. Energy annuity cost (Ce) is more expensive in the unconfined aquifer than a confined aquifer (between 1-15 %) because of its low transmissivity value (500 in comparison with 5.000 or 16.000 m^{-2} day^{-1}). This fact causes relevant differences in the drawdown in the well (dd) (between 0.7 and 22 m).

For plots smaller than 15 ha, the CT have a large increases due to the high contribution of the borehole and electrical line costs on necessary investment cost.

The energy (Ce) is the main component of C^T, getting to represent more than 70 % in the studied cases. Thus, it is really important to take into account the contracted tariff period in the design system and water distribution during the irrigation season. This indicates the necessity for developing algorithms and tools to optimize the performance of water pumping facilities in irrigation systems.

Acknowledgements

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Water Productivity, Irrigation Management and Systematization for Rice Farming Systems in North Region of Uruguay

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Abstract

Rice farming systems in the North Region of Uruguay are mainly irrigated from water stored in dams. Increases in Water productivity would contribute to augment annually rice planted area, allows the allocation of water to irrigate other crops in a rotation and could contribute to reduce pumping irrigation costs. The aim of the experiments is to determine irrigation management practices and field layout techniques that increase water productivity contemplating economic and environmental sustainability of rice farming systems in Uruguay. In this paper the results of the joint analysis of three seasons experiments conducted in the Experimental Unit Paso Farías, Artigas (30.30S, 57.06W) are presented (2012-2013-2014) .Treatments (split plot experimental design) included two types of systematization with different vertical interval between levees (big plots): I. Conventional (VI-8cm) and II. Alternative (VI-4cm), and three irrigation management practices (small plots): 1.Continuous (C), 2.Intermittent until panicle initiation (IP), and 3.Intermittent during all crop cycle (I). In C a water layer of 10cm is maintained after flooding throughout all the crop cycle. In IP and I the water layer is allowed to decrease and is re-established when the soil is still saturated. Crop was direct drilled on 21st October (average) with 160 kg seed/ha with cultivar INIA Olimar (Indica). Basal fertilization was 100 kg ha^{-1} of 18-46-0 (NPK), and urea was 100 kg ha^{-1} fractionated at tillering and panicle initiation. Rainfall was on average 733 mm $year^{-1}$ from October to March. Intermittent irrigation led to a significant savings in water inputs (38 % or 5567 m^3 water ha^{-1}) and a significant increase in water productivity, affecting negatively industrial quality and grain yield (950 kg rice ha^{-1} less) ($P< 0.05$). Water productivity considering only irrigated water were: 0.57(c), 0.73(b) and 0.88(a) (kg grain m^3 $water^{-1}$) for C, IP and I respectively ($P< 0.05$). Regarding Systematization, there was no significant differences in any of the parameters evaluated between treatments ($P <0.05$).

Keywords: water productivity, irrigation management, systematization, rice

Irrigation Management and Greenhouse Gas Emissions in Uruguayan Rice Production Systems

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Abstract

Environmental impact and sustainability of agricultural systems and management practices leading to climate change mitigation are one of the most relevant issues to agricultural production nowadays. Mitigation is the process of reducing emissions or enhancing sinks of greenhouse gases (GHG), to limit global warming potential and restrict future climate change. The most relevant GHG are Carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). The steady increase of its concentrations in the atmosphere over several decades has led to enhance global warming. CH_4 and N_2O are the most relevant GHG emitted mainly in the agricultural sector. It is well known that water management has great impact on GHG emissions from rice paddy fields. One of the most important tools for rice crop production and mitigation of CH_4 emission is the controlled irrigation. However, it could result in a N_2O emission increase and reduced rice yields. For these reasons, it is remarkably important to assess the tradeoff relationship between both GHG and the effect on rice productivity. A 3 year field experiment with two different irrigation systems was set at southeast of Uruguay. Conventional water management (continuous flooding after 30 days of emergence, CF30) and an alternative irrigation system (controlled deficit irrigation allowing wetting and drying, AWDI) were compared. The objective was to study the effect of water management on GHG emission, water productivity and rice yields in order to identify strategies for further progress in sustainable intensification of Uruguayan rice. Results showed that mean cumulative CH_4 emission values for AWDI were 55% lower than CF30 systems; on the other hand, there were no significant differences in N_2O emission among systems. Significant yield differences were not observed in two of the rice seasons, while AWDI recorded a significant yield reduction in one of them. Total irrigation water applied and irrigation water productivity did not showed differences in two of the rice seasons, while CF30 reported a higher amount of water applied and lower water productivity in one of the seasons. It can be concluded that AWDI could be an option to enhance water productivity and GHG emission mitigation. However, grain yield can be compromised in AWDI systems. The adoption of these technology is based on the indispensable assess of an overall tradeoff between the risk of possible yield losses, total water used and GHG emissions.

Keywords: greenhouse gas emissions, methane, nitrous, oxide, water productivity

Water Productivity, Irrigation Management and Systematization for Rice Farming Systems in Central Region of Uruguay

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Abstract

A high proportion of rice farming irrigation in the Central Region of Uruguay is done with water stored in dams. Maximizing water productivity is important as savings in water inputs would reduce pumping irrigation costs, increase rice area planted and allows to allocate water to irrigate other crops in a rotation. The aim of the experiment is to determine irrigation management practices and systematization field layout techniques that increase Water Productivity, contemplating the economic and environmental sustainability of rice farming systems in Uruguay. A split plot experimental design trial was conducted in the Experimental Unit located in Tacuarembó (32.11S, 55.10W). tThis paper includes results of the joint analysis of three seasons (2012-2013-2014). Treatments included two types of systematization with different vertical interval between levees (big plots): I. Conventional (VI-8 cm) and II. Alternative (VI-4 cm), and three irrigation management practices (small plots): 1.Continuous (C), 2.Intermittent until panicle initiation (IP), and 3.Intermittent during all crop cycle (I). In C a water layer of 10 cm is maintained after flooding throughout all the crop cycle. In IP and I the water layer is re-established when the soil is still saturated. Rainfall was above the historical average throughout the crop cycle, 738 mm. Crop was direct drilled on 10th October with 160 kg seed/ha with cultivar INIA Olimar (Indica). Basal fertilization was 160 kg ha^{-1} of 19-19-19 (NPK) and Urea was 100 kg ha^{-1} fractionated at tillering and panicle initiation. Intermittent irrigation (IP and I) in low-infiltration rate soils (planosols) allowed for significant water savings input (35% or 2798 m^3 water ha^{-1}) without reducing rice grain yield (average = 7713 kg rice ha^{-1}) but affecting negatively industrial quality compared to Continuous irrigation (C) ($P<0.05$). Water productivity considering only irrigated water were: 0.99(c), 1.31(b), 2.00(a) kg grain m^3 $water^{-1}$ for C, IP and I respectively ($P< 0.05$). There was no significant effect of systematization in any of the parameters evaluated ($P< 0.05$).

Keywords: water productivity, irrigation management, systematization, rice

Hydrological Balance Implementation in Mendoza's Province. Decision Support and Modeling Tool for Integrated Management of Water Resources

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Abstract

The Province Constitution commands the development of Hydrological Balances (BH) in the basins of Mendoza Province, after a century the General Irrigation Department has implemented the BH programme in the frame of the Water Strategic Plan 2020. Up to now there was the presentation of the BH of the Superior Tunuyan River, that is developed herein as a study case. An integral and conceptual model was created, which considered the characteristics of the Administrative Management Units (AMU), the hydrological components and their interrelations. To define the decision rules, a prospective analysis method was selected and productive context and the climate change circumstances were also taken into account. As methodological strategies, the use of the hydrological model WEAP (Water Evaluation and Planning) was adopted because this tool allows assessments in different scenarios. An Actual Hydrological Balance (AHB) and a Programmed Hydrological Balance (PHB) were modelled. In the first case the present efficiencies, the registered cultivated lands and the coefficient of distribution currently used were taken into account. In the second case an estimated future analysis was done based on an assessed efficiency and on the registered cultivated lands. Future climate changes were taken into account, considering a decrease of the hydrological offer and an increase of this demand due to the higher temperatures. All the AMU exceeds the annual demand coverage in more than 85%. The results show that the values of the demand through the BHP reach the reference values acceptable in the irrigated semiarid regions.

Keywords: hydrological balance, WEAP model, reasonable efficiency, climate change, future analysis

Uniformity Assessment of Irrigation with Centre Pivots in Uruguay

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Abstract

Irrigation with centre pivots has increased exponentially under the last decade in Uruguay; starting with a few sets, now there are more than 350 sets which cover 30.000 ha. To conduct performance evaluations of the centre pivots we selected a representative sample of the sets used in Uruguay: 20 sets in three different regions in the country, whose lateral longitude ranged from 398 to 802 m. Uniformity tests of the equipments were conducted according to the methodology proposed by the international standards: ANSI/ASAE S436.1 (JUN 1996). The uniformity coefficient of Hermann and Hein (CUh) of 16 sets reached acceptable values (80 to 87 %), while the rest obtained very low coefficient values (54 to 71%). Distribution Uniformity values (UD) followed the same tendency as CUh values. The 16 sets with high CUh, obtained high UD values (71 to 85%), whereas the rest got lower UD values (26 to 70%). Centre pivots may attain high application uniformity in Uruguayan agrosystems, given an adequate combination of system design and operation. An inaccurate management of centre pivots due to operation below required pressures and to poor maintenance of sprinklers will directly impact the sheets applied, and the application uniformity and efficiency of the centre pivot system.

Keywords: centre pivot, application uniformity, distribution uniformity

A Model for Developing Reservoir Operation Rules for Irrigation Projects

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Abstract

At a basin scale the criteria for designing reservoirs for irrigation projects are based in three aspects: i) Storage required for supplying crop water requirements at an irrigated area, which are calculated for critical drought conditions. ii) Storage required for releasing the minimum ecological river flow under the described weather condition. iii) Spillway dimensions to evacuate high peak flow events. Those aspects are fundamental for designing a reservoir, however, designing reservoir operation rules is also an important aspect and normally it is a big uncertainty for project managers. This study focuses on developing a mathematical model for operating reservoirs for irrigation projects into an integrated basin context. The crop cycle is simulated for several year based on long term historical hydro-meteorological time series in a daily basis. Irrigation requirements are obtained from those simulations. Those results are clustered in 10-day periods during the crop cycle. Frequency analyses of the irrigation requirements are performed. Those results are applied for building irrigation schedules for dry, normal, and rainy conditions. Furthermore, frequency analyses are performed to the distributed rainfall for determining similar weather thresholds. The reservoir operation consists in first routing the inflow thorough the reservoir to the different outlets. A conceptual hydrological routing model is applied for this purpose. Second, the amount of water to release from the reservoir to the irrigation scheme depends on amount of rainfall measured during the precedent 10-days and on the irrigation schedule for that weather condition. The model was developed for a case study in the Ecuadorian Coast, which is a large irrigation project, called PACALORI. The reservoir operation rules were obtained by modeling the system for 42 years of hydro-meteorological data. The model would be implemented in a real time operation, depending on the monitoring implementation for measuring rainfall, flow, and meteorological variables.

Keywords: reservoir operation rules, irrigation, reservoir routing

Modeling Wet Bulb and Soil Moisture Under Drip Irrigation in of the Bolivian Highlands, Through Dimensional Analysis and Multiple Correlation

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Abstract

Agricultural areas of the Bolivian highlands are located between 3200-4000 meters above sea level, where soils are shallow and show great variability, which hinders the proper application of drip irrigation, as these systems are designed to achieve high efficiencies, however, technology by itself does not guarantee that. Therefore it is necessary consider in the design the wet bulb geometry and soil moisture. In this sense, the objective was to conduct mathematical modeling of wet bulb and humidity under surface drip irrigation, to soil from the highlands of Bolivia. Physical and hydrological characteristics of soil and water dynamics under drip irrigation were determined. For this we used a point source. Mathematical modeling was carried out for saturated and unsaturated zone. In the first case modeling was done using dimensional analysis, obtaining a quadratic equation for the maximum diameter of wet, reaching 28 cm for a flow rate of 1 l/h and 8 hours of irrigation, while the observed value field was 29 cm. In the unsaturated zone modeling was done by the method of multiple correlation, determining a maximum depth of 21 cm for a flow rate of 5 l/h and 4 hours of irrigation, in field a value of 20 cm was observed. Regarding the volumetric soil moiture, modeling was performed using matrix equations, observed that for high flow rates and high time irrigation, the simulated moisture was 0.52 and the observed was 0.54. In general the simulated and observed data of the three parameters had a proper fit.

Keywords: surface drip irrigation, wet bulb, saturated and unsaturated zone, m odeling

Water- and Energy-saving Rice Irrigation Practices in Mississippi

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Abstract

A brief overview of rice irrigation practices used in the mid-south will be presented. Emphasis will be placed on multiple-inlet rice irrigation. First developed in Arkansas in the early 1990's, multiple-inlet rice irrigation (MIRI) uses plastic tubing to simultaneously distribute irrigation to all the rice paddies of a field. Use of MIRI allows an even, shallow flood to be quickly established across a field, reducing the potential for nitrogen volatilization losses and providing the farmer with improved control of the flood. Water savings of up to 50% relative to conventional levee-gate irrigation systems may be obtained, depending on field situation and the farmer's management style. This presentation will discuss MIRI "best practices" developed over the past 20 years. Educational resources available to farmers and case studies where MIRI has been adapted to South American rice field conditions will also be presented.

Keywords: irrigation surface, rice, plastic tubing, irrigation management

Modelling Water Flows in the Vadose Zone and Water Table Interactions at Field Scale in the Lower Mondego Valley, Portugal

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Abstract

The paper presents an approach to modelling water flows interaction in the vadose zone. The study was applied to surface irrigated maize in the Lower Mondego Valley, located in the centre-west of Portugal with 12,000 ha of irrigated area. The study aims at: (i) evaluating the drainage and capillary rise fluxes through the lower boundary of the root zone using the HYDRUS model, and (ii) assessing the impacts of recharge flows due to irrigation and/or originating in the surrounding drainage ditches on the water table using the MODFLOW model. Two different field soil conditions (sandy-loam and silty-loamy) were considered. The parameterization of the unsaturated vadose zone was performed using the Van Genuchten-Mualem equations characterizing the soil hydrodynamics behaviour. Aimed at modelling, field observations included: dynamics of the groundwater table level using piezometer recorders; soil moisture dynamics; meteorological, field irrigation and crop development data. The HYDRUS calibration was performed through adjusting simulated to observed soil water content. Groundwater modelling with MODFLOW was performed using data on aquifer-system geometry, hydrological parameters and the groundwater heads observed. The use of MODFLOW focused the evaluation of recharging flows to the groundwater table consisting in vertical flows from the unsaturated zone (obtained from the HYDRUS), and lateral flows from ditches and the adjacent rice paddies. Drainage flows from water table to ditches and deep percolation to the main aquifer were also evaluated. The application of these two models, adopting an iterative process, allowed to properly simulate the dynamics of water table level variations. The paper presents the comparison between models results and field observation data. In order to minimize irrigation water excess and keeping soil water storage in levels appropriate to obtain maximum yields, a modification of the irrigation schedule is suggested, which is combined with water level control and improvement of surface irrigation performance.

Keywords: water table dynamics, capillarity rise, HYDRUS model, MODFLOW model, surface irrigation, maize

Response to the Suplementary Irrigation of Pasture in Uruguay

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Abstract

Pasture irrigation in Uruguay is used supplementary and strategically in long periods of lack of rainfall between the months of October to March. There are a few studies published nationally on the response of conventional pastures dry matter to the addition of water.This study aimed to know the response to irrigate pasture of white clover, lotus and ryegrass.The experiment was conducted for three consecutive years in the period from October to March of the years 2010-11 , 2011-12 and 2012-13, in a commercial property in "Colonia Rubio", Salto , on a Argiudull soil.The experimental design was random plots with three replications where the treatments were different water depths (surface irrigation) to be applied according to the estimated demand by the Penman - Monteith equation, where it is watered whenever the evapotranspiration of reference reached 20, 40 and 60 mm; plus a rainfed treatment. Determinations of the total dry matter production were done. Irrigation determinations were: applied irrigation depth , soil moisture content in a soil profile up to 80 cm, inflow in each plot, infiltrated depth and uniformity of water application in each treatment. Rainfall occurred during the months of October and March were highly variable among the three years of study, being in some period much higher than the water demand of the pasture so the soil profile had a moisture level throughout the month near the upper limit of water in the soil. Total irrigation depth applied ranged from 508 mm (season 2010-11) to 180 mm in the 2012-13 growing season. The results showed that irrigation applied from October to March caused a significant increase in dry matter of the pasture, this meant an increase in forage production caused by irrigation of almost 3 times more than in some dry periods. Among the different irrigation treatments no significant differences in forage production were observed. The dry matter production when irrigation was applied every 60 mm of evapotranspiration did not differ significantly among treatments with more frequent irrigation.

Keywords: border irrigation, pasture irrigated, depth irrigation response

Spatial Variation in the Water Footprint of Corn under Rainfed and Irrigated Conditions in Northeastern Argentina

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Abstract

The water footprint of a crop shows the volume of evapotranspired water required to produce a given yield. The water footprint splits up into the green water footprint, which is the volume of rainwater consumed, and the blue water footprint, which refers to the volume of surface and ground water applied through irrigation. It is expressed as a water volume per unit of product. The project consists in calculating the green and blue water footprint value for corn in central and northeastern provinces of Argentina under three conditions: 1) rainfed farming, 2) irrigated agriculture, and 3) optimum irrigation and soil fertility conditions. Internationally accepted methodology and the AquaCrop model were used to simulate ETc and crop yield. Once the model was calibrated, crop production was modeled for a twenty-year period (1990-2010) for 10 meteorological stations located in Argentina's corn producing region. The following aspects were taken into consideration: climate, soils in each location, planting density, harvest index, water table depth and furrow irrigation. Simulated yield values were compared with those registered by local institutions. It was observed that by applying irrigation and increasing fertility the water footprint is reduced, and this is due to the increase in yield. The green water footprint represents 92% of the combined sum (green plus blue). The calculated mean water footprint (green plus blue) is 803 L kg^{-1} for rainfed farming, 602 L kg^{-1} for irrigated agriculture; and 488 L kg^{-1} for production under optimum irrigation and soil fertility conditions. The paper suggests a potential target value of the water footprint which producers could reach with proper water management and fertilization practices.

Keywords: AquaCrop, evapotranspiration, irrigation, rainfed

Irrigation Management Alternatives that Mantain High Productivity While Using Less Water in Uruguayan Rice

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Abstract

Improvement of water use efficiency in rice crop systems has gained importance over the last decades as it is a limiting factor for the expansion of rice crop in Uruguay. The current scenario has encouraged the adoption of efficient water use technologies to enhance water productivity and contribute to the rational use of this resource. The objective of this study was to evaluate the effect of different water managements during the vegetative stage of the crop on yield (kg ha^{-1}), total water use (m^3 ha^{-1}), irrigation water use (m^3 ha^{-1}), and water productivity (kg m^{-3}). The experiments were conducted during three consecutive seasons from 2010/2011 through 2012/2013 at Paso de la Laguna Experimental Station (INIA Treinta y Tres, Uruguay). A complete randomized block design with 5 irrigation treatments and four replications was used. An overall three year analysis was done using a linear mixed model. Treatments consisted of a set of three conventional water managements and a set of two controlled deficit irrigations (CDI). Conventional treatments consisted of three different flooding moments: 15, 30 and 45 days after emergence (CF15, CF30 and CF45); and the CDI treatments were intermittent irrigation (II) and alternate wetting and drying (AWD). Results showed that CF15, CF30 and II treatments reached higher yields (10592, 10454 and 10189 kg ha^{-1}, respectively) followed by CF45 and AWD (9653 and 9287 kg ha^{-1}, respectively). Mean total water use reached 11508 m^3 ha^{-1}, while mean irrigation water use was 8044 m^3 ha^{-1}. AWD significantly reduces mean total water use and mean irrigation water use. Mean total water productivity was 0.89 kg m^{-3} while mean irrigation water productivity was 1.31 kg m^{-3}. The study demonstrated that controlled deficit irrigation alternatives were effective to maintain high values of water productivity. However, AWD treatment can compromise yield; therefore the overall tradeoffs between crop productivity and water use should be thoroughly assessed before stimulating farmers the adoption of these technologies.

Keywords: water productivity, water use, controlled deficit Irrigation

Field Calibration of FDR Sensors -Limitations and Potentialities

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Abstract

Monitoring soil moisture content is an appropriate method to optimize agricultural irrigation. The use of capacitance sensors has increased over the last years because they have a convenient cost-benefit ratio when compared to neutron moisture gages or time domain reflectometers, which are the most accurate methods to estimate soil moisture content. This project is about the field calibration of a capacitance sensor in clay soils. Two calibration models were applied: a linear model and a quadratic one, which correlate the gravimetric content measured in field soil moisture samples with the excitation received by the sensor (mV) and with the measured dielectric permittivity (?b). The calibration equations were subsequently validated at two different depths at four field sampling sites. Despite the clay soil texture, high organic matter content and compaction of the soils, the equations correctly estimated soil moisture content with an estimation error of ± 0.02 m^3m^{-3}, a considerable improvement over the manufacturer's calibration equation, which has an average estimation error of ±0.12 m^3m^{-3}. A better understanding of sensor performance in the field should result in more precise water applications. A recommendation is made to perform tests in saline and different textured soils to ascertain the stability and sensitivity of these calibration equations.

Keywords: soil moisture sensors, soil water content, precision irrigation

Effect of Continuous Deficit Irrigation of Soybean [*Glycine max* (L.) Merril] in a Semi-arid Environment of Argentina

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Abstract

An important challenge of irrigated agriculture is to increase irrigation water productivity since there is worldwide scenario of reduced availability of water for irrigation and an increased demand for food production. Continuous and regulated deficit irrigation (CDI and RDI, respectively) could be the appropriated irrigation strategies to tackle this challenge. With the objective of evaluating the effect of different strategies of SDI in soybean, a field experiment was implemented at the INTA-Santiago del Estero Exp. Station. For two contrasting sowing dates (SD), 12/22/2011 and 01/25/2012 five irrigation treatments or water regimes (WR) (T100, T75, T50, T25 and T0%,), were applied, restocking 100, 75, 50, 25 and 0% of crop evapotranspiration. Yield Crop (Y), the Actual Crop Evapotranspiration (ETa), and Total Irrigation Depth belong to all treatments were used to calculate two Water Productivity data for each treatment. The first one was calculated as ratio Y and ETa (WPETa), and the second one was determinate as ratio Y and Total Irrigation Depth (WPirrigation). The crop responses to treatments, were independent of the SD (SD*WR interaction was not significant at $p = 0.05$ for all variables). Y was significantly associated with ETa (Y=0.01*ETa2 + 14.36*ETa - 1479; R2 = 0.81; $p < 0.05$), with both Y and ETa significantly different ($p < 0.05$) between WR and SD. The T75% highlighted among treatments, since its ETa and Y were less or equal than those from T100%, with no significant differences between WR ($p = 0.05$). Conversely, WPirrigation showed significant differences, being higher in treatments with lower irrigation depth. At second SD, yield was lower but both WPETa and WPirrigation significantly increased ($p < 0.05$) due to the lower evaporative demand of the atmosphere (ETo decreased 8%). Results indicate that irrigation water depth could be reduced by 25% without any significant yield losses and that PAETa could be increased with selected SD.

Keywords: continuous deficit irrigation, water productivity, soybean

Survey of Uruguayan Freshwater Water Quality for Crop Irrigation

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Abstract

The increase in global demand for food and biofuels, has led to an high demand for agricultural products. That situation implies an intensification of production systems, and develop strategies to ensure stability against drought, and moreover a better levels of productivity. Objectives that could be achieved with the irrigation of crops; however, it can promote negative impacts due to cumulative effects on soil quality, which depend on the chemical composition of the water used. This paper show the results of a national study of freshwater quality, on 100 river watersheds (up to 100,000 ha), which correspond to a cumulative drainage area of 70% of country surface. In these freshwaters the following parameters was evaluated: electrical conductivity, concentration of major cations (Na, K, Ca, Mg), alkalinity, and pH. The results showed Ca, Mg, K, and Na concentrations in ranges of 0.0-45.1, 0.0-14.1, 0.019-16.8, and 0.78 -139 mg L^{-1}, respectively. The alkalinity was in range of 32 to 420 $CaCO_3$ mg L^{-1}, and this variable was the most important contribution to get the different values of electrical conductivity of water, which had values between 71.6 and 1047 micro Siemens cm^{-1}. These features allow propose at least 3 freshwater ecoregions (coastal and central-south; basalt; Northeast and southeast) at Uruguay, based on the chemical composition of studied freshwaters. Moreover, SAR values (([Na] / [(Ca + Mg) / 2] 1/2) of these waters shown a 99% of them has good quality characteristics for the development of irrigation, because they have a SAR below 10.

Keywords: water quality, major cations, ECw, SAR

Teledetection and Crop

Earth Observation for Monitoring Irrigation Demand

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Abstract

During recent years Earth Observation from space (E.O.) has become the most important source of data for monitoring most of land surface-atmosphere processes, and in particular the hydrology of agricultural and forestry areas. Nowadays, E.O. data are being implemented in operative applications for the management of land and water resources. The technological developments of new generation of sensors such as Sentinel-2 of the European Space Agency -with improved spatial and temporal resolution- provide the opportunity for new observational and modelling perspectives. In this work, we illustrate some recent developments in the utilisation of E.O. techniques in the visible and near infrared ranges for supporting the management of irrigation at both farm and district scale. In particular, the following applications of E.O. in the visible and near infrared ranges will be described: irrigated area monitoring, crop parameters, estimation of crop evapotranspiration under standard conditions and crop water requirements. An operational irrigation advisory and forecast service used in Italy and based on the above mentioned techniques will be illustrated.

Keywords: earth observation satellites, irrigation, evapotranspiration, leaf area index, forecast

Remote Sensing for Crop Water Management

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Abstract

Advancements on Earth Observation science and technology in the last decades have made possible the operative use of dense time series of multispectral imagery at high spatial resolution [5-30 m] to monitor crop development across its growing season at a suitable scale. These time series of images, jointly with meteorological data are able to provide accurate maps of daily evapotranspiration and so crop water requirements by using the remote sensing-based approach crop coefficient, Kc, and reference evapotranspiration, ETo, where Kc is derived from spectral reflectances and ETo from meteorological data. A water balance in the root soil layer enables us to calculate irrigation water requirements at appropriate scale for monitoring water management near- real time. This approach could be coupled to the remote sensing-based surface energy balance which uses surface temperature as primary input. But what we could call «remote sensing-driven crop water management» requires at least two steps more to be placed into the day-to-day routine on farming irrigation: On the one hand, for planning irrigation the users require the forecasting of crop water requirements for the week ahead; it can be achieved by extrapolating crop coefficient trend and by using weather forecasting for ETo estimation. On the other hand, decision makers in charge of irrigation require access to this information in an easy-to-use way on real time. It can be achieved through leading edge webGIS tools, which facilitates co-creation and collaboration with stakeholders.

Keywords: crop water management, remote sensing, weather forecasting, webGIS

Estimation of Basal Crop Coefficient Using Remotely Sensed Vegetation Indices for Center Pivot Irrigated Maize in Southern Brazil

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Abstract

The partitioning between basal crop coefficient (K_{cb}) and soil evaporation coefficient (K_e) of the crop coefficient (K_c) during the crop cycle is lately been used to develop a more reliable and precise irrigation management. A currently approach under development is estimating K_{cb} using vegetation indices, obtained from remote sensors. This approach allows an alternative and independent procedure in comparison with the classical methodological approach described in FAO 56 or models that simulate the soil water balance using land information; one model that uses this approach is SIMDualKc. This estimation could also be done using surface energy balance models, however, these models present greater complexity and greater number of input data than the conventional K_c-ET_o approach. The objective of this study was to determine the initial, mid-season and late-season basal crop coefficients ($K_{cb\ ini}$, $K_{cb\ mid}$, $K_{cb\ end}$) using historical records of the red and near infrared reflectance of central pivots, to calculate the normalized vegetation index (IV), adjusted for the entire maize growth, in conjunction with soil field and phenology data of seven center pivot fields in Southern Brazil. Eight Landsat5/TM satellite images of 222 and 223 orbits in point 80, and information from these seven maize monitoring fields during 2004/2005 growing season were used. Crop height and crop growth stages, as well as meteorological weather data collected from a weather station installed in the area were used. A density coefficient (K_d) determined using the fraction of vegetation ground cover (f_c) was used for the Kcb estimation through VI, incorporating the impact of both the vegetation density and the plant height. The estimated values were: $K_{cb\ ini} = 0.20 \pm 0.09$, $K_{cb\ mid} = 0.20 \pm 0.95$ and $K_{cb\ end}$ 0.52 ± 0.22, considering 95% of probability. The results showed good agreement with K_{cb} values obtained using SIMDualKc model in a previous study of this research group for the southern region of Brazil, which were $K_{cb\ ini} = 0.20$, $K_{cb\ mid} = 1.12$ and $K_{cb\ end} = 0.80$.

Keywords: remote sensing, NDVI, crop coefficient, SIMDualKc

Using NDVI Time-series Profiles for Monitoring Corn Plant Phenology of Irrigated Areas in Southern Brazil

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Abstract

Among the factors that contribute the most for increasing maize cultivated area and grain yield in Southern Brazil are the crop genetic selection, soil, crop and water management and recent advances in crop remote monitoring techniques. The Normalized Difference Vegetation Index (NDVI) obtained with remote sensing techniques may be used to provide historical and real-time evaluation characteristics of a particular crop, such as density and vigor without neither field visits, nor interfering directly or indirectly in crop growth and development. This procedure may substantially reduce monitoring or control costs. In this paper, a temporal profile series of NDVI was generated during the maize crop growth period with the objective of evaluating the crop phenology of seven irrigated areas under center pivots. Eight images from LANDSAT5/TM satellite, of the 222/80 and 223/80 path/row were used. The quantitative intervals of NDVI mean values were evaluated from the temporal profile series based on the crop sowing and harvest dates. The NDVI values varied from: 0.18-0.53for initial crop stage; 0.54-0.80for rapid crop growth; 0.20-0.74 for mid-season; and 0.28-0.41for late season. The use of NDVI allows a good differentiation among the maize crop stages of irrigated areas. There has been a drop in NDVI values in the R1 stage, at 54 days after sowing (DAS), due to detasseling. Maximum NDVI value (0.80) was observed at 63DAS, with maize phenology between R2-R5 stages. NDVI values decreased from R6 growth stage till harvest (134 DAS) due to crop maturity and senescence. During this period the average NDVI value was 0.40.

Keywords: SPRING, LANDSAT5, southern Brazil, center pivots

Early Estimate of Wheat Yield in Irrigation District N^0 38, Rio Mayo, Sonora, Mexico

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Abstract

At the irrigation district N^o 38, Rio Mayo, in Sonora State, Mexico, crop wheat accounts for about 70% of the area under irrigation (about 68,000 ha). Whereby, water users have requested studies aimed to find a method to obtain early crop yield estimation for wheat, using vegetation indices. These values have been obtained from Landsat 7, Landsat 8, and Deimos satellites images. Other studies have been done to estimates crop evapotranspiration (ETc), assessed by two methods, by the relationship: $ETc = Kc_b * ETr$, (ETr reference evapotranspiration) where Kc_b is evaluated as a function of NDVI, and by the method of moisture balance (MATRIC algorithm). Specifically, for early crop yield estimate it has been considered a relationship with the value of the index NDVI at heading of the crop, time when usually achieves its maximum value. There is sufficient background in literature about this kind of relationships among them, the works carried out by the International Water Management Institute in India. Moreover, to assure farmers know their crop conditions, there have built a couple of viewers, accessible in the WEB page of the district. So, as part of the PLEIADeS and SIRIUS projects funded by the European Commission, in which the authors' collaborated, the SPIDER viewer where developed and used for shows values of NDVI on each farm in this district; in addition there is other viewer developed by one of the authors which is available for transfer information to water users. To calibrate the proposed methodology to calculate relationship between the NDVI and the crop yield, the staff of the extension service has been working in measuring yields in many plots within the district, results are presenting in this work.

Keywords: NDVI, evapotranspiration, crop yield, remote sensing

Geographic Information System to Support Irrigation Management Strategies

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Abstract

Meteorological variables, phenology, plant health and crop management, soil physical and chemical properties, water and energy balances as well as variables related to economics, logistics and monitoring processes, among others, create complexity in the management of irrigation, which make it difficult to be administered conceptual or empirical models. Also, physico-mathematical modelsdescribing isolated phenomena cannot cover the overall complexity of the problem. This can be seen, in practice, by the gradual growth of factors which threaten the sustainability of irrigation enterprise. Currently, the advent of geotechnology application in agriculture and its integration with weather information in Geographic Information System (GIS) environments has make possible a more detailed support for irrigation management and planning. The objective of this study therefore was to organize and develop a geo-relational database with information from 30 pivots located in Cruz Alta, RS, Brazil, to further establish the usefulness of GIS in irrigation management. Data base preparation took place in two stages: (i) acquisition, georeferencing, image vectorization, snipping and calculation of vegetation indices relating to 107 images from Landsat5/TM satellite; and (2) creation of geo-related tables for each pivot containing information obtained from fieldsand weather stations in the region. Besides statistical analysis of NDVI values of pixels (picture elements) from each pivot, informationon crop type, planting date, phenological stages, soil type, evapotranspiration and weather data were also included in the database. Image processing, calculations and statistical analyzes, as well as mapping were done using SPRING software. Thus, a geographical database capable of integrating field information with those obtained by remote sensing was created and mapping of the distribution of key crop variables enabled better visualization of the dynamics of processes in progress, thus enabling comprehensive technical background for decision making with respect to planning and management of production systems in irrigated agriculture.

Keywords: Central Pivot, SPRING, Landsat, Cruz Alta