Some considerations on the productivity of the agriculture in Tamghat Valley (Nepal): the case of rice

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Abstract: *Many developing countries present a very low agricultural productions, being of bare subsistence and occupying most of the population. A crop simulation model with a monthly time step was adopted to highlight the possibilities of intensification of rice crop production in the Tamghat Valley (Nepal). Results show that production without limitations due to nutrients, pests and diseases is of about 6 t ha^{-1}, with a remarkable inter-yearly steadiness. This value is significantly higher than real production, which is currently below 2.8 t ha^{-1}. This relevant difference is probably the result of limitations due to pests and nutrients and also to an obsolete park variety. Hence an improvement in agro-technique and genetics is desirable to increase the yields.*
Keywords: *Paddy rice, productivity, monsoon climate, Nepal.*

Riassunto: *Molti paesi in via di sviluppo presentano una produttività agricola molto bassa, di pura sussistenza e che impegna gran parte della popolazione. Un modello di simulazione di produttività con un passo temporale mensile è stato adottato per evidenziare la possibilità di intensificare la produzione di riso nella Valle di Tamghat (Nepal). I risultati mostrano che la produzione, senza limitazioni dovute a nutrienti, parassiti e malattie è di circa 6 t ha^{-1}, con una notevole stabilità interannuale. Questo valore è significativamente più elevato rispetto alla produzione reale, attualmente inferiore a 2,8 t ha^{-1}. Questa rilevante differenza è probabilmente il risultato di limitazioni legate ai parassiti e alle sostanze nutritive, cui si aggiungono i problemi legati ad un varietale obsoleto. Pertanto un miglioramento nelle agrotecniche e nelle risorse genetiche è auspicabile per un aumento delle rese.*
Parole chiave: *Riso in sommersione, produttività, clima monsonico, Nepal.*

1. INTRODUCTION

Yoshida (1981) stated at 6 t ha^{-1} the summer rice potential production in field conditions for subtropical monsoon areas. This value - significantly lower than maxima (13 t ha^{-1} for mid latitudes, 11 t ha^{-1} for subtropics) achievable in most favorable climatic conditions - is justified by two main limitations: the insufficient length of the day (generally less than 13-14 hours, compared to maxima of 15 hours and 43 minutes reached at 45 ° of latitude at summer solstice) and the strong cloud coverage that characterizes the monsoon period from May to October (Yoshida, 1981).

Nevertheless the same limit of 6 t ha^{-1} is often unattainable for developing countries with monsoon climate, characterised by bare subsistence agriculture which employs most part of the population giving rise to a very low productivity. This is the case of Nepal which agriculture employs 65% of the population and achieves the 39% of GDP. The cultivation of rice in Nepal, particularly relevant for food production, shows an average productivity of 2.8 t ha^{-1} (FAO, 2010). This production sounds very low if compared with yields allowed by the state-of-art varieties and the most advanced agro-techniques. A report, freely available on Internet, by Uprety (2005) summarizes the situation of Nepal and quotes the following main limitations to the Nepal agriculture productivity :

- a little or null use of chemical fertilizers, often replaced by manures or compost
- an obsolete varietal park with cultivars unable to exploit the intensive fertilization
- the obsolete agro-techniques, with little attention to pest problems (weeds, fungal diseases, insects) and bad practices of transplant, operated on 30-45 days old plants.

The same report quotes examples of farmers who have overcome the above limitations by adopting a method of intensification called SRI (System of Rice Intensification) and obtaining production of about 6 t ha^{-1}. These relevant results are indirectly confirmed by the production of 5 t ha^{-1} achieved by farmers in the Kathmandu Valley which has the highest application of chemical fertilisers (Pockrel, 1995) and by maximum productions of 4.5 - 5.5 t ha^{-1} for conventional and SRI rice cropping systems reported

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Received 10 June 2011 accepted 28 June 2011

for Andhra Pradesh – India (Adusumilli and Bhagya Laxmi, 2010).
In Nepal, the lack of irrigation water, especially upon the highland, is an important factor that limits agriculture. During drought periods, farmers counteract this lack of water by means of electric pumps and putting the water inside trenches (Dixit *et al.*, 2009). The work of local and international Non Government Organizations (NGO) had allowed a greater access to drinkable water and to water used for agriculture, improving in this way the health and wealth conditions of the farmers.
Dynamic simulation models are mathematical tools useful to simulate crop growth and yield on the base of a set of driving variables that acts on rate variables ruling the exchanges among different state variables (Mariani and Failla, 2007).
This work has been aimed to show how improved genetics and agro-techniques are able to enhance agricultural production in this area. To obtain this, the rice average productivity of the Tamghat Valley was simulated by means of a dynamic simulation model which describes the cascade of matter triggered by solar radiation. Along this cascade a sequence of limitations are applied in order to attain the final production subdivided among shoots, roots, leaves and fruits.

2. DATA AND METHODS

2.1 Study area and crop available data

The Tamghat Valley, object of this study, is crossed by the Jhiku Khola river and is located in the Kavrepalanchok district, 40 Km from Kathmandu, on the central hills of Nepal (Fig. 1). The agriculture practiced in Kavrepalanchock district uses better infrastructures and techniques than the ones used in most part of the other rural areas of Nepal. For this reason, the agriculture in Kavrepalanchock district cannot be considered to be only of subsistence but constitutes also business (Hermann and Schumann, 2002).
The hills that surround the Tamghat valley are between 750 and 2100 m above the sea level.
The land inside the valley is classified in two typologies: the first, corresponds to lands located on the bottom of the valley, easy to irrigate via a system of channels; the second, corresponds to lands located on highland where the irrigation is difficult and the soils show a fast drainage, with low values of soil water reservoir.
The cropping systems of the Tamghat valley are founded on vegetables (potatoes, rapes and other kinds of vegetables that provide more than one harvest per year) and cereal crops, mainly wheat, corn and rice. This latter is cultivated during the monsoon season and the fields are located on the bottom of the valley. while the highland, closer to the houses, hosts a larger number of cultivations (especially vegetables) with a more intensive need of work (Hussan and Giordano, 2003).
By the economic point of view, vegetables are partly cultivated for business and vice-versa cereals are mainly cultivated for subsistence. An important consequence of the subsistence character of the rice crop is the absence of statistical data about rice productivity. However in a preliminary way it is possible to say that rice productivity in Tamghat valley is lower than the above-mentioned mean national productivity of Nepal (2.8 t ha^{-1}). This represents a working

Fig. 1 - Nepal map with the location of the Kavrepalanchok district (source: Wikipedia).
Fig. 1 - Mappa del Nepal con la localizzazione del distretto di Kavrepalanchok (fonte: Wikipedia).

hypothesis that is corroborated by knowledge of other areas of the world characterized by subsistence agriculture.

2.2 The agrometeorological model and simulation conditions

The monthly simulation of productivity operates under the following two conditions:

- In absence of water limitation (paddy rice): a thermal limit is applied to a potential radiative base production, considering as absent the limitations of water, nutrient and biotic/abiotic adversity.
- with water limitation (rice in dry): water limitation, defined by a water balance was applied to the previously described scheme.

This latter condition is only theoretical because, inside the area of study, rice is only grown in submersion; however it can be useful to highlight the dry years during the crop cycle due to the lack of monsoon rains.

A monthly meteorological dataset, related to the period 1977-2008 and coming from the Hydrometeorological Service Station located in Panchkhal (Kavrepalanchock district), feed the model. It includes maximum and minimum temperature (Tx, Tn) [°C] and rainfall (RR) [mm].

Monthly mean temperature (Td) [°C] is defined as:

(1) Td=(Tx+Tn)/2.

The hourly loop of the model, adopted to calculate thermal limitation for rice crop, is fed by hourly temperatures (Th) [°C] produced applying the method of Parton and Logan (1981) to Tx and Tn values of each month. All the outputs obtained on a daily basis have been reported to the single month by multiplying by the number of days.

2.2.1 Climatology of the study area

Analyzing Panchkhal meteorological data is evident that the Tamghat Valley is characterized by a monsoon-type climate, which gives a seasonal mark to the yearly rainfall regime.

An increase of the rainfall during April and May preludes to summer monsoon which reaches his peak during the months of July and August. The start of the monsoon season is relatively gradual, unlike the transition to the dry season (September) is generally more rapid.

Thermal regime shows the monthly minimum in January (mean maximum temperature: 20.6 °C, mean minimum temperature: 5.1 °C), the monthly maximum in May (average maximum temperature of 32.0°C, average minimum temperature of 20.7 °C) and the increase in maximum temperatures during the summer strongly limited by cloud cover and heavy rainfalls.

2.3 Cardinal temperatures and morphometric variables

Morphometric variables are driven by thermal resources that are calculated taking into account the following set of cardinal temperatures: 7°C as minimum (C_{min}), 23°C as lower optimum (C_{optl}), 32°C as upper optimum (C_{optu}) and 38°C as maximum (C_{max}) as reported in table 1 (Yoshida, 1981; Larcher, 1995).

More specifically growing degree days (GDD) [°C] for a given month with specific number of days (ndd_{mm}) have been obtained by means of the equation:

(2) $GDD=ndd_{mm}*(Td- C_{min})$

Using GDD summation (GDD_{sum}) [°C], the Leaf Area Index (LAI) [m^2/m^2 - dimensionless] for each month is estimated with the empirical equation:

(3) $LAI=GDD_{sum}/400$

LAI values respectively below (LAImin : 0.5) and above (LAImax : 6) the cut-off values are equalised to these cut-off (Tab. 1).

The crop coefficient (Kc) [dimensionless] is estimated by the empirical equation

(4) kc=LAI/5.5

2.4 The productivity model

The model firstly involves the estimation of the daily global solar radiation (GSR) [MJ m^{-2} d^{-1}] with the method of Hargreaves (Allen *et al.* 1998).

The fraction of photosynthetic active radiation (PAR) [moles of photons m^{-2} d^{-1}] intercepted by the crop (APAR) is then obtained by applying the Lambert - Beer law for the interception of radiation by an anisotropic mean (Larcher, 1995) with a value of 0.5 (typical of graminaceous crops) adopted for the extinction coefficient (ke) [dimensionless]:

(5) $APAR=0.5 * 4.6 * GSR * (1-e^{(-ke\ LAI)})$

Where 0.5 and 0.46 are respectively the multipliers adopted to convert GSR in PAR and MJ in moles of photons.

The gross assimilation (GASS) [g m^{-2} d^{-1}] is estimated adopting the radiation use efficiency (RUE) [moles CO_2 m^{-2}] standard value of 0.014 (Choudhury, 2001):

(6) GASS=APAR*RUE

The potential net assimilation (PNA) [moles CO_2 m^{-2}] is obtained with:

(7) PNA=GASS*eg

The multiplier coefficient (eg), assumed equal to 0.7, accounts the losses related to the maintenance respiration and translocation.

The hourly thermal limitation was obtained using the

Parameter	Achronim	Value
Minimum cardinal	Cmin	7 °C
Maximum cardinal	Cmax	38 °C
Lower limit of Optimal range	Coptl	20 °C
Upper limit of Optimal range	Coptu	30 °C
Minimum LAI accepted	LAImin	0.5
Maximum LAI accepted	LAImax	6.0
Latitude	LAT	27°
Longitude	LON	85°
Altitude	Hh	865 m asl
Harvest index	HI	0.4
Maximum water capacity*	Mwc	250 mm
Field capacity*	Fc	200 mm
Wilting point*	Wp	100 mm
Sowing date	Sod	15/4
Transplanting date	Tpd	1/5
Harvest	Hrv	31/8

(*) for the soil layer explored by roots. (*) per lo strato di suolo esplorato dalle radici.

Tab. 1 - Parameters adopted for rice crop simulation.
Tab. 1 - Parametri colturali adottati per la simulazione colturale.

following response curve that produces a coefficient (krtp) [dimensionless] with values between 0 and 1 (values below 0 or above 1 are respectively equalised to 0 and 1):

$$(8)\ krtp = -0.0001512270321*th^3 + + 0.006891188223*th^2 - - 0.03329786301*th - 0.01997994562$$

The values calculated over 24 hours were averaged to obtain a multiplier coefficient that expresses the daily thermal limitation (tl) [dimensionless].
Therefore, the final monthly production thermally limited (NPP) [moles CO_2 m^{-2}] is given by:
(9) $NPP=tl*PNA*ndd_{mm}$
This value is then converted in final values [t ha^{-1}] of coarse rice production adopting as multipliers 30 [atomic weight of CH_2O] to switch from moles of CO_2 to g of dry matter, 10^{-6} to convert g in t and 0.4 (Harvest Index) to convert crop weight into useful product weight).
An analogous equation was adopted to calculate the water limited production (NPP) [moles CO_2 m^{-2}]:
(10) $NPP=tl*wl*PNA*ndd_{mm}$
Where water limitation (wl) has been obtained by means of the algorithm hereafter described.

The hydrologic characters of reservoir are a water content of 200 mm at field capacity (fc) [mm] and 100 mm at wilting point (wp) [mm], which means an Available Water Content (AWC - Total water reservoir between field capacity and wilting point) of 100 mm.
The following continuity equation (mass conservation for water) was applied to the soil layer explored by roots (reservoir):
(11) $WC_{t+1}=WC_t+rr-ET0*kc-inf$
using the following inputs: the soil water content (WC) [mm], the reference crop evapotranspiration (ET0) [mm] obtained through the method of Hargreaves and Samani (Allen *et al.*, 1998), the rainfall (rr) [mm], the crop coefficient (kc) was used to obtain the crop maximum evapotranspiration (etm) from ET0 and the infiltration loss (inf) [mm] is the water exceeding AWC.
Once obtained, the soil water content at a given time (WC), the water limitation (wl) [dimensionless] is obtained adopting the following algorithm:
(12) wl=(WC-wp)/(wccr-wp)
where the threshold of sensitivity to water deficit (wccr) [dimensionless] is obtained with the equation:
(13) wccr=wp+(1-dp)*(fc-wp)
where the soil water depletion factor (dp) [dimensionless] describes the easiness of extracting

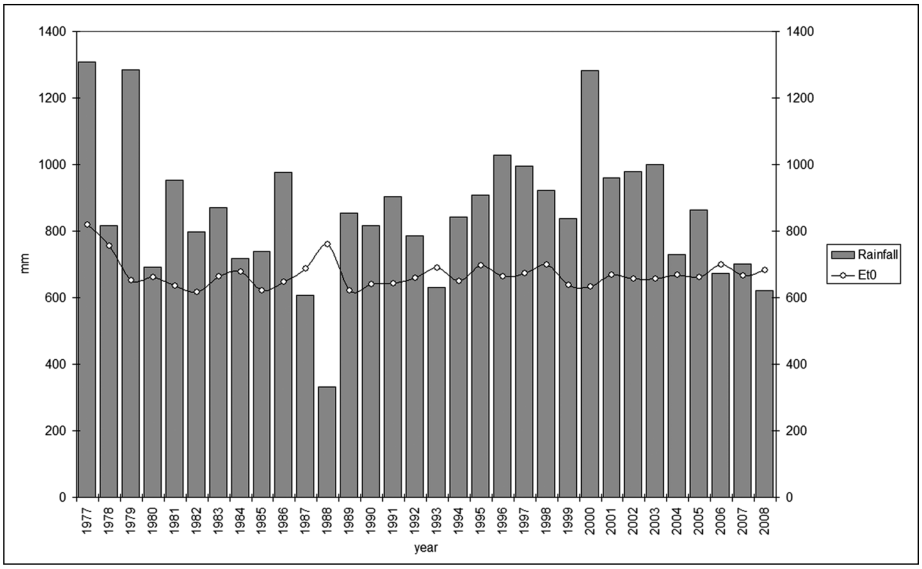

Fig. 2 - Yearly values of rainfall and reference crop evapotranspiration ET0 (mm) of Panchkhal weather station (reference period 1977-2008). The biennial drought 1987-1988 is evident.
Fig. 2 - Valori annui di pioggia ed evapotraspirazione da coltura di riferimento ET0 per la stazione meteorologica di Panchkhal (periodo 1977-2008). Si noti la fase siccitosa del biennio 1987-1988.

water from the soil (atmospheric water demand) as a function of ET0 and is expressed by the equation:
(14) dp:=ts/(ts+ET0)
In this equation a value of 9 has been assigned to the characteristic potential transpiration rate (ts) [mm/month] (Doorenbos *et al.*, 1978).

3. RESULTS AND DISCUSSIONS
3.1 Simulations
The remarkable inter-annual stability of harvest data (average and standard deviations) for the reference period 1977-2008 (Fig. 3) shows one of the more positive aspects of the monsoon climate. The stability is mainly the result of the absence of a trend in main meteorological driving variables (Fig. 2).
However the monsoon climate reduce also the light energy available to plants, when thermal conditions are often optimal for photosynthesis (Williams and Joseph, 1970) and water stress is absent.
The annual average production of paddy rice for 1977-2008 period has been 5.7 t ha^{-1}, with a standard deviation of 0.20 t ha^{-1}. Compared to that, rainfed crop has shown a very limited reduction in average yields with annual average production of 5.4 t ha^{-1} and standard deviation of 0.91 t ha^{-1}. Nevertheless this reduction (Fig. 3) is relevant on the period 1987-1988, characterized by a delayed onset of monsoon with quite low summer rainfall in the northern part of the Indian subcontinent (Kailasa Nathan, 1994). As a matter of fact, the delay on the monsoon onset, doesn't allow the flooding of rice fields with obvious productivity problems.

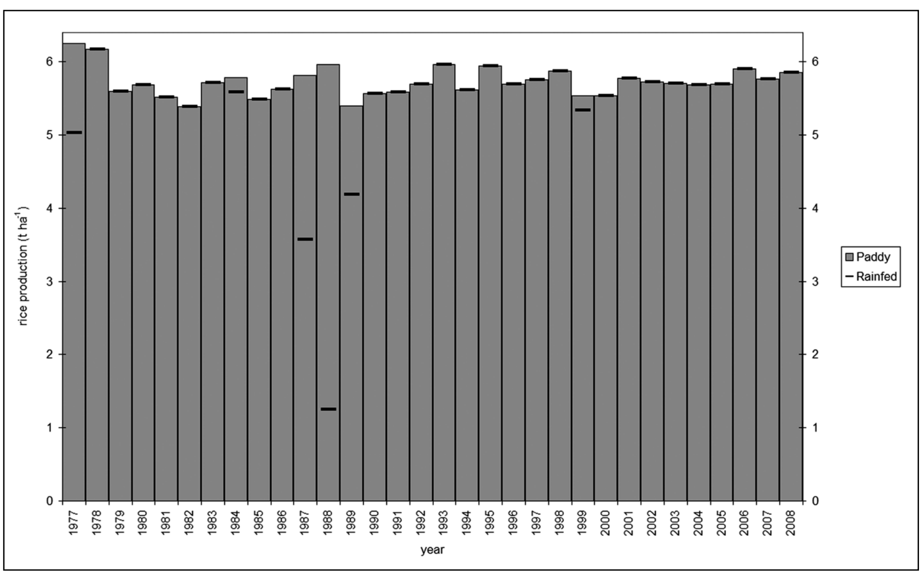

Fig. 3 - Yield of paddy and rainfed rice for the period obtained with the simulation model applied to the 1977-2008 time series. Low productivity of rainfed rice in specific years is mainly attributable to a delay in monsoon onset.
Fig. 3 - Produzione di riso in sommersione ed in coltura asciutta ottenuta con il modello di simulazione applicato al periodo 1977-2008. La bassa produttività osservabile per il riso in asciutta in annate particolari è soprattutto da attribuire al ritardo nell'arrivo del monsone.

4. CONCLUSIONS

A multi-year estimate of rice production in the Tamghat Valley was carried out by means of a dynamic simulation model fed by monthly meteorological data produced by the local meteorological station.

Various limitations come from the monthly step of the model. For example the effects of sub-optimal or super-optimal temperatures cannot be taken into account in a realistic way due to the very long time step adopted and in the same way the simulation of water balance shows some limitations.

The results reveal that the simulated productivity in the Tamghat Valley are double compared with real production (NAPA, 2010). Causes of this significant differences might be searched in the limitations related to pest management and nutrients and also in the obsolete park variety. The discrepancy found indicates that the optimization spaces are relevant.

Obviously intensification of paddy rice crop at farm level should be promoted by specific technical assistance activities, carried out by agronomists and technicians. Thus, it is confirmed the diagnosis provided by Uprety (2005) and in conclusions it is possible to state that productivity intensification based on agro-techniques and genetics is an effective instrument to enhance food safety in Nepal.

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