ISSN 0858-2114

International Agricultural Engineering Journal

CONTENTS

Vol. 17, No. 1-4, 2008

Research Papers:

Published by

THE ASIAN ASSOCIATION FOR AGRICULTURAL ENGINEERING (AAAE)

International Agricultural Engineering Journal

An International Journal on Research and Development in Agricultural Engineering
Published by the Asian Association for Agricultural Engineering (AAAE)

INTERNATIONAL

AGRICULTURAL ENGINEERING

JOURNAL

Published by

ASIAN ASSOCIATION FOR AGRICULTURAL ENGINEERING (AAAE)

Vol. 17, No. 1-4, 2008

Aims and Scope: The aim of this journal is to communicate advances in Agricultural Engineering, with particular reference to Asia, to practicing professionals in the field. The scope will include soil and water engineering, farm machinery, farm structures, post-harvest technology, biotechnology food processing and emerging technologies. Subjects of general interest to agricultural engineers such as ergonomics, energy, systems engineering, precision agriculture, protected cultivation, terramechanics, instrumentation, environment in agriculture, and new materials are also included.

Publication Schedule: International Agricultural Engineering Journal is published in four issues per year.

Subscriptions: For institutions in Asia the annual subscription is US$ 135 and outside Asia US$ 150 per calendar year. The journal copies will be mailed by air mail.

Correspondence: All manuscripts and other correspondence should be directed to the Editor, International Agricultural Engineering Journal, c/o Agricultural Engineering Department, 218B Davidson Hall, Iowa State University, Ames IA 50011, U.S.A. with e-mail: rskanwar@iastate.edu

International Agricultural Engineering Journal 2008, 17(1-4):1-7

ENERGY ANALYSIS OF WET SEASON RICE PRODUCTION IN NORTHERN THAILAND

Tanate Chaichana*, Sumpun Chaitep†, Wasan Jompakdee† and Natthawud Dussadee‡

ABSTRACT

This study was designed to record the production factors, analyze energy consumption and formulated the mathematical model for prediction energy requirement in the future of wet season rice production. The study areas were located in six provinces of Northern Thailand. The rice production process comprised of soil preparation, cultivation, cultural practice and harvest. During these processes, production factors were determined and changed to an equivalent value of energy consumption per production area (MJ/Rai). Subsequently, they were calculated for a multiple correlation of production factors and energy consumption in order to estimating future energy requirement. It was found that in order to obtain an average paddy yield of 626.26 kg/Rai, the average commercial energy consumption was 2,246.65 MJ/Rai and non-commercial energy consumption was 181.11 MJ/Rai. So, the average energy consumption was 2,427.76 MJ/Rai. The majority part of energy is from chemical fertilizer of 39.25% of total energy following by the energy from agriculture machinery of 35.46% and 17.23%, 3.39%, 4.07% and 0.06% for the energy from fuel, labor, seed and chemical substance respectively. Farmers should reduce the chemical fertilizer and use more organic fertilizer which is not only lower the energy consumption and cost but also save the environment and keep healthy. The mathematical model is accurately to predicting the energy consumption and planning to use the production factors in the future. The model is not depending on production factors price, but it is up to the quantity of using.

Keywords*: *Rice; Energy consumption; Northern Thailand; © 2008 AAAE

1. INTRODUCTION

Agriculture is both a producer and consumer of energy. It used both commercial and non-commercial energy such as labor energy, animal energy, seed, fuel, fertilizer and chemicals etc. Efficient use of energy helps to activate planning and decreased or change production factor to increase the advantage and enjoy a happy life of rural living.

Rice is a primary cultivation for the yield which forms an important part of the staple food in many countries, especially in Asia. Grains are quite nutritious when not polished. The nutritional values of rice (white) have carbohydrate 71–77% and protein 5–8%, brown rice vitamin contains in g/100g: 0.34 g B_1, 0.05g B_2, 0.62 g Niacin, 1.50 titanic acid, 20.0g folic acid (Thanchotikan, 2546).

Thailand has 57,740,000 Rai (1 Rai = 1,600 m^2 or 0.16 ha) of rice cultivated area in wet season of 2005 (Department of Agricultural Extension, 2003). The major activities of rice cultivation process in Thailand are composed of 4 processes (Meajo University, 2545). First the preparation process is involved of 3 steps including rough plough for the first time, plough in regular furrows for the second time and plough up and over. Next the plantation or cultivation process consists of 2 systems including broadcasting cultivation system and transplanting cultivation system. Third the cultural practice process such as fertilizer, herbicide and irrigation etc. The last step is the harvesting, this process can be operate by 3 major working procedures, i.e. utilize all human labor, use mix labor in harvest but with machine in thresh rice thirdly use all machinery.

The season of rice production in Thailand is to be decided by area and irrigation system such as; there are 3 times of rice production in irrigated area and 2 times in non- irrigated area. Generally there are 2 times of rice production in Northern Thailand, wet and dry season. The majority expenses for rice

* PARA and FAME laboratory, Faculty of Engineering, Chiang Mai University, Thailand, and Corresponding Author.
† Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Thailand.
‡ Energy Research Center, Maejo University, Thailand.

production are land rent, fertilizer and machinery, secondary expenses are irrigation and herbicide (Herdt, 1987).

The objective of this study is to record the production factor of rice production and analyze energy consumption and develop the mathematical model for estimating energy requirement in the future.

2. EXPERIMENT AND ANALYSIS

The sample sites chosen for this study were 44 sites, 322.369 Rai in 6 provinces of Northern Thailand, i.e. CHIANG MAI, LAMPHUN, LAMPANG, PHICHIT, PHITSANULOK and SUKHOTHAI. The rice production processes are comprised of soil preparation, cultivation, cultural practice and harvest process.

Production factors have been determined including engine type (Walking tractor, water-pump, chemical-pump, etc.), power output of the engine (hp.) and fuel consumption (liter), labor (man), seed-quantity (kg), seed-price (Bath/kg), fertilizer(kg, N-P-K), chemical substance (kg or liter), working time (hour), paddy yield (kg) and cultivation area (Rai). The field data transformed to an equivalent value of energy consumption per cultivated area (MJ/Rai) by using energy equivalent in Table 1.

The production factors data changed to energy consumption in unit MJ/Rai by used equation (1) to (9) are: (Chaicana, 2004)

Labor and animal

$$\text{Energy (MJ/Rai)} = \frac{\text{E - Eq.(MJ/hour/unit) x Working Time (hour) x Unit}}{\text{Working Area (Rai)}} \quad (1)$$

Fuel

$$\text{Energy (MJ/Rai)} = \frac{\text{E - Eq. of Fual (MJ/unit) x Quantity (Unit)}}{\text{Working Area (Rai)}} \quad (2)$$

Fertilizer

$$\text{Energy (MJ/Rai)} = \begin{bmatrix} \text{NUR (kg/Rai) x E - Eq. of N (MJ/kg)} \\ + \text{PUR (kg/Rai) x E - Eq. of P (MJ/kg)} \\ + \text{KUR (kg/Rai) x E - Eq. of K (MJ/kg)} \end{bmatrix} \quad (3)$$

$$\text{NUR (kg/Rai)} = \frac{\text{TFUR (kg/Rai) x Present of N}}{100} \quad (4)$$

$$\text{PUR (kg/Rai)} = \frac{\text{TFUR (kg/Rai) x Present of P } (P_2O_5)}{100} \quad (5)$$

$$\text{KUR (kg/Rai)} = \frac{\text{TFUR (kg/Rai) x Present of K } (P_2O)}{100} \quad (6)$$

$$\text{TFUR,(kg/Rai)} = \frac{\text{Total Quantity of Fertilizer Use (kg)}}{\text{Working Area (Rai)}} \quad (7)$$

Chemical

$$\text{Energy (MJ/Rai)} = \frac{\text{E - Eq. of Chemical (MJ/kg) x Quantity (kg)}}{\text{Working Area (Rai)}} \quad (8)$$

Seen

$$\text{Energy (MJ/Rai)} = \frac{\text{E - Eq. of Seed (MJ/B) x Quantity (kg)} \times \text{price (B/kg)}}{\text{Working Area (Rai)}} \quad (9)$$

When

E – Eq. = Energy Equivalent
TFUR = Total Fertilizer Use Rate
PUR = Phosphorus (P (P_2O_5)) Use Rate
NUR = Nitrogen (N) Use Rate
KUR = Potassium (K (K_2O)) Use Rate

3. RESULTS AND DISCUSSION

3.1 Soil Preparation Process

The soil preparation process are composed of 3 steps including rough plough roughly for the first time, plough in regular furrows for the second time and plough up and over. The main type of agriculture machinery is walking type tractor. It has engine power rang from 5.0 to 15.0 hp. This process required average working – time of 3.86 hour/man/Rai, diesel consumption 3.32 liter/Rai and energy consumption was 362.05 MJ/Rai. The data show in Fig. 1.

3.2 Cultivation Process

There are two systems of operating in this process, i.e. broadcasting cultivation system and transplanting cultivation system, seed - sow in to transplant paddy seedlings area about 10% of total cultivated area, after 25 – 30 day young plant can be pulled transplant in the field.

From Table 2, broadcasting cultivation system required 0.21 hour/man/Rai in working time and 35.33 kg/Rai in rice seed. The energy consumption was analyzed from labor energy and rice seed energy. It was 159.40 MJ/Rai. Transplanting cultivation system required working – time of 1.63 hour/Rai and seed 7.57 kg/Rai and average energy consumption was 93.85 MJ/Rai.

3.3 Cultural Practice Process

Rain is the main water sources to activation in wet season, but in some areas farmers have to use water – pump in order to sufficient water and use fertilizer for increasing yield as well as chemical substance eradicate epidemic and bugs. There have 2 types of water-pumps; gasoline engine and diesel engine. There are 3 ways for chemical–pumping are gasoline engine, diesel engine and labor- sprayer. The fertilizer–formula (N-P-K) are 16–20–0, 21–0–0, 14–14–21, 30–0–0, 17–12–6 and 18–8–6. The energy consumption in the cultural practice process is shown in the Table 3.

3.4 Harvest Process

In this report, the limited of harvest process is started from reap to thresh rice. There are three systems operated in the harvest process i.e. operation by whole human labor from reap to thresh rice, mixed human labor for reap but with machine thresh and total machine operated for reap and thresh rice. The production factor required and energy consumption in the harvest process is shown in Table 4.

The total working–time for rice production process from soil preparation to harvest process was 6.94–14.19 hour/man/Rai decided by cultural method, e.g. the plantation or cultivation process, it consisted of 2 systems including broadcasting and transplanting,

Table 1: Energy Equivalent

Energy Type	Energy Equivalent		Referent
Labor	1.96	MJ/man/hour	[5]
Animal			
weigh 350-450 kg	10.10	MJ/ hour	[5]
Fuel			
diesel	43.3	MJ/liter	[6]
gasoline	39.7	MJ/liter	[6]
electricity	14.4	MJ/kW-h	[6]
Fertilizer			
N	76	MJ/kg	[7]
P (P_2O_5)	14	MJ/kg	[7]
K(K_2O)	10	MJ/kg	[7]
manure	0.303	MJ/kg	[8]
Chemical	120	MJ/kg	[9]
Rice seed	0.674	MJ/price (Bath)	[10]
Machinery			
Water and chemical – pump (4 – 6 hp.)	13.59	MJ/Rai	[11,12]
Working tractor (15 – 24 hp.)	70.31	MJ/Rai	[11]
Driving tractor (80 – 110 hp.)	337.62	MJ/Rai	[12,13]
Harvesting tractor (100 hp.)	423.41	MJ/Rai	[12,13]
Harvesting tractor (185 – 215 hp.)	708.96	MJ/Rai	[12,14]

cultural practice process in some area do not use water–pump because the sufficiency of rainfall and the way in the harvesting process etc. Rice production process required total diesel fuel of 11.82 liter/Rai, gasoline fuel 4.78 liter/Rai. Transplanting cultivation required seed 7.57 kg/Rai but 35.33 kg/Rai for broadcasting cultivation. Fertilizer required 38.79 kg/Rai and chemical substance of 1.13 kg/Rai.

The total energy consumption ranged from 1,644.36–2,666.26 MJ/Rai depends on cultural method, cultivation step, maintenance step and harvesting process. The average energy consumption was 2,115.18 MJ/Rai for transplanting cultivation and 2,181.37 MJ/Rai for broadcasting cultivation. The

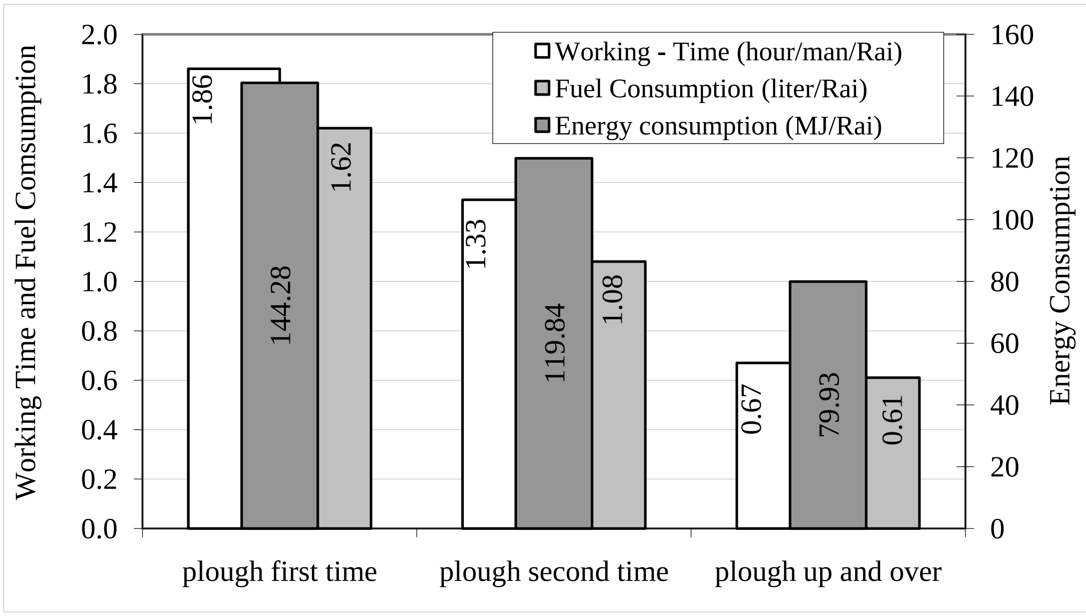

Fig. 1: Energy consumption in soil preparation process

Table 2: Energy consumption in cultivation Process

Cultivation system	Step	Working – tine (hour/man/Rai)	Seed (kg/Rai)	Energy consumption (MJ/Rai)
Transplanting	Seed - sow	0.18	7.57	40.39
	Pull	0.69	-	15.11
	Transplant	0.76	-	38.35
	Total	1.63	7.57	93.35
Broadcasting	Seed - sow	0.21	35.33	159.40

Table 3: Energy consumption in the cultural practice process

Process	Working – tine (hour/man/Rai)	Fuel (liter/Rai)	Fertilizer (kg/Rai)	Chemical (kg/Rai)	Energy consumption (MJ/Rai)
Water – pump					
Gasoline	5.47	4.72	-	-	215.88
Diesel	2.03	2.31	-	-	167.49
Fertilizer	0.44	-	38.79	-	954.73
Chemical					
Gasoline	0.10	0.61	-	0.59	23.05
Diesel	0.11	0.17	-	2.42	104.53
Labor	0.24	-	-	0.64	11.59

commercial energy consumption, fuel, fertilizer, chemical substance and machinery were 2,246.65 MJ/Rai and non–commercial, labor and seed was 181.11 MJ/Rai.

The ratio of energy consumption for rice production process is shown in Fig 2. The main energy is energy from fertilizer of 39.25% of total energy following by the energy from agriculture machinery 35.46 % and 17.23%, 3.39%, 4.07% and 0.06% for energy from fuel, labor, seed and chemical substance respectively.

From the energy consumption ratio we can save energy from fertilizer because the comical fertilizes it a high nitrogen component and the energy equivalent of nitrogen is very high farmer should be avoided or use manure or organic fertilizer and use nature chemicals substitute for example, lemongrass and herb etc., not only can save energy, but also can protect environment and keep healthy. Choose the agricultural machinery be compatible with characteristic of the work and maintenance on time.

3.5 Mathematic Model

Calculation energy consumption; The data of production factor, working-time (hour/man/Rai), fuel (liter/Rai), seed (kg/Rai), fertilizer (kg/Rai), chemical (kg/Rai) and paddy yield (kg/Rai) were used to

Table 4: Energy consumption in the harvest process

Factor required and Energy consumption	System 1		System 2		System 3
	Reap	Thresh	Reap	Thresh	Reap and Thresh
Working – tine (hour/man/Rai)	1.44	1.10	1.19	0.03	0.06
Fuel (Diesel) (liter/Rai)	-	-	-	3.39	3.64
Paddy (kg/Rai)	511.08[A]		588.46[A]		678.25[B]
Energy (MJ/Rai)					
Labor	32.39	22.28	38.73	5.63	3.24
Fuel	-	-	-	103.36	157.48
Engine	-	-	-	423.41[C]	708.96[D]
Total energy (MJ/Rai)	32.39	22.28	38.73	532.39	869.68
	54.67		571.12		

[A] Rice- humidity after Thresh is 17 – 19 % wb.
[B] Rice- humidity after Thresh is 23 - 25 % wb.
[C] Harvesting tractor (100 hp.)
[D] Harvesting tractor (185 – 215 hp.)

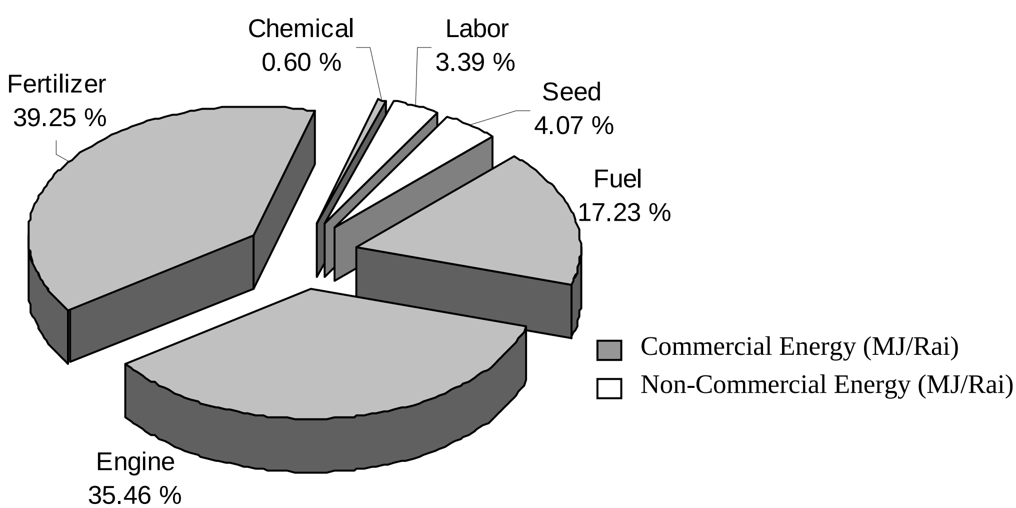

Fig.2: Commercial and non – Commercial energy consumption

analyzed math-model for calculate energy consumption (MJ/Rai) when we know all energy factor. The equation show relative between all production factor and energy consumption was done by used from the complex regression equation is;

$$E = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k \qquad (10)$$

Where

E is Energy consumption (MJ/Rai)

X_i is Energy Factor

β_0 is value of E when $X_1 = X_2 = \ldots = X_k = 0$

β_0 is partial regression coefficient

From energy factor data, equation 10 and using model of least square for determine partial regression coefficient (β_0). The coefficient of determine (r^2) of all production factor (quantity unit) and total energy consumption was 0.8920 as follow;

$$Energy\ (MJ/Rai) = \left[\begin{array}{l} 0.058\,(Yield) + 5.297\,(Fer.) \\ -\,54.358\,(Chem.) + 44.629\,(Seed) \\ +\,151.210\,(Fuel) - 3.327\,(Working) \\ -\,152.206 \end{array}\right] \qquad (11)$$

Prediction energy consumption in the future; The statistic data of wet season rice cultivation area in Northern Thailand from 1977/78 and 2001/02 were 2,434,000 Rai to 12,598,800 Rai respectively (Department of Agricultural Extension, 2003). The average energy consumption from 2003/04 was 2,427.76 MJ/Rai. The converted rice cultivated area data (Rai) to energy consumption (MJ) and the invert equation. The result showed relative between energy consumption (E, MJ) and year (t, give 1 at cultivation year 1977/78). The coefficient of determine (r^2) of cultivation year and total energy consumption was 0.9568 as follow;

$$E = a + b/t \qquad (12)$$

4. CONCLUSIONS

Rice production factor in wet season obtained an average paddy yield of 626.26 kg/Rai. It required working time of 6.91 – 14.19 hr./person/Rai, diesel 11.82 liter/Rai, gasoline 4.78 liter/Rai, fertilizer 38.79 kg/Rai, chemical substance 1.13 kg/Rai and seed 7.57 kg/Rai for transplanting cultivation or 35.33 kg/Rai for broadcasting cultivation. The total energy consumption ranged from 1,644.36 – 2,666.26 MJ/Rai decided by cultural method, maintenance step and harvesting process.

The average energy consumption was 2,115.18 MJ/Rai and 2,181.37 MJ/Rai for transplanting cultivation and broadcasting cultivation, respectively. The average commercial energy consumption was 2,246.65 MJ/Rai and non-commercial energy consumption was 181.11 MJ/Rai and average energy consumption was 2,427.76 MJ/Rai. The energy consumption of each process show in table 6: The mathematic model can predict the energy consumption from production factor and can predict energy in the future for rice productions at coefficient of determine (r^2) was 0.8920 and 0.9568 respectively. The model could be still consider, although, the price of production factor will be change. Due to, the model is not depending on the price, but it's up to the quantity of production factor using.

The energy was mainly used is a commercial energy, especially engine and chemical fertilizers. These were imported and very expensive which led to higher the cost of cultivation. Therefore, the natural agriculture or organic agriculture is the best way for a farmer which is not only lower the energy consumption and cost but also keep healthy and save the environment. This method is corresponding to the sufficient economy and the new method agricultural idea. Also, this idea was established for an environmentally sustainable development.

ACKNOWLEDGEMENTS

This work has been supported by Energy Policy and Planning Office, Ministry of Energy, Thailand and Energy research center Meajo University, Thailand by the project "Development of a Database on Energy Consumption for rice production in Thailand".

Thanks also due support of laboratory and equipment from the Establishment program of Agricultural Engineering Department, Chiang Mai University.

Table 5: Energy consumption of wet season rice production in Northern Thailand

Process and step	Energy consumption (MJ/Rai)						
	labor	fuel	machinery	seed	fertilizer	chemical	total
Soil preparation							
plough first time	3.64	70.33	70.31	-	-	-	144.28
plough second time	2.61	46.91	70.31	-	-	-	119.84
plough up and over	1.32	26.30	70.31	-	-	-	97.93
Cultivation							
transplanting	53.81	-	-	40.03	-	-	93.85
broadcasting	1.86	-	-	157.54	-	-	159.40
Cultural practice							
Water – pump							
Gasoline	15.03	187.26	13.59	-	-	-	215.88
Diesel	5.62	91.56	70.31	-	-	-	167.49
Fertilizer	1.77	-	-	-	952.96	-	954.73
Chemical							
Gasoline	0.37	2.22	13.59	-	-	6.88	23.05
Diesel	0.85	7.47	70.31	-	-	25.91	104.53
Labor	0.99	-	-	-	-	10.60	11.59
Harvest							
Type 1	54.67	-	-	-	-	-	54.67
Type 2	44.35	103.36	423.41	-	-	-	571.12
Type 3	3.24	157.48	708.96	-	-	-	869.68

REFERENCES

1. Chaichana, T. (2004). Energy Analysis for Rice Production Process in Northern THAILAND., M. Eng. Thesis, Chiang Mai University, Thailand.
2. Department of Agricultural Extension (2003). Agricultural statistic of rice cultivation area and buddy yield, Ministry of Agricultural and Cooperative, Thailand.
3. Dipankar De., Singh, R.S. and C. Hukun (2001) Technological impact on energy consumption in Rain fed soybean cultivation in Madhya Pradesh. Applied Energy, 70: 193-213.
4. Gezer, I. (2003). Use of energy and labor in Apricot Agriculture in Turkey. Biomass & Bioenergy, 24: 251-219.
5. Herdt, R.W. (1987). Economic use pattern in production agriculture of a typical village in arid zone, India Part I. Energy conservation and Management, 43: 2275-2286.
6. Institute for Science and Technology Research and Development, (2004) “Data of heating value of gasohol, diesel and electricity”, Chiang Mai University.
7. KasetPhattana Group, Thailand,. “Data of harvesting tractor” 126 M 1 T. Smokae, Muang, Phitsanulok province, Thailand, 56000, http://www.kpn.co.th, (2004).
8. Mandal M.G., Suda, K. P., Ghosh, P.K., Hati, K.M. and K.K. Bandyopadhyay (2002) Bioenergy and economic analysis of soybean-based crop production system in central India. Biomass and Bioenergy, 23: 337-345.
9. Meajo university (2545). Energy examine and analysis of rice production for staff project handbook. (In Thai)
10. Pittayapak, A. (2003). Evolution of Alternative Fuel Production Potential for Local Oil Plant. M. Eng. Thesis, Chiang Mai University, Thailand.
11. Samootsakorn, P. (1982). Energy Budgeting for Thai Rice Agriculture, Ph.D. Thesis Reading University.
12. Siam Kubota Co., Ltd. “Data of Working tractor (15 – 24 hp.) and Driving tractor (80 – 110 hp.),http://www.kubota.com,(January 2003).
13. Thanchotikan, Y. (2546). “Organic Rice” Earth Net Foundation, ISBN 9749150147 (In Thai)
14. Venturi, P. and G. Venturi (2003) Analysis of energy comparison for crops in European agricultural systems. Biomass & Bioenergy, Faculty of agricultural, University of Bologna. Italy.

International Agricultural Engineering Journal 2008, 17(1-4):9-18

IMPACT OF PLANTING PATTERN AND WATER STRESS ON YIELD AND OIL QUALITY OF SUNFLOWER (*Helianthus annuus* L.)

Javeed S. Dar[*], M.A. Cheema[*], R.S. Kanwar[†], A. Wahid[*], and N.S. Dar[*]

ABSTRACT

The field experiments were conducted for three years (2005-2007) to determine the effect of planting pattern and water stress on sunflower yield and oil quality. Experimental treatment included four different water stress levels under four planting patterns. The results of this study indicated that planting pattern has no significant impact on oil quality, whereas, water stress at pre anthesis and anthesis stage had significant impact on sunflower yield and oil quality.

Keywords: *Planting Pattern; Water Stress; Yield; Oil Quality; Sunflower*

1. INTRODUCTION

Sunflower is a crop well adapted to drought and consequently it is being grown with increasing success in many semi-arid environments. The nutritional quality of sunflower oil is due to the high percentage of fatty acids, in particular linoleic and oleic acid, which together represent about 90% of the fatty acid total, with the remainder being made up of palmitic and stearic acid. In general, a diet rich in vegetable oils prevents heart disease (Krajcovicova- Kudlakova et al., 1997).

Many agro-management practices have been used for several years to improve agricultural productivity. Raised bed and ridge planting have been found to be most effective measures to reduce the cost of cultivation. To obtain maximum storage of moisture under any irrigation (rainfall) condition, soil needs to absorb as much water as possible and bring evaporation and transpiration losses to a minimum. Ridges and raised bed systems can intercept water from light rains, retain surface runoff from heavy rains, and reduce unproductive evaporation (Tian et al., 2003; Jia et al., 2006). Raised bed planting and ridge planting had lower water consumption than the flat planting due to the decreased use of irrigation water and reduced evaporation from topsoil (Zhang et al., 2007)

Yield responses to inter-row distances are variable. The uniform distribution decreases plant to plant competition for available water, nutrient and light and increases seed yield and biomass production (Andrade et al., 2002). Planting geometry not only affects plant growth and development by balancing the interplant competition (Malik et al., 1992) but also determines the distribution pattern of plants over a field. It directly affects solar energy interception and evaporation and indirectly affects water use efficiency. Narrow row spacing ensures more uniform distribution of plant over a given area and makes a plant canopy more effective in intercepting radiant energy and shading weeds (Saeed, 1994).

Sunflower has the potential to be grown in both irrigated and rainfed areas where precipitation and soil water supply are limited, and sunflower responds positively to irrigation with respect to growth and yield (Unger, 1990).

Among various factors responsible for low yield, the water requirement of the crop is most important because water has direct relationship with the growth, development and yield of crop. An efficient irrigation system is a pre-requisite for increasing agricultural production since water is a basic input for agricultural growth. Judicious and timely application of irrigation at critical growth stages of sunflower increases yield. Increase in the irrigation interval reduced crop yield (Kakar and Soomro, 2001).

Even limited irrigation-water, applied at different growth stages of sunflower, can significantly increase seed yields (Stone et al., 1996), especially during the

[*] University of Agriculture, Faisalabad, Pakistan.
[†] Iowa state university, Ames, Iowa, USA

three growth periods - heading, flowering, and milking stages - or end of flowering (Osman and Talha, 1975; Alessi et al., 1977; Demiro¨ren, 1978; Unger, 1983 and Chimenti and Hall, 1992).

In favour of impact of irrigation, Talha and Osman (1974) reported an increase in the ratio of oleic/linoleic acid ratio under water stress conditions. On the other hand, Unger (1982) found a positive correlation between oleic acid content and water use at the vegetative stage, while Salera and Baldini (1998) observed no effect of water management on oleic acid content. When water stress occurs during the grain filling period on standard and high oleic genotypes, an increase in the oleic/linoleic acid ratio is observed with respect to more favorable water regimes (Flagella et al., 2002).

The overall objective of this study was to determine the effect of water stress and planting patterns on yield and sunflower oil quality.

2. MATERIAL AND METHODS

Field experiments were conducted for three years 2005-2007 at the Agronomy Research Farm of the University of Agriculture, Faisalabad, Pakistan to determine the effect of planting patterns and water stress on sunflower yield and oil quality. The soil at this experimental site is sandy clay loam. Before sowing, soil analysis was carried out according to methods given in Handbook No. 60 (US Salinity Lab. Staff., 1954) except available P, which was determined by Olsen method (Watanabe and Olsen, 1965), and texture by Moodie *et al*. (1959).

Four planting patterns were selected for this study (sowing on flat with row to row distance of 60 cm; sowing on ridges with row to row distance of 60 cm: sowing on flat with double row strip of 90 cmx30 cm; and sowing on beds with 90 cm bed and 30 cm furrow) placed in main plots and four water stress (no stress, water stress at pre-anthesis stage, water stress at anthesis stage, Water stress at post-anthesis stage) in sub plots.

The experiment was laid out in randomized complete plot design with split arrangement and replicated three times. Net plot size was 3.6 x 7.0 m. Buffer plots of 1.2 m between the sub plots were maintained to avoid the seepage/border effect of irrigation among various treatments.

In each season the experimental field was wetted to field capacity by heavy irrigation (locally called *rouni*) and seedbed was prepared by cultivating the soil 2-3 times with tractor mounted cultivator, each followed by planking when the field was at proper moisture condition. Crop was sown on 14th February during all the years. Planting was done by dibbling and placing two seeds per hill at 25 cm distance from each other. After crop establishment, at 2-4 leaf stage one plant per hill was maintained.

Fertilizer was applied @ 150 kg N and 100 kg P_2O_5 ha^{-1}. Urea and Diammonium Phosphate (DAP) were used as a source of fertilizer. Half of N and full phosphorus were applied at sowing, remaining N was applied either with first irrigation in the plots to be irrigated or incorporated at the same time in plots not to be irrigated. All other agronomic practices were kept normal and uniform for all the treatments. Plant protection measures were adopted to keep the crop free from weeds, insect pests and diseases.

Six siphon tubes were calibrated and shifted into three different plots. A water control barrier was prepared at the cross channel area to make and control the flow of water. Time measurement was done with the help of a stop watch and at a measured time, siphons were shifted to the other field.

2.1 Statistical Analysis

The data were statistically analyzed by using the computer statistical program MSTAT-C (Freed and Scott, 1986). Analysis of variance technique was employed to test the overall significance of the data, while the least significance difference (LSD) test at P=0.05 was used to compare the differences among treatments means.

3. RESULTS AND DISCUSSION

3.1 Weather Data

All climatic data were obtained from a meteorological station situated at the experimental site. Climatic conditions were favorable for high yield of sunflower during 2005 in comparison to 2006 and 2007. Average temperature was higher in 2006 as compared to 2005 and 2007. Total rain during growing season (15 February to 15 June) was 117.4 mm, 81.2 mm and 83.8 mm in 2005, 2006 and 2007 respectively.

Table 1: Fifteen day mean weather data for the growing season of the study during 2005, 2006 and 2007.

Date	Max Temp. (°C)			Min. Temp. (°C)			Avg. Temp. (°C)			Rain (mm)			ET_0 (mm)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
1-15 Jan	20.8	20.2	20.0	7.6	5.3	2.5	14.2	12.8	11.2	20.0	8.20	0.00	1.7	1.2	1.4
16-31 Jan	18.1	21.4	21.3	6.1	7.2	6.1	12.1	14.3	13.7	12.8	0.00	0.00	1.6	1.5	2.0
1-14 Feb	19.6	27.0	21.6	11.2	11.3	10.9	15.4	19.2	16.3	29.5	0.00	36.5	1.4	2.3	1.8
15-28 Feb	20.5	28.1	20.0	8.3	14.7	9.6	14.4	21.4	14.8	5.6	14.6	19.4	2.0	3.0	1.8
1-15 Mar	27.2	28.3	22.1	14.7	14.7	11.5	21.0	21.5	16.8	6.2	8.40	25.8	2.5	2.9	2.1
16-31 Mar	28.3	28.0	28.4	15.9	14.5	15.1	22.1	21.3	21.8	42.4	28.6	15.5	3.0	3.4	2.8
1-15 Apr	33.4	35.2	34.5	16.8	18.5	19.1	25.1	26.9	26.8	0.0	0.00	0.00	5.2	6.4	4.7
16-30 Apr	36.7	40.1	40.1	19.6	22.8	22.5	28.2	31.5	31.3	10.8	0.00	0.00	6.2	7.6	6.8
1-15 May	36.4	43.5	41.0	21.9	26.7	25.0	29.2	35.1	33.0	18.4	0.60	15.8	6.0	8.4	7.7
16-31 May	39.7	41.1	39.5	24.8	27.8	25.4	32.3	34.4	32.4	0.0	23.4	0.30	8.4	7.6	8.3
1-15 Jun	41.6	41.7	43.3	27.0	27.2	29.5	34.3	34.5	36.4	4.5	5.60	7.00	7.8	9.0	9.1
16-30 Jun	45.0	38.9	36.4	30.4	26.8	26.6	37.7	32.9	31.5	58.0	50.0	22.9	9.6	6.9	5.7

3.2 Effect of Planting Pattern and Water Stress on Seed Yield (kg ha^{-1})

Grain yield increase in response to narrow rows was closely related to the improvement in light interception during the critical period for grain set. Changes in response of grain number to reduce row spacing ranged from nil to 25% increase (Calvino et al., 2004). Malik et al., (2001) reported that the planting patterns ridge sowing (60 cm apart) produced the maximum seed yield (2600 kg ha^{-1}) among various planting patterns (60 cm apart single rows, 90 cm apart double row strip planting, 60cm apart ridge sowing and 90/30cm bed sowing) were used for evaluation.

Final seed yield is the function of combined effect of all the yield components under the influence of a particular set of environmental conditions. The seed yield variability of the years affected significantly which regards from a minimum of 2186 kg ha^{-1} in 2007 to a high of 3674 kg ha^{-1} in 2005 and it is due to the difference between the treatments and variation in maximum and minimum temperature during the growing season.

The planting pattern crop sown on ridges (3293, 3190 and 3235 kg ha^{-1} in 2005, 2006 and 2007 respectively) produced the maximum seed yield. Irrigation treatment significantly influenced seed yield of sunflower during the seasons of experimentation. Highest seed yield (3210, 3126 and 3150 kg ha^{-1} in 2005, 2006 and 2007 respectively) was recorded in fully irrigated crops. On an overall average basis, pre-anthesis produced 21.5%, 17.7% and 8.3% less seed yield than no stress, post anthesis and anthesis stress. Minimum seed yield was recorded from pre anthesis stress (2525, 2454 and 2469 kg ha^{-1} in 2005, 2006 and 2007 respectively).

Interaction of planting pattern and water stress for seed yield showed significant differences. Seed yield (3674, 3569 and 3584 kg ha^{-1} in 2005, 2006 and 2007 respectively) resulted in combined effect of ridge sown crop with normal irrigation treatment. These results were at par with crop sown at ridges with post anthesis stress during 2005 and 2006. Minimum seed yield was recorded from the crop sown under flat 90/30 with pre anthesis stress which produced 2270, 2205 and 2186 kg ha^{-1} in 2005, 2006 and 2007 respectively. Seed yield (Table 5) was positively and significantly correlated with leaf area index.

Fereres et al., (1986) also reported that best correlation was found between grain yield and biomass yield. Hussain et al., (2001) stated that leaf area had positive and significant correlation with seed yield. Positive correlation was also reported between seed and oil yield. Positive and significant correlation existed between leaf area and seed yield reported by Tahir and Mehdi, 2001.

Andrade et al., (2002) also reported that crops with more severe water deficit, yield response ranged from 25% reduction in yield. Results were also supported by Browne (1997) who concluded that seed yield was increased by 19 % when final irrigation was applied 22 days after mid flowering, rather than at mid flowering. The higher yield resulted principally from an increase in the number of harvestable seeds. Aiken and Lamm, (2006) reported that supplemental irrigation scheduled by the water balance method results in higher yields. Yield reductions depend on the degree of plant water stress at critical stages of growth. Irrigated sunflower yield ranged from 2200 to 2900 kg ha^{-1}. When supply of water limits crop water use, seed yields are frequently limited as well.

There was a positive and linear relationship between biological yield and seed yield. The regression accounted for 88% of the variance in the yield. Achene yield was also linearly and positively related to the no. of seed per head, 1000 seed weight and leaf area index. Regression accounted for 93%, 95% and 82% variance in seed yield respectively. The correlation results are confirmatory to the findings of Contagallo et al., (1997) and Mercan et al., (2001) who reported that the number of seeds and seed weight were the components more closely associated with yield.

3.3 Effect of Planting Pattern and Water Stress on Biological Yield (kg ha^{-1})

It is the overall expression of biomass forces embodied in a production system which are affected by the treatment applied. The effect of planting pattern and irrigation treatments significantly affected biomass yield.

Ridge sowing produced 14% more biomass yield over flat 90/30 sowing. The study showed that ridge sowing produced maximum biomass yield of 9058, 8772 and 8893 kg ha^{-1} in 2005, 2006 and 2007 respectively. Normal irrigation achieved better yield regarding all other treatments that produced 8934, 8601 and 8731 kg ha^{-1} in 2005, 2006 and 2007 respectively and the lowest was recorded from pre-anthesis stress.

A combined effect of planting pattern and irrigation treatment presented significant differences. Better biomass yield was recorded from crop sown under ridge sowing with no stress (9684, 9460 and 9565 kg ha^{-1} in 2005, 2006 and 2007 respectively). Lowest biomass yield was produced by crop sown at flat 90/30 along with pre anthesis stress (7315, 6932 and 7047 kg ha^{-1} in 2005, 2006 and 2007 respectively). Biomass yield (Table 5) was positively and significantly correlated (Table 5) with seed yield

Table 2: Effect of different planting pattern and water stress on seed yield and biomass yield of sunflower during 2005, 2006 and 2007

	Seed Yield (kg ha^{-1})				Biomass Yield (kg ha^{-1})			
TREATMENTS	**2005**	**2006**	**2007**	**Average**	**2005**	**2006**	**2007**	**Average**
Planting Pattern (P)								
P_1= Flat 60 cm	2937 b	2854 b	2866 b	2886 b	8405 b	8038 b	8173 b	8205 b
P_2 = Ridge 60 cm	3293 a	3190 a	3235 a	3239 a	9058 a	8772 a	8893 a	8908 a
P_3 = Flat 90/30 cm	2596 d	2521 c	2537 d	2551 d	7856 d	7550 c	7662 d	7689 d
P_4 = Bed 90/30 cm	2734 c	2657 c	2688 c	2693 c	8136 c	7858 b	7997 c	7997 c
LSD (5%)	132	145	113	119	195	197	126	130
Water stress (I)								
I_0 = No Stress	3210 a	3126 a	3150 a	3162 a	8934 a	8601 a	8731 a	8755 a
I_1 = Pre Anthesis Stress	2525 d	2454 d	2469 d	2483 d	7670 d	7346 d	7461 d	7492 d
I_2 = Anthesis Stress	2756 c	2669 c	2698 c	2708 c	8256 c	7979 c	8090 c	8108 c
I_3 = Post Anthesis Stress	3069 b	2973 b	3008 b	3017 b	8594 b	8292 b	8443 b	8443 b
LSD (5%)	78	75	60	46	106	101	96	103
Interaction (PxI)								
P_1 I_0	3363 b	3268 b	3289 c	3307 c	8863 cd	8400 c	8538 e	8601 d
P_1 I_1	2481 h	2410 h	2396 h	2429 i	7760 hi	7389 ij	7545 k	7565 h
P_1 I_2	2773 def	2695 def	2711 fg	2726 fg	8328 f	8018 de	8129 g	8159 e
P_1 I_3	3130 c	3042 c	3068 d	3080 d	8665 de	8343 c	8478 e	8496 d
P_2 I_0	3674 a	3569 a	3584 a	3609 a	9684 a	9460 a	9565 a	9570 a
P_2 I_1	2842 de	2762 de	2814 ef	2806 ef	8050 g	7850 ef	7948 h	7950 f
P_2 I_2	3121 c	3032 c	3081 d	3078 d	9053 c	8828 b	8913 c	8931 c
P_2 I_3	3535 a	3397 a	3459 b	3464 b	9445 b	8950 b	9147 b	9181 b
P_3 I_0	2890 de	2835 d	2864 e	2863 e	8503 ef	8058 d	8192 g	8251 e
P_3 I_1	2270 i	2205 i	2186 i	2220 j	7315 j	6932 k	7047 m	7098 j
P_3 I_2	2475 h	2372 h	2391 h	2413 i	7688 i	7477 hi	7563 k	7576 h
P_3 I_3	2749 ef	2671 ef	2705 fg	2709 g	7917 gh	7733 fg	7845 i	7832 fg
P_4 I_0	2912 d	2830 d	2864 e	2869 e	8685 de	8484 c	8628 d	8599 d
P_4 I_1	2509 gh	2437 gh	2481 h	2476 i	7554 i	7213 j	7303 l	7357 i
P_4 I_2	2653 fg	2578 fg	2608 g	2613 h	7954 gh	7594 gh	7754 j	7767 g
P_4 I_3	2863 de	2782 de	2799 ef	2815 ef	8349 f	8142 d	8303 f	8265 e
LSD (5%)	156	150	121	91	213	201	88	131
Year Mean	2890	2805	2831	2842	8364	8055	8181	8200

Means having different letters differ significantly at 5% probability.

and leaf area index. Significant correlation between grain yield, biomass yield and oil content was reported by Fereres et al., (1986).

Ridge sowing facilitates more light penetration of the canopy thereby providing better conditions for establishment, growth and development. One of the other benefits of ridge sowing is to change from flood irrigation to irrigation in a partial areas decreased irrigation amount and controlled evaporation from top soil. Shafi and Khan (1992) reported the maximum yield was obtained in the crop sown on ridges. Calvino *et al.,* (2004) apply more severe water deficit developed around anthesis. Crop exposed to mild water deficit in all three critical stages and water stress was most severe. Yield response to narrow row was significant. Crop response significantly to narrow rows and highlights the interaction between row spacing and water deficit. For crop with moderate or low deficit, yield did not respond to narrow rows when conditions were conductive to full interception in wide row crops and yield increased up to 15%.

Mahal et al. (2000) concluded that sowing on ridges reduced the adverse effect of flooding and gave 9.9% more yield than flat sowing. Sidhu et al. (1995) also present similar results and found that the highest seed yield was obtained from the crop sown on ridges.

Values of biomass yield in these studies were similar to Rawson and Turner, 1983; Conner et al., 1985; and Anderson et al., 1998, who concluded the reduction in biomass yield when sunflower was grown under dry land conditions without supplemental irrigation. Further they reported that if watering was commenced at or before budding, the crop still had the capacity to grow and accumulate substantial biomass. Rawson and Turner (1982) have ascribed this capacity to the ability to gain leaf area on commencement of irrigation which, in turn, depended on the time of commencement of irrigation. Sunflower irrigated before or at budding accumulated significantly more dry matter than those not irrigated or those initially irrigated at later growth stages.

3.4 Effect of Planting Pattern and Water Stress on Seed Oil Contents (%)

The strategic role of the sunflower crop depends mainly on the characteristics of the oil produced, which can be used, directly or after processing, in

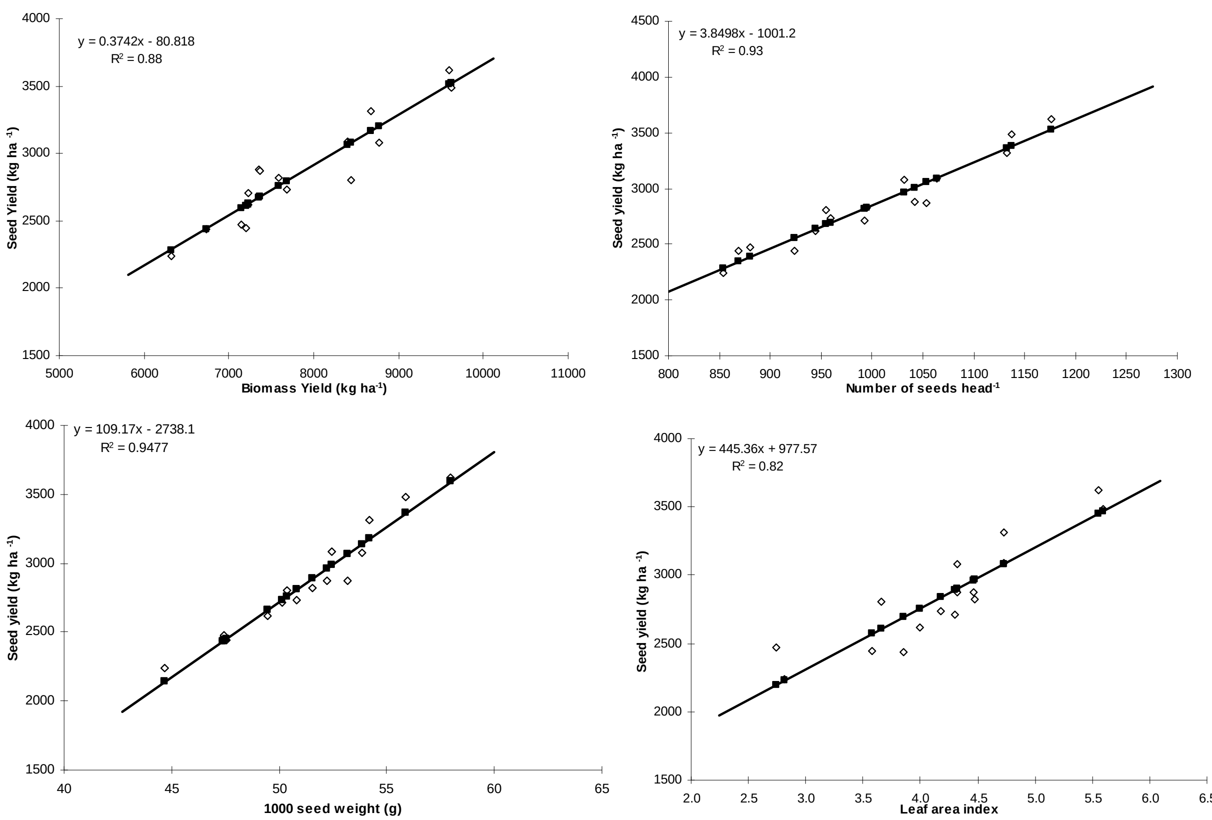

Fig. 1. Relationship of seed yield (kg ha^{-1}) with biomass yield (kg ha^{-1}), number of seeds head^{-1}, 1000-seed weight and leaf area index of sunflower (average data).

Table 3: Effect of different planting pattern and water stress on seed oil and protein content of sunflower during 2005, 2006 and 2007

TREATMENTS	Oil Contents (%)				Protein Contents (%)			
	2005	2006	2007	Average	2005	2006	2007	Average
Planting Pattern (P)								
P_1=Flat 60 cm	39.9	38.9	39.1	39.3	15.4	14.9	14.8	15.0
P_2=Ridge 60 cm	40.0	39.0	39.3	39.4	15.7	15.4	15.6	15.6
P_3=Flat 90/30 cm	39.6	39.2	39.0	39.3	15.0	14.7	14.7	14.8
P_4=Bed 90/30 cm	39.2	38.6	38.9	38.9	15.4	15.1	15.0	15.2
LSD (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Water stress (I)								
I_0=No Stress	44.7 a	43.9 a	44.5 a	44.4 a	16.6 a	16.3 a	16.4 a	16.4 a
I_1=Pre Anthesis Stress	34.9 d	34.2 d	34.4 d	34.5 d	14.2 d	13.9 d	14.0 d	14.0 d
I_2=Anthesis Stress	38.1 c	37.4 c	37.5 c	37.7 c	14.9 c	14.5 c	14.5 c	14.6 c
I_3=Post anthesis Stress	41.0 b	40.2 b	40.5 b	40.6 b	15.7 b	15.3 b	15.6 b	15.5 b
LSD (5%)	0.57	0.55	0.61	0.58	0.41	0.40	0.43	0.42
Interaction (PxI)	NS	NS	NS	NS	NS	NS	NS	NS
Year Mean	39.7	38.9	39.2	39.3	15.4	15.0	15.1	15.2

Means having different letters differ significantly at 5% probability.

many sectors of the food and non food industries. (Veer Meersh, 1996 and Santonoceto et al., 2002)

A different planting pattern did not influence the seed oil contents (%) of sunflower. Effect of planting pattern, as well as interactive effect of planting pattern and irrigation treatment,was non significant on percent of seed oil. The data ranged between 34.2% to 44.7% during the years of experimentation. A different irrigation treatment had a significant influence on the seed oil content of sunflower and highest (44.7%, 43.9% and 44.5% during 2005, 2006 and 2007 respectively) was recorded in no stress and was the lowest under pre anthesis stress (34.9%, 34.2% and 34.4% in 2005, 2006 and 2007 respectively). On an overall average basis, no stress produced 22.3%, 15.1% and 9.6% more oil contents than pre anthesis stress, anthesis stress and post anthesis stress respectively.

Seed oil content was not affected significantly by any of the planting patterns, in both the seasons (spring and autumn) Nazir et al. (1991). Johnson et al., (2003) also reported that row spacing influenced seed oil contents but differences were not biomassly important. Ardakani *et al.*, (2005b) reported that water stress treatments and no irrigation at any stage reduced oil percent. Flagella et al., (2002) reported that oil percentage increased with irrigation. The lowest value of oil percentage was recorded from severe stress. Oil content (Table 5) was significantly and positively correlated with seed yield, biomass yield and leaf area index. Fereres et al., 1986 and Razi and Assad, 1999 reported that seed yield had significant positive correlation with biomass yield and oil content.

Findings do not correspond to Goksoy et al., (2004) who reported that oil percentage, an important quality component in sunflower was not affected by irrigation treatments applied at different growth stages. Mean oil percentage varied from 43.7 to 45.8% in all treatments. Sufficient water is necessary during grain filling to achieve a high oil concentration (Debaeke et al., 1998).

3.5 Effect of planting pattern and water stress on seed protein content (%)

Sunflower is grown mainly for oil, but following extraction the meal contains protein and offers a valuable source of protein for animal and human consumption.

The results were statistically non significant among all the treatments for planting pattern. Seed protein content values ranged from 13.9% to 16.6% during all growing seasons. Results were supported to those of Agha (1989) who evaluated the effect of different planting patterns.The seed protein content was not affected significantly by the different planting patterns. Nazir et al. (1991) conducted a field study to determine the effect of different planting patterns on seed yield, oil and protein content of sunflower at uniform plant population during the autumn and spring. Seed protein content was not affected significantly by any of the planting patterns during the growing seasons.

Different irrigation regimes had a significant influence on seed protein contents of sunflower. Maximum protein content (16.6%, 16.3% and 16.4% in 2005, 2006 and 2007 respectively) was recorded for no stress. It decreased in the order of post anthesis stress > anthesis stress > pre anthesis stress. Minimum seed protein content was recorded for pre anthesis stress (14.2%, 13.9% and 14.0% in 2005, 2006 and 2007 respectively). The combined effect of planting pattern and irrigation treatment was non significant. Protein contents (Table 5) shows the positive and significant correlation with seed yield, biomass yield, leaf area index and oil content.

Results are in line with Debaeke at al., (1998) who reported that early sunflower growth was limited when the water availability was reduced during flowering. Protein concentration was negatively related with stress conditions. Protein concentration was decreased with the stress condition while it was maximum with normal irrigation.

3.6 Fatty acid Profile Effect of Planting Pattern and Water Stress on Linoleic Acid (%)

There is no significant impact of planting pattern on linoleic acid concentration. The data range varied between 59.8% to 64.1% among all the treatments.

Irrigation regimes significantly influenced the linoleic acid concentration of sunflower seed oil. Maximum linoleic acid concentration was recorded from pre anthesis stress (64.1%, 61.9% and 62.3 in 2005, 2006 and 2007 respectively). On an average basis, pre anthesis stress produced 3.34%, 2.87% and 1.91% more linoleic acid than no stress, post anthesis stress and anthesis stress respectively. Minimum linoleic acid was obtained from no stress treatment (60.7%). Interactive effect of planting pattern and irrigation treatment was non significant. Linoleic acid (Table 5) showed significant but negative correlation with seed yield, oil contents, protein contents and

Table 4: Effect of different planting pattern and irrigation levels on Linoleic acid and Oleic acid contents of sunflower oil during 2005, 2006 and 2007

TREATMENTS	Linoleic acid (%)				Oleic acid (%)			
	2005	**2006**	**2007**	**Average**	**2005**	**2006**	**2007**	**Average**
Planting Pattern (P)								
P_1=Flat 60 cm	62.9	60.6	60.9	61.5	25.5	26.2	26.4	26.0
P_2=Ridge 60 cm	62.6	60.6	61.2	61.5	25.1	26.0	25.8	25.6
P_3=Flat 90/30 cm	62.7	60.1	61.1	61.3	24.8	25.9	25.3	25.3
P_4=Bed 90/30 cm	62.6	61.1	61.4	61.7	25.7	26.6	26.5	26.3
LSD (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Water stress (I)								
I_0=No Stress	61.8 c	59.8 c	60.4 c	60.7 c	26.6a	27.5a	27.2 a	27.1 a
I_1=Pre Anthesis Stress	64.1 a	61.9 a	62.3 a	62.8 a	23.7c	24.6c	24.3 c	24.2 c
I_2=Anthesis Stress	62.7 b	60.7 b	61.5 b	61.6 b	24.6b	25.6b	25.2 b	25.1 b
I_3=Post anthesis Stress	62.2 bc	60.1 bc	60.7 c	61.0 bc	26.0a	27.0a	26.7 a	26.6 a
LSD (5%)	0.75	0.66	0.69	0.71	0.82	0.84	0.81	0.80
Interaction (PxI)	NS	NS	NS	NS	NS	NS	NS	NS
Year Mean	62.7	60.6	61.2	61.5	25.2	26.2	25.9	25.8

Means having different letters differ significantly at 5% probability

Table 5: Correlation coefficients among different characters of spring sunflower

	Biomass Yield	LAI	Oil Contents	Protein Contents	Stearic Acid	Palmitic Acid	Linoleic Acid	Oleic Acid
Seed Yield	0.942***	0.875***	0.690***	0.729***	-0.119 ns	0.280**	-0.329**	0.419***
Biomass		0.755***	0.427***	0.533***	-0.142 ns	0.348**	-0.177 ns	0.223*
LAI			0.773***	0.776***	-0.10 ns	0.174 ns	-0.391***	0.561***
Oil Contents				0.858***	-0.049 ns	0.035 ns	-0.478***	0.665***
Protein Contents					-0.017 ns	0.231*	-0.342**	0.573***
Stearic Acid						0.038 ns	0.276**	-0.063 ns
Palmitic Acid							0.178 ns	-0.005 ns
Linoleic Acid								-0.543***

oleic acid. There was non significant and negative correlation found with biomass yield.

Santonoceto et al., (2002) reported the approving results by examining the variation in the content of the four major fatty acids (Oleic, linoleic, palmitic and stearic). It showed that the fatty acid composition of the oil in the initial phases of seed formation differed substantially from that of the mature seed. Treatment I_{67} and I_{100} gave, at all samplings, a significantly lower linoleic acid concentration than that of treatments I_0 and I_{33}. The values were always significantly higher in the less irrigation treatments.

3.7 Effect of Planting Pattern and Water Stress on Oleic Acid (%)

Contradictory results were reported by Unger (1983) Linoleic and oleic acid concentrations in oil increased and decreased. Water stress at a seed development stage and mean temperature probably affected linoleic and oleic acid concentration of the oil. Average linoleic and oleic concentrations of the oil were not statistically affected by irrigation treatments.

Planting pattern presented a non significant difference among all the treatments. The data ranged from 23.7% to 27.5% during the growing season.

Oleic acid concentration of sunflower seed oil under different irrigation treatments varied significantly and the highest was recorded under no stress (26.6%, 27.5% and 27.2% during 2005, 2006 and 2007 respectively). These results were statistically at par with post anthesis stress (26.0%, 27.0 and 26.7% in 2005, 2006 and 2007 respectively). Lowest oleic acid was recorded from pre anthesis stress (23.7%, 24.6% and 24.3% in 2005, 2006 and 2007 respectively). The combined effect of planting pattern and irrigation treatment were found to be non significant. Oleic acid (Table 5) was significantly and positively correlated with seed yield, biomass yield, leaf area index, oil contents and protein contents.

Encouraging results by Santonoceto et al., (2002) examined the variation in the content of the four major fatty acids (Oleic, linoleic, palmitic and stearic) and showed that the fatty acid composition of the oil in the initial phases of seed formation differed substantially from that of the mature seed. The values were always significantly higher in the three irrigation treatments than in the rainfed one. Unger (1983) reported that Linoleic and oleic acid concentrations in oil increased and decreased. Water stress at a seed development stage and mean temperature probably affected linoleic and oleic acid concentration of the oil. In conclusion of Flagella et al., (2002) supplemental irrigation resulted in a notable rise in seed yield and in a decrease in the oleic and linoleic ratio in high oleic sunflower genotype.

4. CONCLUSIONS

There is an urgent need to improve irrigation efficiency by combining the best planting pattern and irrigation management. This study indicated that ridge sowing with no water stress (P_2I_0) produced 38% more seed and 26% more biomass yield in comparison to the flat 90/30 with pre anthesis stress (P_3I_1). Oil quality parameters (oil contents and protein contents) were not affected by planting pattern but significant changes were observed under different water stress levels. Concerning all the treatments of planting pattern and water stress levels, ridge sowing with no stress is suitable to achieve the maximum yield of spring sunflower.

REFERENCES

1. Agha, K.H. (1989). Studies on maize productivity as affected by maize legume intercropping and geometry of planting. Ph.D. Thesis, Dept. Agron., Univ. Agri., Faisalabad, Pakistan.
2. Ahmad, G., Qureshi, Z. and H. Ullah (2000). Effect of different sowing methods on the performance of sunflower. Pak. J. of Biol. Sci. 3(11): 1829-1830.
3. Aiken, R.M. and F.R. Lamm (2006). Irrigation of oilseed crops. In: Proc. Central Plains irrigation Conference, Colby, K.S., Feb. 21-22, 2006. Available from CPIA, 760N. Thompson, Colby, K.S. pp. 162-172.
4. Alessi, J., Power, J.F. and D.C. Zimmerman (1977). Sunflower yield and water use as influenced by planting date, population, and row spacing. Agron. J. 69:465–469.
5. Anderson, R., Yocum, J., Roth, G. and M. Antle (1998). Narrow row management [Online]. Available at http://www.agronomy.psu.edu/Extension (verified 16 May 2002).
6. Andrade, F.H., Calvino, P., Cirilo, A. and P. Barbieri (2002). Yield response to narrow rows depend on increased radiation interception. Agron. J. 94:975-980.

7. Ardakani, M. R., Shirani, A. H. S. and D. Habibi (2005b). Drought stress effects on quantitative characters of commercial sunflower cultivars and Hybrids. Interdrought-II, the second international Conference on integrated approaches to sustain and improve plant production under drought stress; Rome, Italy, September, 24-28(2005):pp-132.
8. Browne, C.L. (1977). Effect of date and final irrigation on yield and yield components of sunflowers in a seni-arid environment. Aust. J. Agri. Anim. Husb. 17(86):482- 488.
9. Calvino, P., Sadras, V. and M. M. Canepa (2004). Yield responses to narrow rows as related to interception of radiation and water deficit in sunflower hybrids of varying cycle. Field Crops Res. 88:261-267.
10. Chimenti, C.A. and A.J. Hall (1992). Sensibilidad del numero de frutos por capitulo de girasol (Helianthus annuus L.) a cambio en el nivel de radiacion durante la ontogenia del cutivo. In: 19th Reunion Nacional de Fisiologia Vegetal. Huerta Grande, Argentina, pp. 27-28.
11. Connor, D.J. and T.R. Jones (1985). Response of sunflower to strategies of irrigation. II.
12. Morphological and physiological responses to water stress. Field Crops Res. 12:91–103.
13. Debaeke. P., Cabelguenne, M., Hilaire A. and D. Raffaillac (1998). Crop management systems for rainfed and irrigated sunflower (Helianthus annuus) in South Western France. J. Agric. Sci. Cambridge 131:171-185.
14. Demiro¨ren, T. (1978). Determination of evapotranspiration of sunflower in Tokat, No. 25. Journal of Tokat Region Soil Water Research Institute, Tokat, pp. 27.
15. Fereres, E., Gimenez C., and J.M. Fernandez (1986). Genetic variability in sunflower cultivars under drought. I. Yield relationships. Aust J Agric Res 37: 573–582.
16. Flagella. Z., Rotuuno, T., Tarantino, E., Caterina, R.D. and A.D. Caro (2002). Changes in seed yield and oil fatty acid composition of high oleic sunflower (Helianthus annuus L.) hybrids in relation to the sowing date and the water regime. Eurp. J. Agron. 17:221-230.
17. Freed, R.D. and D. E. Scott (1986). MSTATC. Crop and Soil Sci. Dept., Michigan State University, Michigan, USA.
18. Fsechie, H.A., Flias, S., Rodriguez, V. and H.S. Al-Asmi (1996). Response of sunflower (Helianthus annuus L.) to planting pattern and population density in a desert climate. J. of Agri. Sci., 196(4): 455-461
19. Ghani, A., Hussain, M. and M.S. Qureshi (2000). Effect of different irrigation regimens on the growth and yield of sunflower. Int. J. of Agri. and Biol. 2(4): 334-335.
20. Goksoy, A.T., Demir, A.O., Turan, Z.M. and N. Dagustu (2004). Response of sunflower (Helianthus annuus L.) to full and limited irrigation at different growth stage. Field Crop Research 87: 167-178.
21. Hussain, N., Khan, M.B. and M. Asif (2001). Growth and yield of spring sunflower (Helianthus annuus L.) as influenced by planting geometry. Pak. J. of Biol. Sci. (supp. issue no. 1): 48-49.
22. Jia, Y., Li, F.M., Wang, X.L. and H.M. Yang (2006). Soil water and alfalfa yields as affected by alternating ridges and furrows in rainfall harvest in a semiarid environment. Field Crop Res. 97, 167–175.
23. Johnson, B.L., Zarnstorff, M.E. and J.F. Miller (2003). Row spacing and plant population influence on sunflower performance. Proceedings of Manitoba agronomists Conference pp:134.
24. Kakar, A.A. and A.G. Soomro (2001). Effect of water stress on the growth, yield and oil content of sunflower. Pak. J. Agri. Sci. 38(1-2):73-74.
25. Krajcova-Kudlackova M., Simoncic R., Bederova A. and J. Klvanova (1997). Plasma fatty acid profile and alternative nutrition. Annals Nutr. Metab. 41 (6) 365-370.
26. Mahal, S.S., Dejenu, D.G. and M.S. Gill (2000). Growth and yield of maize (Zea mays L.) as influenced by flood under different planting methods and nitrogen levels. Environ. and Ecolo. 18(4): 789-792.
27. Malik, M.A., Akram, M. and A. Tanvir (1992). Effect of planting geometry and fertilizer on growth yield and quality of a new sunflower cultivar "SF-100". Journal of Agriculture Resources, 30(1): 59-63.
28. Malik, M.A., Saleem, M.F., Cheema, M.A. and S. Ahmad (2003). Influence of different nitrogen levels on productivity of sesame (Sesamum indicum L.) under varying planting patterns. Int. J. Agric. Biol. 5(4):490-492.
29. Malik M.A., Shah, S.H., Mahmood, S. and M.A. Cheema (2001). Effect of various planting geometries on the growth, seed yield and oil contents of New Sunflower hybrid (SF-187). Int. J. Agri. Biol. 3(1):55-56.
30. Moodie, C.D., Smith, H.W. and P.R. McCreery (1959). Laboratory manual of Soil Fertility. Staff Collage of Washington, D. C., USA, pp. 175.

31. Nazir, M.S., Gill, M.B., Ahmad, R. and T. Mahmood (1991). Response of Hysun-33 sunflower to autumn and spring planting at different geometrical patterns. Pak. Sci. Ind. Res., 34(1): 34-36.
32. Osman, F. and M. Talha (1975). The effect of irrigation regime on yield and consumption of sunflower seed oil. Egypt J. Soil Sci. 15: 211–218.
33. Rawson, H.M. and N.C. Turner (1982). Recovery from water stress in five sunflower (Helianthus annuus L.) cultivars .I. Effects of the timing of water application on leaf area and seed production. Aust. J. Plant Physiol. 9(4):437-448.
34. Rawson, H.M. and N.C. Turner (1983). Irrigation timing and relationships between leaf area and yield in sunflower. Irrigation Science 4(3):167-175.
35. Razi, H. and M.T. Assad (1999). Comparison of selection criteria in normal and limited irrigation in sunflower. Euphytica 105: 83-90.
36. Saeed, M. (1994). Crop water requirements and irrigation systems. In “Crop production” E. Bashir and R. Bantel (eds.) National Book Foundation, Islamabad: 48-83.
37. Salera, E. and M. Baldini (1998). Performance of high and low oleic acid hybrids of sunflower under different environmental conditions. Note II. Helia 21 (28), 55–68.
38. Santonoceto, C., Anastasi, U., Riggi, E. and V. Abbate (2002). Accumulation Dynamics of Dry matter, oil and major fatty acids in sunflower seeds in relation to genotype and water regime. Ital. J. Agron. 7(1):3-14.
39. Shafi, M. and K. Khan (1992). Effect of seed treatment and ridged and flat planting on the growth and yield of sugarbeet. Sarhad J. Agric., VIII(1): 11-15.
40. Sidhu, M.S., Sharma, R.K., Singh, Suthvinder and S. Singh (1995). Effect of sowing dates and planting techniques on performance of hybrid sunflower. J. Res., 32:19-23.
41. Stone, L.R., Schlege, A.J., Gwin, R.E. and A.H. Khan (1996). Response of corn, grain sorghum, and sunflower to irrigation in the high plains of Kansas. Agric. Water Manage. 30, 251– 259.
42. Talha, M. and F. Osman (1974). Effect of soil water stress on water economy and oil composition in sunflower (*Helianthus annuus* L.). J. Agric. Sci. Cambridge 84, 49–56.
43. Tian, Y., Su, D., Li, F.M. and X.L. Li (2003). Effect of rainwater harvesting with ridge and furrow on yield of potato in semiarid areas. Field Crop Res. 84, 385–391.
44. U. S. Salinity Lab. Staff (1954). Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, Washington, DC, USA.
45. Unger, P.W. (1982). Time and frequency of irrigation effects on sunflower production and water use. Soil Sci. Soc. Am. J. 46, 1072–1076.
46. Unger, P.W. (1983). Irrigation effect on sunflower growth, development and water use. Field crop research 7: 181-194.
47. Unger. P.W. (1990). Sunflower. In; B. A. Stewart and D. R. Nielson (Editors), Irrigation of Agricultural Crops, ASA Monograph No. 30, ASA, CSSA, SSSA, Madison, WI, pp. 775-791.
48. Vermeersch G. (1996). Industrial uses of sunflower oil. OCL, I, 3, 19-21.
49. Watanabe, F.S. and S.R. Olsen (1965). Test of an ascorbic acid method for determining P in water and bicarbote extracts from soil. Soil Sci. Soc. American Proc., 29:677-678.
50. Zhang, J., Sun, J., Duan, A., Wang, J., Shen, X. and X. Liu (2007). Effect of different planting patterns on water use and yield performance of winter wheat in the Huang-Huai-Hai plain of China. Agricultural Water Management. 2:41-47.

International Agricultural Engineering Journal 2008, 17(1-4):19-25

IRRIGATION AND FERTIGATION EFFECTS ON NITROGEN USE EFFICIENCY AND TOMATO YIELD

O. Cukaliev*, V. Tanaskovik*, R. S. Kanwar†, Lee Kheng Heng‡, D. Mukaetov§

ABSTRACT

The primary objective of this study was to determine the best irrigation and fertigation practice for tomato crop (Lycopersicon esculentum Mill.) in order to achieve highest yield with maximum fertilizer use efficiency. The field experiments were conducted during the period of May to September in 2002, 2003 and 2004. Five experimental treatments investigated in this study included the following: The first three treatments (T1, T2, T3) included a combination of drip irrigation and fertigation, treatment #4 (T4) included drip irrigation, but with conventional application of fertilizer, and the fifth treatment, (T5), included furrow irrigation practice with conventional application of fertilizer. To determine fertilizer use efficiency, part of nitrogen was applied as labelled urea with ^{15}N stable isotope. The results of this study indicated that the tomato crop positively responded to the simultaneous application of water and fertilizer under a drip system of irrigation in comparison with conventional application of fertilizer. Overall conclusion of this study indicated clearly that to obtain acceptable/maximum tomato yield with high nitrogen fertilizer use efficiency (NFUE) the practice of drip irrigation in combination of fertigation with irrigation frequency of either two (T1) or four (T2) days is recommended.

Keywords: *Tomato; Irrigation; Fertigation; Labelled Urea; ^{15}N; Yield; NFUE*

1. INTRODUCTION

The application of fertilizer through the drip irrigation system (fertigation) is a common practice in modern irrigated agriculture. This practice has several advantages over the conventional methods. The advantages of drip fertigation are: The supply of nutrients can be more carefully regulated and monitored (Burt et al. 1995), minimal losses of water and plant nutrients (Papadopoulos 1985), decrease leaching and volatilization losses and minimize the chances for ground water pollution (Miller et al. 1982, Gardner et al. 1984), improved fertilizer use efficiency – FUE (Miller et al. 1981, Papadopoulos 1995), improved yield and water use efficiency (Al-Wabel et al. 2002), improved yield quality parameters (Aleantar et al. 1999) etc.

Geographic location and climatic conditions in the Republic of Macedonia enable high quality agricultural production, but the limiting factors for high and more profitable yield is improper use of water and fertilizers.

Therefore, the main objectives of this study were to compare conventional irrigation and fertilization method with drip fertigation; to evaluate nitrogen fertilizer use efficiency (NFUE) in both methods of application; to determine best fertigation practice for tomato crop and to evaluate yield quantity as affected by methods of application. With these results we plan to increase interest among Macedonian farmers for higher usage of drip fertigation in their fields in order to increase their income and to reduce the cost of the production and to protect the environment from agro-chemical pollution.

2. MATERIAL AND METHODS

* Faculty of Agricultural Sciences and Food, University St. Cyril and Methodius, Skopje, Republic of Macedonia
† Department of Agricultural and Biosystems Engineering, Iowa State University of Science and Technology, Ames, Iowa, U.S.A.
‡ Soil and Water Management and Crop Nutrition Section, Joint FAO/IAEA Division, International Atomic Energy Agency, Vienna, Austria
§ Institute of Agriculture, Skopje, Republic of Macedonia

A field experiment was carried out on a small experimental field near the Faculty of Agricultural Scinces and Food in Skopje (42^o 00' N, 21^o 27' E). The experiment was carried out during the period of May to September in 2002, 2003 and 2004. The investigated crop was tomato (Lycopersicon esculentum Mill.), hybrid Optima. The soil type is coluvial (deluvial) soil (FAO Classification) disturbed with urban activities. The soil pH was 7.5. The soil 0-60 cm layers contained respectively 2.40 mg/100 g available forms of N, 19 mg/100 g available P_2O_5 and 18 mg/100g available K_2O. According to the recommendations and literature data for the region, tomato planted in an open field in our condition yields up to 80 t/ha (in good growing season with good agricultural practice). That yield needs the following amount of nutrients: N 260 kg/ha, P_2O_5 160 kg/ha and K_2O 320 kg/ha. The common practice to split application of fertilizer in two portions (before planting and in the growing season) was followed. Application of the most common fertilizer in the country, NPK 15:15:15 in amount of 333 kg/ha (or about 50 kg of each macronutrient) was done before planting of tomato. The rest of the fertilizer needed for achieving the targeted yield was planned to be applied through the fertigation system for drip fertigation treatments (spread during the growing season) and conventional fertilization on soil for control treatments (spread in two phases, flowering and fruit formation). The fertigation equipment for drip fertigation treatments was Dosatron 16, with a plastic barrel as reservoir for concentrated fertilizer. The whole amount of fertilizer was dissolved in the barrel and barrel was sealed to avoid evaporation of the water. The dilution of the concentrated fertilizer in irrigation water was 1%. The source of water was the water supply system for the city of Skopje (very high quality of water).The irrigation of the experiment was scheduled according long-term average daily evapotranspiration for tomato in Skopje area. Long term average evapotranspiration was calculated by FAO software CROPWAT for Windows 4.3 using crop coefficient (kc) and stage length adjusted for local condition by Faculty of Agricultural Sciences and Food. Because the use of drip irrigation and application of the water was only on part of the total surface, the daily evapotranspiration of drip irrigation treatments was decreased for 20% (coefficient of the coverage). The irrigation scheme used in the experiment was designed according to randomized block design for experimental purposes with five treatments in three replications.

Experimental Treatments: Experimental treatments were set up according to the daily evapotranspiration rate. The idea was to investigate frequency of fertigation and its effect on crop yield and NFUE.

- Treatment 1 (T1). Fertigation according to daily evapotranspiration with application of water and fertilizer every two days.
- Treatment 2 (T2). Fertigation according to daily evapotranspiration with application of water and fertilizer every four days.
- Treatment 3 (T3). Fertigation according to daily evapotranspiration with application of water and fertilizer every six days.
- Treatment 4 (T4). Drip irrigation according to daily evapotranspiration with application of water every four days and conventional fertilization (spreading of fertilizer on soil).
- Treatment 5 (T5). Furrow irrigation according to daily evapotranspiration with application of water every seven days and classic fertilization (spreading of fertilizer on soil).

The size of each plot (replication) was 7.2 m2 (18 plants in 0.8 m of row spacing and 0.5 m plant spacing in the row). Each plot (replication) was designed with three rows of crop. There were six plants in each row. The rows from left and right hand side were border rows. The middle row was assumed for experimental purposes. The two plants from each end of the middle row were border plants. Experimental plants were just two plants in the middle of the experimental row and these plants were used for sampling of ^{15}N. All material of these two plants was collected (leaf, steam, fruits) and yield of the fresh and dry weight (at 70oC for 48 hours) was measured. Samples were ground to pass a 0.2 mm sieve. The average samples were prepared and used for analysis (FAO/IAEA sample preparation techniques of biological material for isotope analysis). The experiment with labeled urea was conducted only in years 2002 (3 % ^{15}N a.e. urea as isotope) and 2003 (2.5 % ^{15}N a.e. urea as isotope), as results of limitation with labeled urea and application of fertilizer to whole plot in order to eliminate side effect in the experiment. The total N analysis was done with micro-Kjedahl method and the ^{15}N abundance was measured with emission spectrometry by the Institute for Nuclear Techniques in Ankara, Turkey.

Collected data were subjected to statistical analysis of variance and means were compared using the least significant difference (LSD) at the 5% level of probability ($P<0.05$) test.

3. RESULTS AND DISCUSSION

3.1 The Meteorological Conditions During the Investigation

Air temperature, rainfall and relative humidity for the experimental site during 2002, 2003 and 2004 are presented in Table1.

The average seasonal temperature (average in the growing period) in 2002, 2003 and 2004 was 21.0^{o}C, 22.2^{o}C and 20.5^{o}C respectively. During the period of the biggest fructification (June-August) the average temperature in all three years was in the frame of the optimum values. It is well known that tomato is most sensitive to water shortage (drought) during the flowering and fruit formation. The Skopje area in that period is characterized with highest temperatures and insolation, so evapotranspiration is highest. Usually rainfalls are in minimum in that period. Data presented in the table shows that years 2002 and 2004 were characterized as very wet years with a lot of rainfall in the growing season (316.7 mm in 2002 and 250.3 mm in 2004) and is extraordinary unusual. Especially unusual was very high rainfalls in the period July-September, 2002 and May-July, 2004. This created a favorable condition for plant diseases. Another problem was that experiment was set up according to the average evapotranspiration rate, so in a very wet period we had problems with too much water. In the case of fertigation, avoiding each application of water meant less readily available nutrients for the crop. This created problems with the application of the total amount of nutrients with fertigation, especially in 2002, while in 2004 the total amount of nutrients was applied as a result of better time disposal of rainfall. Year 2003 was about average. There was a little bit higher rainfall in May-June, but the other period was much lower than average. In the period of most active yielding there was a huge shortage of water and very high temperatures, so fertigation had a much higher effect in this year.Tomato crop is characterized as crop that is tolerant to low relative air humidity, even though optimal values are in the rank of 55-65%. The average relative humidity values during the all three years of investigation were close to normal.

3.2 Yield and Effect of Fertigation Treatments on Tomato Yield

It is interesting to see yield and differences in yield among different treatments because each of the treatments receive the same amount of fertilizer and water. Differences are results of differences in application regime of water and fertilizers. The yields achieved in the experiment are shown in Table 2.

There is not a statistically significant difference in yield between treatment T1 (118.03 t/ha) and treatment T2 (114.94 t/ha). So, in this case, decision of the frequency of fertigation in a range two to four days should be done according other parameters, not according to the yield. If two days frequency is applied instead of four days frequency, the design of irrigation system can be done with pipes with smaller diameters, so it can be less expensive. Fertigation frequency of every two or four days achieves a yield that is significantly higher than the yield if fertigation is applied with six days frequency (T3). Doorenbos et al. (1986) reported that prolonged water deficit limits growth and reduces yields of tomato crop. So, our results show that going in time difference between two applications of water and fertilizers higher than four days will significantly decrease the yield of tomato due to increased water deficit and water stress. Phene (1995) reported better tomato yields with high-frequency surface drip irrigation in comparison with low frequency surface drip irrigation.

As seen in Table 2, the drip fertigation treatments (T1, T2, T3) shows a statistically significant difference compared with treatment with drip irrigation and spreading of fertilizer (T4). This can be explained by the fact that with drip fertigation the root zone of the plant in the same time is provided with water and readily available nutrients. Our research data concur with literature reporting that fertigated tomatoes produced fruit yield of 72 t/ha while those under conventional drip irrigation and fertilization yielded only 44 t/ha (Pan et al. 1999). Tomato yields were significantly higher when fertilizers were injected through the drip system in comparison with conventional application (Locascio and Myers 1974). Also, to see the effect of drip fertigation, it is more interesting to present yield differences among treatment T2 and treatment T4, where each of the treatments receives the same amount of fertilizer and water, but differences are in the method of application of fertilizers.Yield difference between treatments when application of water was every four days shows that if part of the fertilizer is applied through the drip irrigation system the yield is higher by about 22% in comparison with spreading of fertilizer on the soil. These results are related to the fact that under drip irrigation only a small part of volume around each plant is wetted, so, crop root growth is essentially restricted to this volume of soil and nutrients within that volume can be depleted by crop uptake. Haynes (1985) reported that if nutrients are applied outside the wetted soil volume they are generally not available for crop use.

Finally, the treatment with drip irrigation and spreading of fertilizers on soil (T4) show a statistically significant difference compared with treatment with furrow irrigation and same application of the fertilizers (T5). This can be explained by the fact that with drip irrigation the plants are permanently provided with readily available water related with crop water requirement. Increased yields using drip irrigation can be attributed to several factors: higher water use efficiency because of precise application directly to the root zone and lower losses due to reduced evaporation, runoff and deep percolation; less fluctuations in soil water content resulting in the avoidance of water stress and etc. (Dasberg and Or 1999). The effect of drip irrigation on increasing of tomato yield is about 12%. Changing of irrigation system from furrow irrigation to drip irrigation and gaining just 12% higher yield seems like a topic for discussion if application of fertilizer is not through the drip system. The agricultural growers indicate the importance of fertigation under micro irrigation systems in producing higher yielding and better quality of tomato crop (Burt et al. 1995). Generally, the results from our investigation clearly show that if drip irrigation is applied then fertilizers or part of the fertilizers should be applied by drip irrigation system.

3.3 Nitrogen Fertilizer Use Efficiency

The experiments with FUE were conducted only in years 2002 and 2003, as results of limitation with ^{15}N labeled urea and application of fertilizer to whole plot in order to eliminate side effects in the experiment.

The effect of conventional application of water and fertilizer, drip irrigation with spreading of fertilizer and drip fertigation method with different frequency of water application on the nitrogen uptake by tomato is presented in Table 3.

From the results shown in Table 3, it can be concluded that the total dry matter yield (D.M.yield t/ha) under the drip fertigation method showed a statistically significant difference compared with control treatments T4 and T5. The total dry matter yield shows the same pattern as a fresh fruit yield, which would once again indicate yield increase with simultaneous application of water and nutrients through the drip irrigation system. Sagheb and Hobbi (2002) reported that with the same quantity of fertilizer but different methods of application, drip fertigation shows about 2.7 times more total dry matter in comparison with treatment with furrow irrigation and spreading of fertilizers on soil.

The total N percentage (% N Total) of the dry matter for the treatments was 2.11%, 2.20%, 2.09%, 1.95% and 1.87%, respectively. There was a statistically significant difference between the treatments under drip fertigation and treatments with conventional application of fertilizer. From the table we can conclude that, even if the percent of nitrogen is higher in T2, the treatment T1 in interaction with higher yield dictates the highest amount of total nitrogen uptake (N yield kg/ha) of about 210.80 kg/ha. The lowest N uptake was found in T5 with 136.51 kg/ha or 54.4% less in comparison with the treatment T1, which shows a close connection of total N percentage with yield. All treatments under drip fertigation showed a statistically significant difference compared to control treatments T4 and T5. Some research data (Zuraiqi et al. 2002) have also shown that with drip fertigation total N percentage and amount of total nitrogen uptake of the dry matter are the highest in comparison with spreading of fertilizers on soil.

From the data obtained from analysis of percent of ^{15}N atom excess, once again it is clear that the treatments under drip fertigation indicated the best results with a statistically significant difference in comparison with T4 and T5. Hence, the highest values for the percent of nitrogen derived from the urea fertilizer (% N d.f.f.) have the treatments T1, T2 and T3 while control treatments T4 and T5 have the lowest one. The results show a significant difference between the treatments under drip fertigation and

Table 1: Monthly and growing season temperature, precipitation and relative humidity for Skopje, Macedonia in 2002, 2003 and 2004

Months	Temperature			Precipitation			Relative humidity		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
	°C			mm			%		
May	18.0	18.1	.3	47.4	93.0	.6	66	60	5
June	23.2	23.8	.3	16.1	62.3	.2	56	57	5
July	24.9	25.2	.1	71.0	2.3	.4	58	51	6
August	21.9	26.2	.0	99.1	11.5	.1	70	49	7
September	17.0	17.7	.8	83.1	21.3	.0	75	64	2
Total/Average	21.00	22.2	.5	316.7	190.1	0.3	65	56	1

Table 2: The response of irrigation and fertigation treatments on tomato yield and comparison of the treatments

Treatments	Yield (t/ha)	Increased tomato yield in comparison with furrow irrigation (%)	Increased tomato yield in comparison with drip irrigation and spreading of fertiliser (%)
T1	118.03[a]	138.91	124.33
T2	114.94[a]	135.27	121.08
T3	106.55[b]	125.39	112.24
T4	94.93[c]	111.72	100.00
T5	84.97[d]	100.00	

*Values in rows followed by the same letter are not significantly different at the 0.05 probability level

Table 3. Nitrogen uptake by tomato plant (fruits and shoots)

Treatment	D.M.yield t/ha	N yield kg/ha	% N d.f.f.	% N d.f.s.	% N (Total)	% ^{15}N excess	Quantity of ^{15}N kg/ha	NFUE (%)
Whole plant								
T1	9.99[a]	210.80[a]	38.91[a]	61.09[a]	2.11[a]	1.07[a]	80.02[a]	30.80[a]
T2	9.50[a]	209.00[a]	36.73[a]	63.27[a]	2.20[a]	1.01[a]	76.70[a]	29.53[a]
T3	8.71[b]	182.04[b]	35.64[a]	64.36[a]	2.09[a]	0.98[a]	64.90[a]	24.96[a]
T4	8.16[c]	159.12[c]	16.73[b]	83.27[b]	1.95[b]	0.46[b]	26.62[b]	10.24[b]
T5	7.30[d]	136.51[d]	12.72[b]	87.28[b]	1.87[b]	0.35[b]	17.36[b]	6.68[b]

*Values in rows followed by the same letter are not significantly different at the 0.05 probability level

D.M. yield = dry matter yield per unit area; N yield kg/ha = the total amount of N contained in the crop;
Ndff = percentage of nitrogen derived from fertilizer; Ndfs = percentage of nitrogen derived from soil;
% N (Total) = total N concentration (%) in dry matter; % ^{15}N excess = percentage of ^{15}N excess in plant; Quantity of ^{15}N kg/ha = the amount of ^{15}N fertiliser taken up by the crop; NFUE = nitrogen fertilizer use efficiency;

treatments with conventional application of fertilizer. Also, the total quantity of ^{15}N kg/ha uptake by the whole plant is in relation with previously mentioned results. The nitrogen (^{15}N kg/ha) taken up by the whole plant for the respective treatments was 80.0, 76.7, 64.9, 26.6 and 17.4 kg/ha. The value for treatments T1, T2 and T3 were almost 5, 4 and 3.5 times higher than treatment with conventional application of water and fertilizer. Generally, this is presumably because the water and fertilizer are applied directly into the small volume of soil where the active crop roots are concentrated, so there are minimal chances for leaching of nutrients, especially of nitrogen. Persaud (1976) reported that when fertilizers are simply broadcast over the entire soil area may become limiting to plant growth. Also, this could be because the fertilizer is leached from the root zone during irrigation as well as because of volatilization losses (Miller et al. 1981).

Calculations of nitrogen fertilizer use efficiency confirm all results mentioned above. The nitrogen fertilizer use efficiency (%NFUE) for whole plants showed that treatments T1, T2 and T3 under drip fertigation had a higher statistically significant difference than treatments T4 and T5. Similarly, Miller et al. (1981) found that nitrogen was used more efficiently by tomato plants, when applied through the drip irrigation, than when banded and furrow irrigated or banded and drip irrigated. Also, our results correspond with those of Halitligil et al. (2002), which reported that the percentage of NFUE was significantly increased when the N fertilizer was applied in irrigation water (drip fertigation) as compared to the soil N application at the same level. If our results for the percentage of NFUE are presented in comparative values, then the NFUE in the treatments T1 and T2 were more than four times higher in comparison with T5, while in comparison with T4 the value for NFUE was about three times higher. Also, the treatment T3 obtained more than two times higher nitrogen fertilizer use efficiency in comparison with T4 and about three times in comparison with T5, as a result of application of fertilizer through the system of irrigation.

Generally, the results from our study indicate that simultaneous application of water and fertilizer through the system of drip irrigation not only caused an increase in yield, but also enhanced the NFUE. This is very important especially if we want to protect the environment from nitrogen pollution. Various research reports indicate that drip fertigation create high fertilizer use efficiency and at the same time decreases leaching of fertilizers and minimizes the chances for soil or ground water pollution (Gardner et al. 1984, Papadopoulos 1995).

4. SUMMARY AND CONCLUSIONS

A three year long experiment on tomato crop was conducted to compare performance of the drip fertigation treatments (T1, T2, T3) with surface broadcast of fertilizer with drip irrigation (T4) and furrow irrigation.

The results of this study show that the drip fertigation treatments (T1, T2, T3) yielded significantly higher tomato yields in comparison to surface broadcast of fertilizer under drip and furrow method of irrigation. The drip fertigation method yielded 39 % more tomato yield in comparison with surface broadcast of fertilizer under furrow irrigation and 24 % more drip irrigation. The effect of different method of fertilizer application shows significant differences in tomato fruit yield among treatment T2 and treatment T4. Yield difference between these treatments (when same ammount of water was applied with same frequency - every four days) shows that if fertilizer is applied through the drip irrigation system (T2) the yield is higher by about 22% in comparison with surface spreading of fertilizer on the soil (T4).

The nitrogen fertilizer use efficiency (%NFUE) for the entire plant (fruit plus the biomass) showed that treatments T1, T2 and T3 under drip fertigation had a higher and statistically significant nitrogen use efficiency in comparison to treatments T4 and T5. The treatment T3 resulted in more than two times higher nitrogen fertilizer use efficiency in comparison with treatment T4 and about three times higher in comparison with treatment T5.

Therefore, this resulted in making a recommended to farmers that, if drip irrigation system is used with fertigation not only an increase in tomato yield was obtained but also resulted in increasing the NFUE. In addition, fertigation is an effective method to protect the environment from nitrogen pollution Finaly, the best option is drip irrigation with application of fertilizers through fertigation with frequency of irrigation application of two to four days.

ACKNOWLEDGEMENT

The authors would like to thank IAEA for their technical support. Appreciation is also extended to the Institute for Nuclear Techniques in Ankara, Turkey for analysis of the ^{15}N samples.

REFERENCES

1. Aleantar, G.G., Villarreal, R.M., Aguilar, S.A. and A.P. Papadopoulos (1999). Tomato growth (Lycopersicon esculentum Mill) and nutrient utilization in response to varying fertigation programs. International Symposium on growing media and hydroponics, Winsdor, Ontario, Canada. Vol. 1 Acta Horticulture No. 481: 385-391.
2. Al-Wabel, M.I., Al-Jaloud, A.A., Hussain, G. and S. Karimulla (2002). Fertigation for improved water use efficiency and crop yield. IAEA-TECDOC-1266, Water balance and fertigation for crop improvement in West Asia, Results of a technical co-operation project organized by the Joint FAO/IAEA/ Division of Nuclear Techniques in Food and Agriculture: 69-84.

3. Burt, C., O'Connor, K., and T. Ruehr (1995). Fertigation. Irrigation Training and Research Center, California Polytehnic State University, San Luis Obispo, California.
4. Dasberg, S. and D. Or (1999). Drip Irrigation. Applied Agriculture. Springer-Verlag Berlin Heidelberg New York.
5. Doorenbos, J., Kassam, A.H., Bentvelsen, C.L.M., Branscheid, V., Plusje, J.M.G.A., Smith M., Uittenbogaard, G.O. and H.K. Van Der Wal (1986). Yield response to water. FAO Irrigation and Drainage Paper 33, FAO/UN, Rome.
6. Gardner, B.R. and R.L. Roth (1984). Applying nitrogen in irrigation water. Nitrogen in crop production. American Society of Agronomy. CSSA, Madison. WI, Hauck ed.: 493-506.
7. Halitligil, M.B., Akin, A.I., Kislal, H., Ozturk, A. and A. Deviren (2002). Yield, nitrogen uptake and nitrogen use efficiency by tomato, pepper, cucumber, melon and eggplant as affected by nitrogen rates applied with drip-irrigation under greenhouse conditions. Fertirigation for improved water use efficiency and crop yield, IAEA-TECDOC-1266, Water balance and fertigation for crop improvement in West Asia, Results of a technical co-operation project organized by the Joint FAO/IAEA/ Division of Nuclear Techniques in Food and Agriculture: 99-110.
8. Haynes, R.J. (1985). Principles of fertilizer use for trickle irrigated crops. Fertilizer research 6. Martinus Nijhoff/Dr W. Junk Publishers, Dordrecht. Printed in the Nederlands.: 235-255.
9. Locascio, S.J. and J.M. Myers (1974). Tomato response to plug-mix mulch and irrigation method. Proc. Fla. State Hort. Soc. 88: 126-136.
10. Miller, R.J., Rolston, D.E., Rauschkolb, R.S. and D.W. Wolfe (1981). Labelled nitrogen uptake by drip-irrigated tomatoes. Agron J 73: 265-270.
11. Pan, H.Y., Fisher, K.J. and M.A. Nichols (1999). Fruit yield and maturity characteristics of processing tomatoes in response to drip irrigation. J. Veget. Crop. Prod. 5: 13-29.
12. Papadopoulos, I. (1985). Constant feeding of field-grown tomatoes irrigated with sulfate water. Plant and Soil 88: 213-236.
13. Papadopoulos, I. (1995). Use of labeled fertilizers in fertigation research. International symposium on nuclear and related techniques in soil-plant studies for sustainable agriculture and environmental preservation. IAEA, Vienna: 399-410.
14. Persaud, N., Locascio, S.J. and C.M. Geraldson (1976). Effect of rate and placement of nitrogen and potassium on yield of mulched tomato using different irrigation methods. Proc. Fla. State Hort. Soc. 89: 135-138.
15. Phene, C.J. and F.R. Lamm (1995). The sustainability and potential of subsurface drip irrigation. Microirrigation for a changing world conserving resources-preserving the environment. Proc. 5^{th} Int. Microirrig. Congr., Orlando, Florida ASAE Publ 4: 359-367.
16. Sagheb, N. and M.S. Hobbi (2002). Field evaluation of urea fertilizer and water use efficiency by tomato under trickle fertigation and furrow irrigation in Iran. Fertirigation for improved water use efficiency and crop yield, IAEA-TECDOC-1266, Water balance and fertigation for crop improvement in West Asia, Results of a technical co-operation project organized by the Joint FAO/IAEA/ Division of Nuclear Techniques in Food and Agriculture: 3-13.
17. Zuraiqi, S., Qawasami, W., Deek, I. and M.J. Mohammad (2002). Management of nitrogen fertigation of tomato with the use of ^{15}N technology. Fertirigation for improved water use efficiency and crop yield, IAEA-TECDOC-1266, Water balance and fertigation for crop improvement in West Asia, Results of a technical co-operation project organized by the Joint FAO/IAEA/ Division of Nuclear Techniques in Food and Agriculture: 27-40.

International Agricultural Engineering Journal 2008, 17(1-4):27-39

DEVELOPMENT OF CROP STAGGERED IRRIGATION DEMAND ASSESSMENT TOOL (CSIDAT)

Devesh Pandey[*], S. N. Panda[†], N. S. Raghuwanshi[‡] and Damodhara R. Mailapalli [§]

ABSTRACT

A simulation model, CSIDAT, is developed for assessing the existing variations in water supply-demand-gap and rescheduling of the canal operation to meet the demand within the existing irrigation system. The model was applied to Banahil distributary in India where canal is flowing continuously throughout the cropping season. The model require input data on crop, soil, weather and water in its different forms for estimating daily volumetric crop evapotranspiration (ET_c), gross irrigation requirement (GIR) and total irrigation demand (TID) for served area (SA), target area (TA) and potential area (PA) of the irrigation command. The model estimated GIR 145 cm for summer rice which had close agreement to the experimentally determined value of 150 cm of the region. On average, seasonal applied water (216 cm) was about 78% and 60% more than the seasonal TID of summer rice for the SA and TA, respectively. The saving of irrigation water can brought more area (an additional area of 1750 ha) under summer rice with the rescheduling of canal operation, with the same amount of seasonal water supply. The model was also tested for other *rabi* crops (wheat, sunflower, mustard, gram and safflower). Simulation results showed that covering 100% of cultural command area (CCA) under wheat will save 43% of irrigation water supply that can be used for tail-end commands.

Keywords: *Crop staggering; India; Irrigated Agriculture; Major Irrigation Project; Simulation; Software Development; Supply-Demand*

1. INTRODUCTION

1.1 General

Irrigation is directly responsible for complete self-sufficiency in food production of developing countries such as India, Pakistan and Sri Lanka (Chambers, 1998). It has also increased employment opportunities and improved the economic conditions of the agricultural labourers (Chitale, 1994). However, most of the major irrigation projects in the developing countries have failed to provide the benefits envisaged at the time of their commissioning. A high degree of mismatch between the irrigation water supply and crop water demand is commonly reported, this leads to waterlogging, salinity and other environmental hazards in the irrigated command (Sanmugnathan and Bolton, 1988). Moreover, growing population of India, which is expected to reach 1395 million by 2025 (United Nation, 2005), may result in increasing municipal, industrial and hydropower sectors and will need to share the water available for irrigation. In India, the irrigated areas are likely to shrink from the present 93% to 83% by 2025 (Biswas, 1994). Thus, in future, irrigation needs to be more efficient and produce more crop yield per unit of water use which requires proper planning based on simulation and optimization techniques, considering the location specific conditions. Several possible approaches and technologies have been used in irrigation scheduling for effective and rational uses of water. The delivery system, which needs to operate as per the irrigation

[*]Senior Scientist, Water Management Project, Indira Gandhi Krishi Vishwavidyalaya, College of Agriculture and Research Station, Bilaspur, Chhattisgarh, India, 495 001, devesh-p@mailcity.com
[†] Professor and Corresponding Author, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India, 721302, snp@iitkgp.ac.in
[‡] Professor, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India, 721302, nsr@agfe.iitkgp.ernet.in
[§] Post Doctoral Scholar, Land, Air and Water Resources Department, University of California, Davis-95616, CA, dam.iitkgp@gmail.com

requirement, is the immediate necessity for simulating actual situation of the command area.

1.2 Problems of the study area

The Hasdeo-Bango irrigation project is one of the major projects in the state of Chhattisgarh, India that provides irrigation facilities to about 255,000 ha in 801 villages of 3 districts (Korba, Janjgir, and Raigarh) and also generates 120 MW hydel power. The *kharif* (monsoon) rice occupies almost 100% of the CCA but the area under *rabi* (winter)-summer season varies according to the availability of water in the reservoir. Banahil Distributary, originated from RD 3415 m of Akaltara Branch Canal of Hasdeo-Bango Irrigation Project, was selected for the present study (Fig. 1). The distributary lies between latitude of 21°51’30” and 21°59’15” North and longitude of 82°16’50” and 82°26’30” East. The distributary started in 1991 to irrigate 11106.43 ha of *kharif* rice in 22 villages comprising of 14 villages of Pamgarh and 8 villages of Akaltara Blocks in Janjgir district. The length of the distributary is 12.78 km with 5 sub-distributaries and 10 minors. The present average target of summer rice is about 20% of the CCA of the distributary, which shows that each irrigator can cultivate summer rice, in the rotation, once in 5 years in the studied command. Further, the farmers of the area are completely dependent on the mercy of the State Water Resources Department (SWRD) with respect to canal release schedule. Since the SWRD presently does not possess any decision support system, the water allocation is frequently subjected to negotiations with the farmers and politicians. Such practices lead to poor performance of the irrigation system because of large deviation between the crop water demand and supply. Therefore, a study was required to assess the existing variations of water supply-demand and to provide a suitable tool, which can optimize the canal release to meet the crop water demand within the existing infrastructures. In the light of the aforesaid problems and possible technologies, a computer based water allocation model, CSIDAT (Crop Staggered Irrigation Demand Assessment Tool), was developed for simulating canal water distribution and providing suggestions on economically viable cropping pattern for the study area where canals are flowing continuously throughout the cropping seasons.

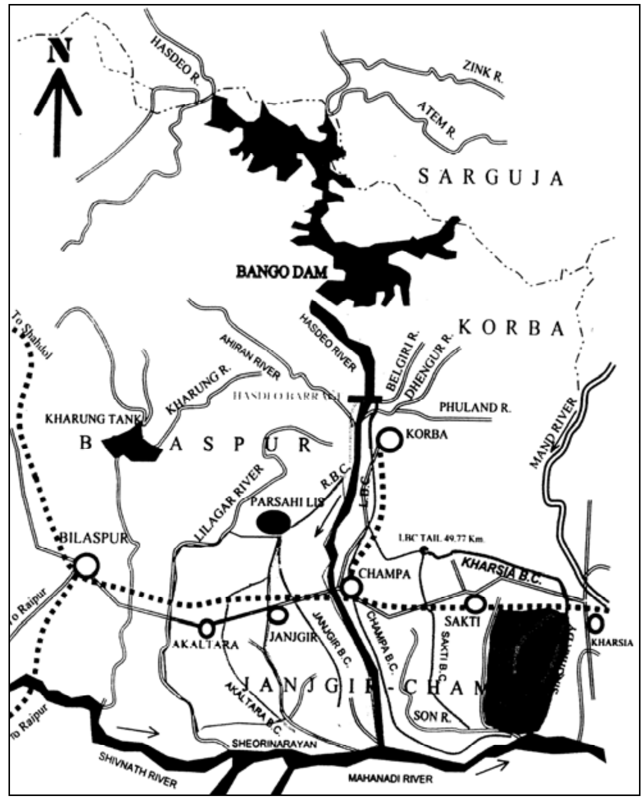

Fig. 1: Index map of the Hasdeo-Bango irrigation project

2. MATERIALS AND METHODS

2.1 Development of CSIDAT

Estimation of irrigation requirement of rice is different from other field crops because it requires extra irrigation water not only to meet the evapotranspiration demand but also the seepage and percolation losses from the fields. Hence, in formulating the water balance, the focus changes from soil moisture approach to water level approach (Fig. 2). The gross irrigation requirement of rice, on daily basis, can be expressed as (Azhar et al., 1992; Singh et al., 1997):

$$GIR_{cst} = ET_{c,cst} + DP_{cst} + DR_{cst} - ERF_{cst} \quad (1)$$

where, GIR is the gross irrigation requirement; ET_c is the crop evapotranspiration; DP is the deep percolation and seepage; DR is the runoff; ERF is the effective rainfall; c is the unit command index; s is the crop stagger index; and t is the time index.

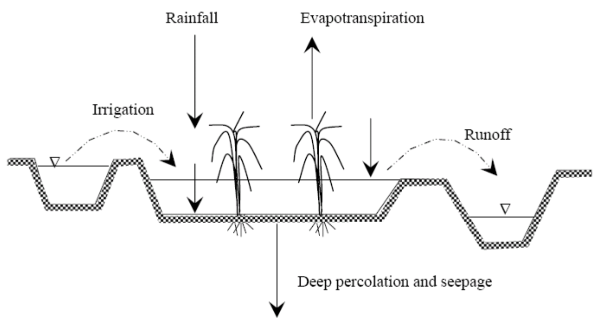

Fig. 2: Water balance components of a rice field

In *kharif* rice, water flows from one field to another as runoff and finally enters to the lowest point (natural drain). However, in case of summer rice, runoff water (if any) is fully utilized by the dike rice field or the lowland fields due to low rainfall and inadequate supply of the irrigation water. Therefore, the GIR of the summer rice can be calculated without considering the runoff component (DR = 0).

Daily ET_c, ERF and DP for all the three crop staggers are estimated and these values are used to estimate total irrigation demand at the supply system source that consists of 15 unit commands (sub-distributaries and minors) of each distributary under study, using the following equations:

$$TID = \sum_{c=1}^{15}\sum_{s=1}^{3}\sum_{t=1}^{T}\left(GIR_{cst} + CS^{UC}{}_{ct}\right) + \sum_{t=1}^{T} CS_t^D \tag{2}$$

where, TID is the total irrigation demand; T is the total number of simulation days; CS^{UC} is the canal seepage in unit command; and CS^D is the canal seepage in distributary level.

The components of the field water balance are estimated by the standard methods as follows.

2.1.1 Reference evapotranspiration

The reference crop evapotranspiration was calculated by the Penman-Monteith equation (Allen et al., 1989)

$$ET_o = \frac{0.408\Delta(R_n - G) + \dfrac{890\gamma U_2(e_a - e_d)}{T_m + 273}}{\Delta + \gamma(1 + 0.339U_2)} \tag{3}$$

where, ET_o is the reference crop evapotranspiration, mm/day; $\Delta$is the slope of the saturation vapour pressure temperature curve, kPa/°C; Υ is the psychometric constant, kPa/°C; R_n is the net solar radiation, MJ/m^2/day; T_m is the mean daily air temperature, °C; $(e_a$-$e_d)$ is the vapor pressure deficit of air, kPa; G is the soil heat flux density, MJ/m^2/day; and U_2 is the wind velocity at 2 m height, m/s.

The wind velocity adjustment is made as (Allen et al., 1993)

$$U_2 = \frac{4.852U_z}{\ln\left(\dfrac{z - 0.08}{0.015}\right)} \tag{4}$$

where, U_z is the measured wind velocity at a height of z (m) above the ground surface, m/s.

2.1.2 Crop evapotranspiration

The volumetric daily crop evapotranspiration is estimated by

$$ET_c = K_c \times ET_o \times A \times 10 \tag{5}$$

where, ET_c is the crop evapotranspiration, m^3/day; K_c is the crop coefficient; and A is the crop area, ha.

2.1.3 Effective rainfall

The volumetric daily effective rainfall (ERF) is calculated by the fixed-percentage approach as proposed by Smith (1992)

$$ERF = 0.8\ (RF \times A \times 10) \tag{6}$$

where, ERF is the effective rainfall, m^3/day; RF is the rainfall, mm/day.

2.1.4 Deep percolation and seepage

$$DP = DPR \times A \times 10$$

where, DP is the volume of deep percolation and seepage losses in the rice field, m^3/day; and DPR is the depth of deep percolation and seepage losses under rice cultivation, mm/day.

CSIDAT is developed using the above procedure for estimating volumetric daily GIR and TID. The flow chart of CSIDAT is shown in Fig. 3. The procedure is coded in Visual Basic Programming language with graphical user interface. CSIDAT consisted of input window and two output windows. The input window requires information on soil, texture, area, deep percolation and seepage; on crop, crop growth stages, stage duration and crop coefficient, number of staggers; start and end date of stagger (duration); on water, canal flow, canal seepage, rainfall, and evapotranspiration. The output (results) window consists of stagger wise estimation of ET_a, EFR and DP; and the daily supply-demand-gap. The graphical output of the model is obtained by clicking the “Graph” button seen at the bottom. The model estimated daily TID and the gap were assessed for SA and TA areas. Further, PA, i.e. the extent of the maximum possible area that can be brought under irrigation with the available trend of the canal flow, was also assessed.

2.2 Data Collection and Preliminary Analysis

The data on crops, soils, weather and canal pertaining to the study area were collected from various state government departments/agencies like SWRD, Agriculture Department and Indira Gandhi Krishi Vishwavidyalaya (IGKV), College of Agriculture and Research Station (CARS), Bilaspur and from personal contact with farmers of the command area. The collected data, for six *rabi*-summer seasons of the study period (1995- 2000), were analyzed for using in CSIDAT.

2.2.1 Crop, cropping pattern and agronomic data

Data on crop, cropping pattern and agronomic management for the study period were obtained from the local office of the Agriculture Department. Crop staggers (different planting dates adopted at various locations to suit their crop rotation) were determined with personal contact with the officers of the agriculture department, local experienced personals and farmers of the area. Rice is the pre-dominant crop and occupies almost 100% of CCA in *kharif* season. Whereas, some of the farmers grow wheat, sunflower, mustard, gram and safflower and most of the area remains fallow in *rabi* season. Summer rice is being grown as second crop since1994 and covers about 20% of the CCA by replacing almost all *rabi* crops in the area. This is because, summer rice requires less expenditure towards the application of pesticide and labour as compared to the *kharif* rice and *rabi* crops. The other reason is the low cost of canal water (i.e., Indian Rupees 494/ha), which is fixed, based on crop grown area but not on the frequency of irrigation. The average yield of summer rice is about 3864 kg/ha. Normally, summer rice sowing (either sprouted or germinated seeds) starts from the first week of January and continues up to the first week of February. The summer rice and *rabi* crops sowing period was divided in to three staggers of 10-day (5^{th} to 14^{th} January, 15^{th} to 24^{th} January and 25^{th} January to 3^{rd} February) and 5-day interval (1^{st} to 5^{th} November, 6^{th} to 10^{th} November, and 11^{th} to 15^{th} November) with sown area of 30, 50 and 20%, respectively. The crop was assumed to have five different growth stages (establishment, vegetative, flowering, yield formation, ripening) according to the FAO (Doorenbos and Pruitt, 1977 and Doorenbos and Kassam, 1979).

2.2.2 Soil data

Soil data of 22 villages of Banahil Distributary command were obtained from the local government offices of Soil Survey, Soil Testing, and CARS, Bilaspur. The soil texture of the command area varied from sandy clay loam to clay. The reaction of soil is neutral with no salt problem. The available soil moisture is 13.28, 15.14 and 16.01 cm/m for sandy clay loam, clay loam and clay soils, respectively. The DP losses can be considered as constant throughout the growth period (Bolton and Zandstra, 1981). The DP losses in summer rice fields values are 9, 5 and 3 mm/day for sandy clay loam, clay loam and clay soil, respectively (Seasonal Research Reports, 1997).

2.2.3 Weather data

The daily weather data, that included minimum temperature (MNT), maximum temperatures (MXT), relative humidity (RH), sunshine hour (SSHR), wind velocity (WV), collected from the Agro-meteorological observatory of CARS, Bilaspur, were used for calculation of ET_o by Penman Monteith method (Allen et al., 1989). The daily rainfall (RF) collected from the Akaltara Block head quarter of Janjgir district, was used for estimation of effective rainfall in the simulation model. The daily ET_c was determined by model with calculated ET_o multiplied by the K_c for each growth stages of the crop.

2.2.4 Canal operational data

The SWRD, Distt. Janjgir, Chhattisgarh provided the canal configuration and operational data of the Banahil distributary including dates of canal openings and closing, daily flow (discharge), and SA and TA of the distributary for the study period. The distributary is started operating from 1995 for summer rice. Normally, the supply starts in the first week of January and continues till the first week of May and on an average it runs for about 122 days. The SA of the distributary is increased from 1600 ha in 1995 to 2250 ha in 1999. The average SA of the distributary is about 2046 ha. The design discharge of Banahil distributary is 9.498 m^3/s and its supply varies from 0.68 to 5.116 m^3/s with an average of 3.851 m^3/s during the study period. The canal running days range from 114 to 133 days with an average of 122 days. The seepage losses in canal, range from 1.5 to 4.0 ha-m/day/million-m^2 of wetted area as recommended by the Ministry of Water Resources (GWREC, 1997), was taken into consideration.

3. RESULTS AND DISCUSSION

The CSIDAT estimated stagger-wise daily ET_c, GIR, TID and supply-demand-gap at the system supply source level for a cropping season on a volume basis. The seasonal ET_c of summer rice was found to be 55, 54, 53, 52, 53, and 67 cm for the year 1995 to 2000, respectively. For the corresponding periods, the values of GIR for summer rice were 152, 146, 144, 128, 142, and 156 cm (including 20 cm for the land preparation). The average seasonal ET_c and GIR were 56 and 145 cm, respectively. The model estimated GIR (145 cm) was very close to that reported by the All India Coordinated Research Project on Water Management, operational in the study area (150 cm) (Annual Progress Report, 2000).

The CSIDAT estimated daily water supply and demand at the supply system source of summer rice for the SA during the study periods (Fig. 4 and Table 1) showed that the supply was more than the demand in most of the days. Only for a few days, the supply was less than the demand. The maximum and minimum SA was 2304 and 1600 ha in the years 1997 and 1995, respectively, where as, maximum and minimum water delivered was 55.945 and 35.34 Mm^3 in the years 2000 and 1995, respectively. The applied depth of water varied from 188 to 252 cm with an average of 216 cm. On seasonal basis, the water delivered (44.249 Mm^3) was 78% higher than of the demand (24.903 Mm^3). This is also reflected in the water management indices (WMI, ratio of water delivered by the required). The water supply-demand trend analysis was also performed for the TA (Fig. 5 and Table 1) and observed that the supply-demand trends were same as in the case of SA with average supply was 59% more than the demand (WMI = 1.59). These results clearly indicate that the supply is sufficient for meeting the irrigation demand of TA and further, the 59% excess supply can be used for increasing the more area (PA) of summer rice in the command. Similarly, the analysis for supply-demand patterns was also performed for PA and the estimated supply-demand trends were not similar with the previous cases of SA and TA (Fig. 6 and Table 1). Most of the days, the demand is greater than the supply but the total seasonal supplies were almost matching with the seasonal demand (WMI = 1.0). This means that the supply were sufficient for meeting the irrigation demand of PA with the change in the canal flow pattern as per the demand (keeping same amount of total seasonal water delivery).On an average, 3778 ha (about 1732 ha more than the average SA, 2046 ha) can be brought under summer rice cultivation. The CSIDAT was also used to select the alternative *rabi* crops for the distributary with the average canal flow and weather data for the PA. The simulation results showed that the supply was more than the demand for all the chosen *rabi* crops (wheat, sunflower, mustard, gram, and safflower) and covering 100% of CCA under wheat will save 43% of irrigation water supply that can be used for tail-end commands (Fig. 7).

4. CONCLUSIONS

The CSIDAT estimated seasonal GIR (145 cm) for summer rice was in close agreement with the experimentally determined value (150 cm) of the region. Therefore, the CSIDAT can be used as a tool for determining stagger wise crop water requirement of the canal command. On an average the seasonal canal water supply (44.249 Mm^3) was about 78 and 60% more than the seasonal water demands of summer rice for the SA and TA, respectively. Therefore, more command area can be brought under summer rice cultivation. The CSIDAT simulation shows that the daily canal supply fell below the

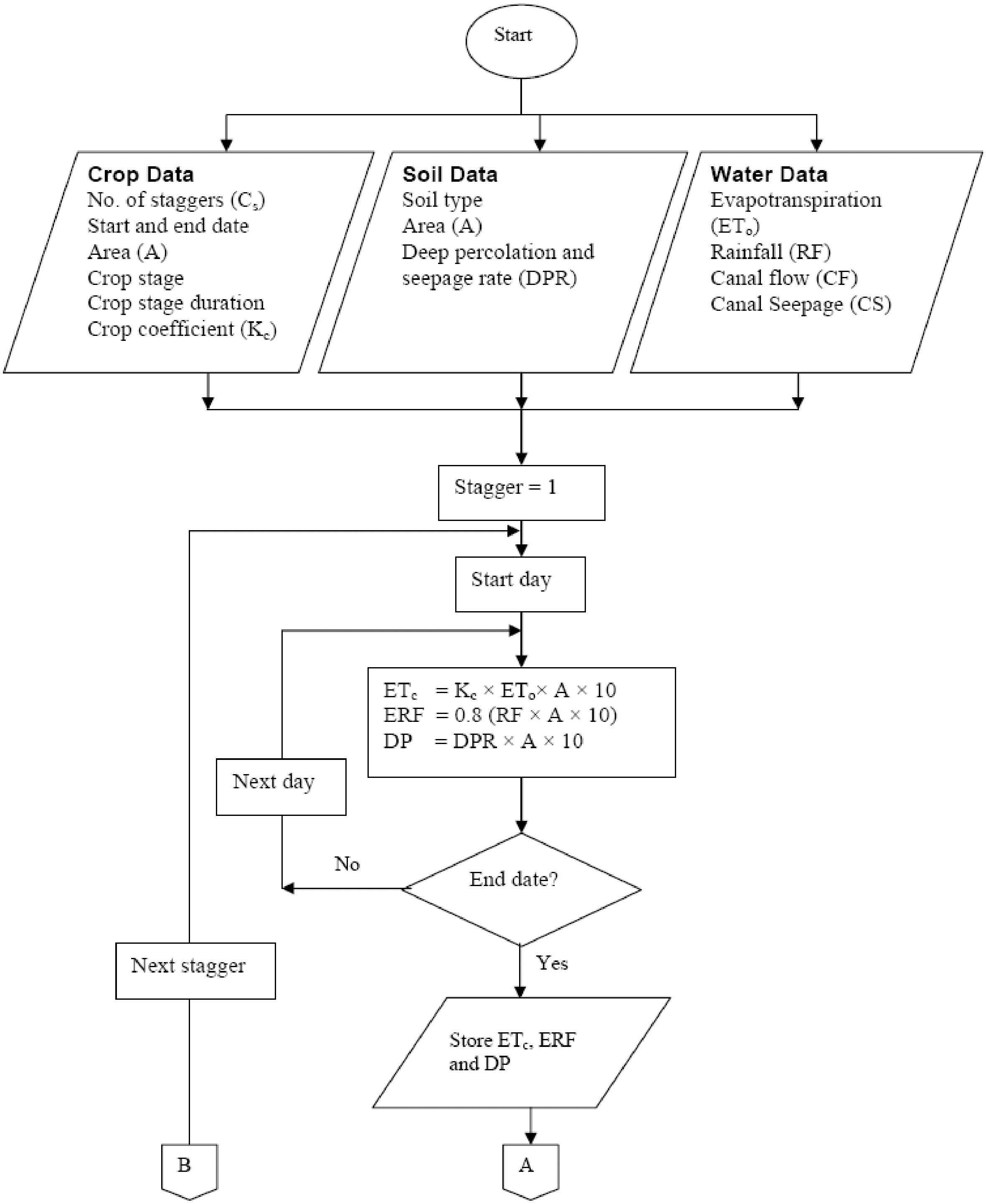

Fig. 3: Flow chart of CSIDAT

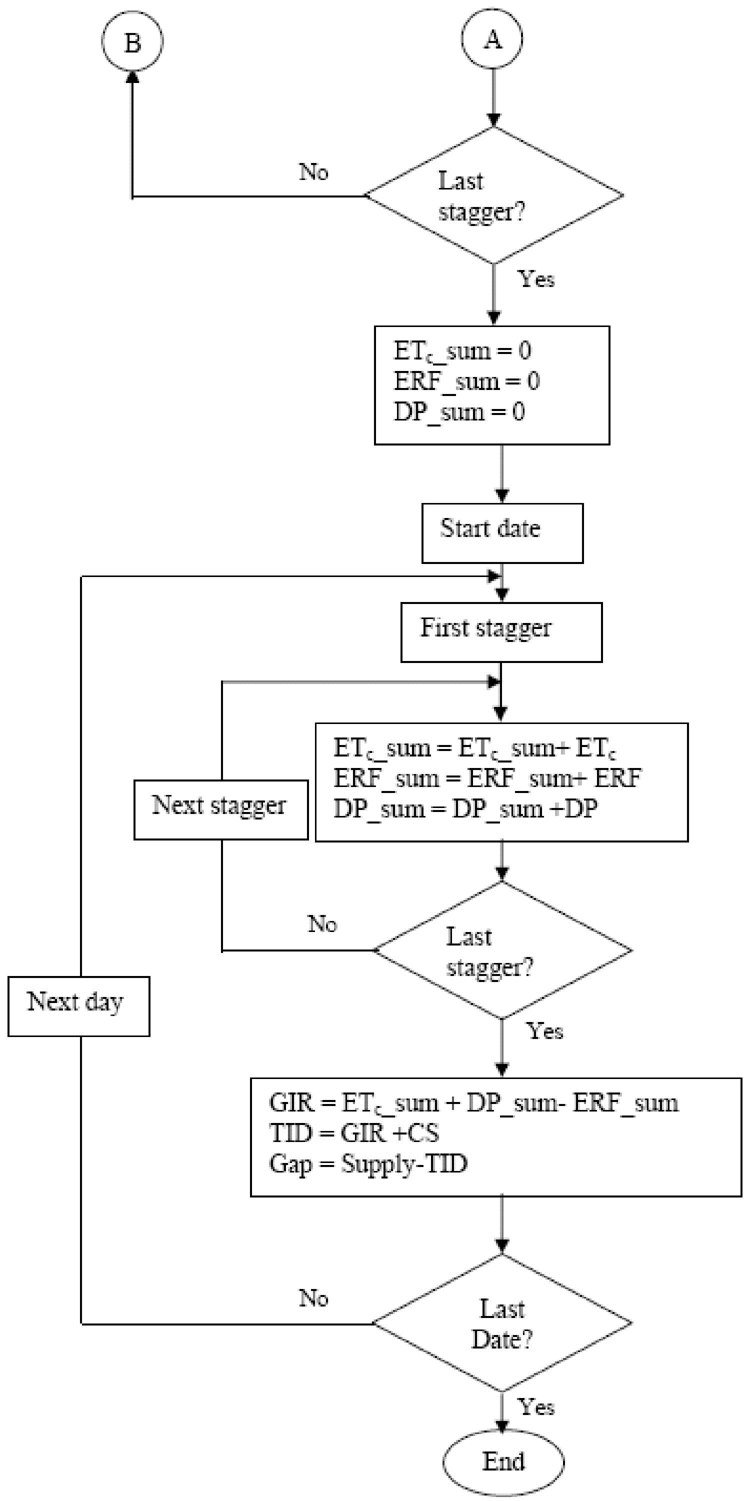

Fig. 3: Flow chart of CSIDAT (continued)

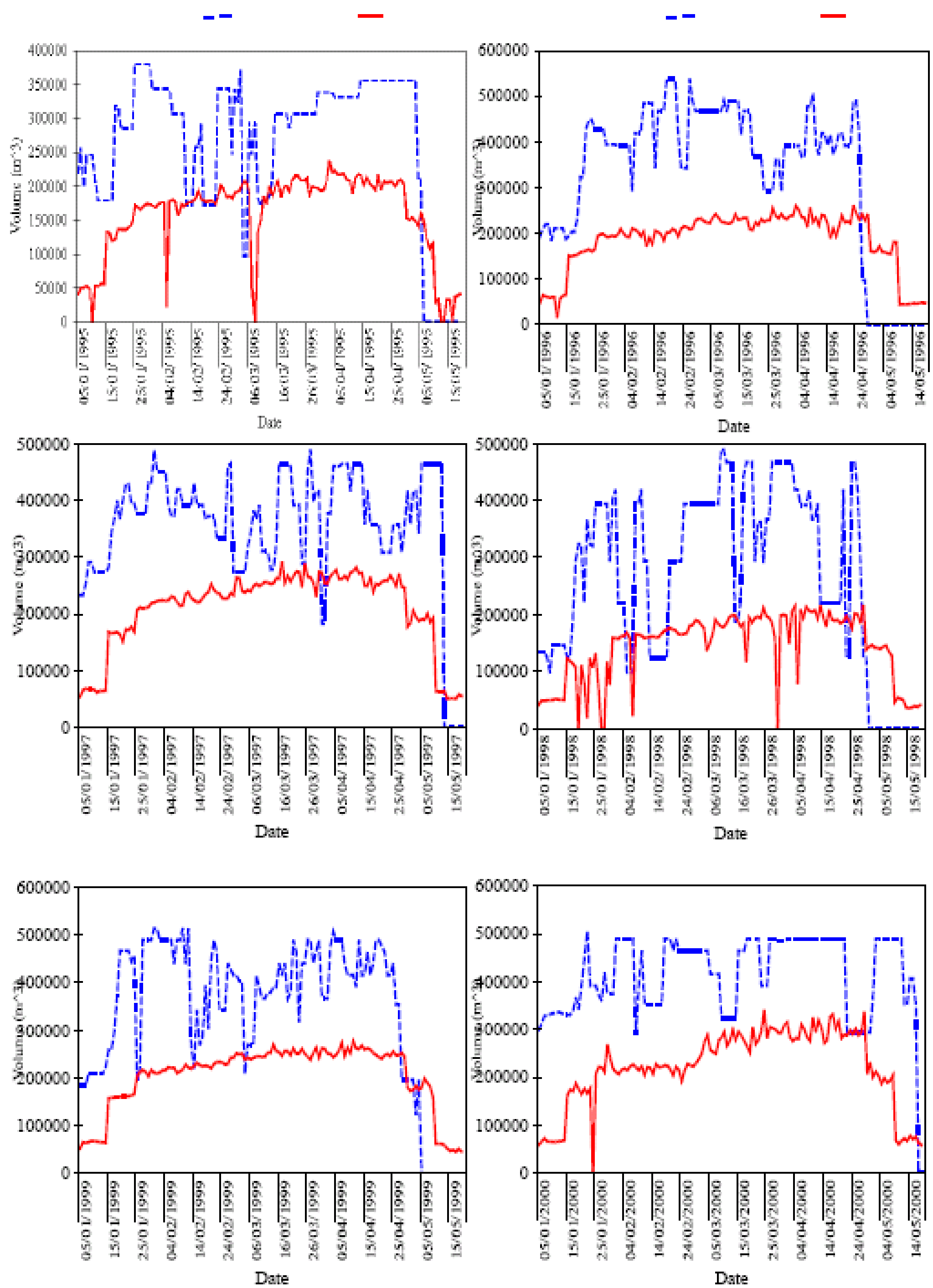

Fig. 4: Daily water supply and demand pattern of SA for 1995-2000

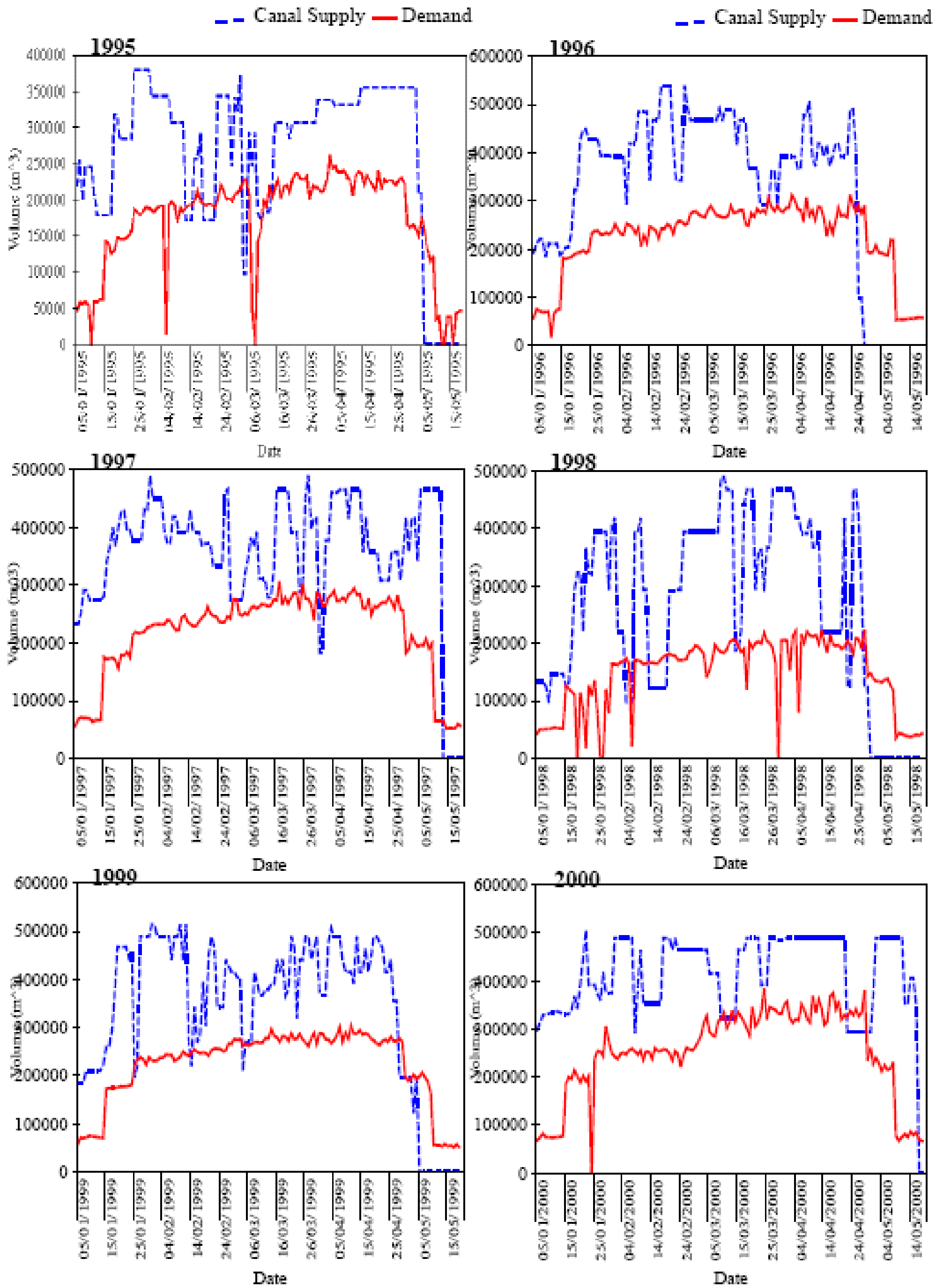

Fig. 5: Daily water supply and demand pattern of TA for 1995-2000

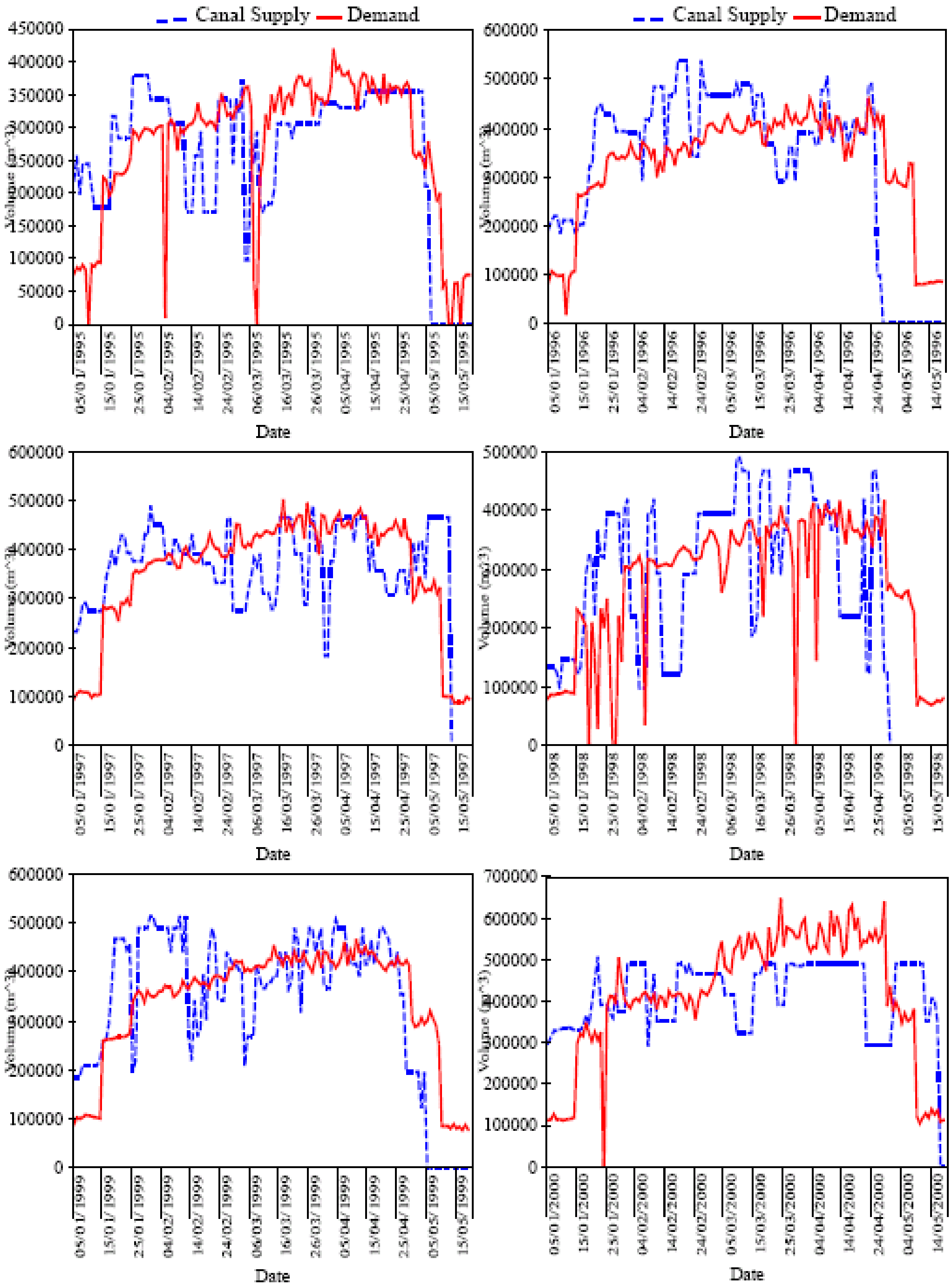

Fig. 6: Daily water supply and demand patterns of PA for 1995-2000

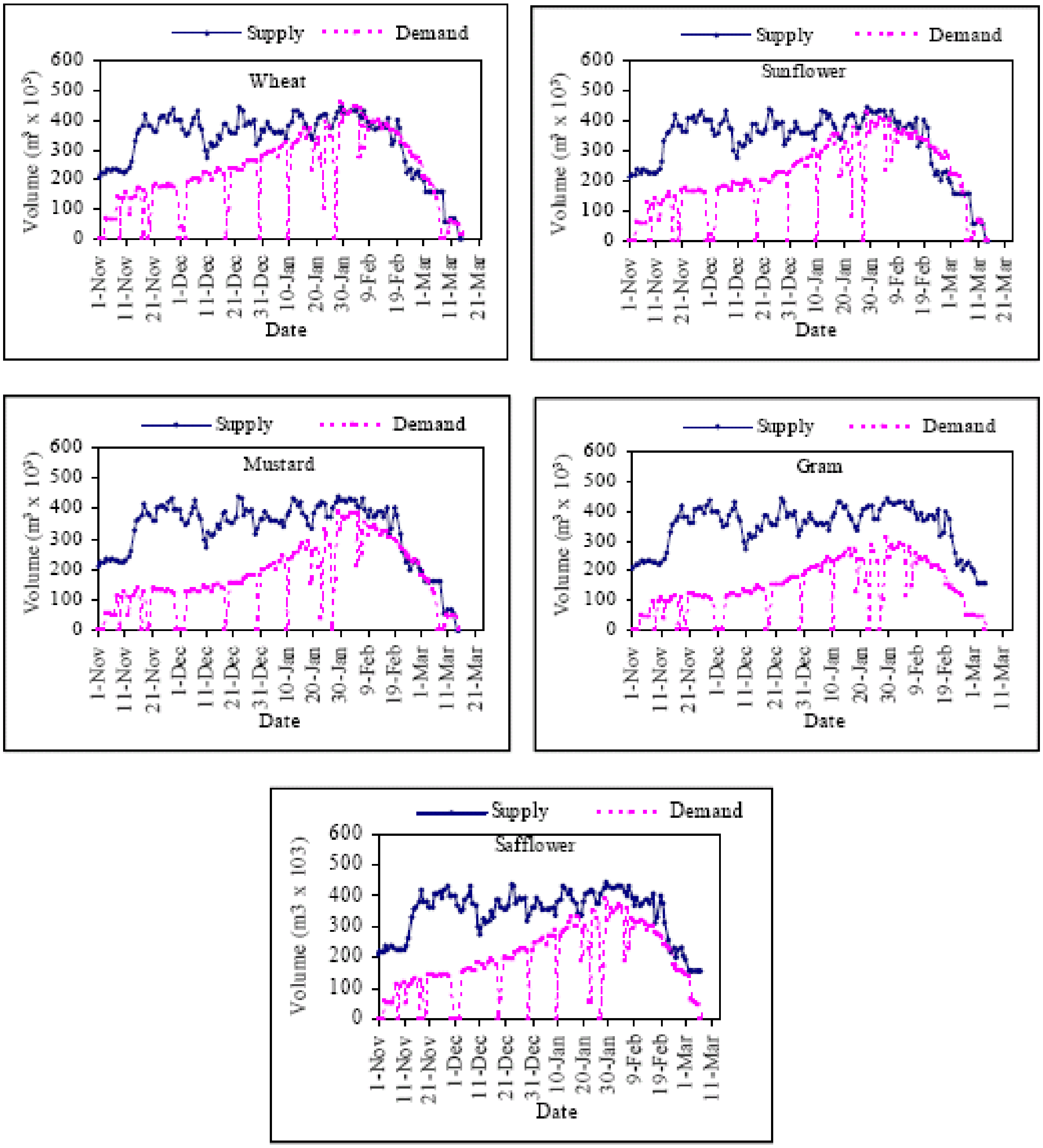

Fig. 7: Water supply-demand scenario for alternative *rabi* cropping pattern

demand of PA for several days, however, the total seasonal canal supply was almost matching with the demand. Therefore, using the same seasonal quantity of canal water supply with the changing flow patterns, an additional area of 1750 ha can be brought under summer rice cultivation. Among the *rabi* crops (wheat, sunflower, mustard, gram and safflower), covering 100% of CCA, wheat, which is relatively highest water requiring crop, can save 43% of average seasonal canal supply (44.249 Mm^3). The saved water can be used for tail-end commands.

REFERENCES

The financial support from the Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India, for carrying out the research is duly acknowledged.

REFERENCES

1. Allen, R.G., Jensen, M.E., Wright, J.L. and R.D. Burman (1989). Operational estimates of reference evapotranspiration. Agronomy Journal, 81(4): 650-662.
2. Allen, R.G., Smith, M., Perrier, A. and L.S. Pereira (1993). Updated reference evapotranspiration definition and calculation procedures. Draft manuscript for presentation at The Hague, ICID Bulletin.
3. Annual Progress Report (2000). Indian Council of Agricultural Research, All India Coordinated Research Project on Water Management, Indira Gandhi Krishi Vishwavidyalaya, College of Agriculture and Research Station, Bilaspur, Chhattisgarh, India.
4. Azhar, A.H., Murty, V.V.N. and H.N. Phie (1992). Modelling irrigation scheduling for lowland rice with stochastic rainfall. Journal of Irrigation and Drainage Division, ASCE, 118(1): 36-55.
5. Biswas, A.K. (1994). Considerations for sustainable irrigation development in Asia. International Journal of Water Resources Development, 10(4): 457-474.
6. Bolton, F.R., and H.G. Zandstra (1981). A soil moisture-based yield model of wet land rainfed rice. Paper No. 62, IRRI Publication, Los Banos, Philippines.
7. Chambers, R. (1998). Managing canal irrigation: Practical analysis from South Asia. Cambridge University Press, Cambridge, UK.
8. Chitale, M.A. (1994). Irrigation for poverty alleviation. International Journal of Water Resources Development, 10 (4): 383-391.
9. Doorenbos, J. and W.O. Pruitt (1977). Guidelines for predicting of crop water requirements. Irrigation and Drainage Paper No. 24, Food and Agricultural Organization of the United Nations, Rome, Italy.
10. Doorenbos, J. and A.H. Kassam (1979). Yield response to water. Irrigation and Drainage Paper No. 33, Food and Agricultural Organization of the United Nations, Rome Italy.
11. GWREC (1997). Norms for estimating the recharge due to canal network. Report of Ground Water Recharge Estimation Committee (GWREC), The Ministry of Water Resources, Government of India.
12. Sanmugnathan, K. and P. Bolton (1988). Water management in third world irrigation scheme-lesson from the field. ODI Bulletin 11, Hydraulic Research, London, UK.
13. Seasonal Research Report (1997). Indira Gandhi Krishi Vishwavidyalaya, College of Agriculture and Research Station, Bilaspur, Chhattisgarh, India.
14. Singh, R., Refsgaard, J.C., Yde, L., Jorgensen, G. H. and M. Thorsen (1997). Hydraulic-hydrological simulations of canal-command for irrigation water management. Irrigation and Drainage System, 11(3): 185-213.
15. Smith, M. (1992). CROPWAT- A computers programme for irrigation planning and management. Irrigation and Drainage Paper 46, FAO Land and Water Development Division, Food and Agricultural Organization of United Nations, Rome, Italy.
16. United Nation (2005). World Population Prospectus. Released on February, 24 at New York, USA.

Volume 17, Contents and Author Index, 2008

International Agricultural Engineering Journal

Published by

THE ASIAN ASSOCIATION FOR AGRICULTURAL ENGINEERING

CONTENTS

NUMBER 1 - 4

Research Papers:

AUTHOR INDEX

International Agricultural Engineering Journal

Guidelines for Authors

The International Agricultural Engineering Journal contains original papers only and submission of a manuscript will be taken to imply that the material is original and that no similar paper has been or is being submitted elsewhere. Papers are invited from all disciplines of agricultural engineering.

Copy: Manuscripts must be typewritten in English on A4 size paper (210 mm x 297 mm) on one side of the paper only, in double-spacing with liberal margins. The copies supplied must be complete with all figures, diagrams, drawings, photographs, tables, etc. Original for figures are essential on submission. An original and two copies should be provided. Generally, the length of the manuscript should not exceed 6000 words or about 12 printed pages inclusive of figures and tables.

Headings: The title of the paper should be as short as possible. All principal words should have capital initials. All section headings, table headings and figure captions should have an initial capital letter for the first word of each expression only, while all other words, with the exception of proper names, should be in lower case letters throughout. There should be no stop at the end of any title, footnote, heading, caption, etc., unless the last word is an abbreviation of which the stop is part. To show the hierarchical order of section headings, these should be numbered on the decimal system, e.g. 1, 1.1, 1.1.1 etc. Units in the table headings, legends to illustrations, etc., should follow the expression after a comma, not in parentheses, e.g. Max. output, kW.

Abstract: Each paper should have an abstract, not exceeding 200 words, between the title and the beginning of the paper.

Units, Symbols and Abbreviations: Systeme Internationale (SI) units must be used.

Illustrations: Illustrations, whether line drawings, graphs or photographs, are given a figure number (e.g. Fig. 1) in the same sequence and in ascending numerical order as reference is first made to them in the text. A separate list of figure captions should be supplied. Line drawings should preferably be in Indian ink on tracing paper, Bristol board or faintly lined graph paper. The captions, rather than the illustrations, should contain any explanation or keys, unless already given in the text. Figures should be complete with all legends and captions. As far as possible photos should be avoided. Wherever necessary, supply a black and white photograph on glossy paper.

In general, it is not permissible to give the same information in the form of a photograph and a drawing or in both graphic and tabular form. In each case, the most appropriate presentation should be selected.

Tables: Tables are numbered by Arabic numerals, e.g. Table 2, in ascending numerical order as reference is first made to them in the text. Tabulated data should not duplicate those shown graphically. The most appropriate presentation should be chosen.

Conclusions: Papers should have a final section headed "Conclusions", which succinctly summarizes important conclusions emerging from the work.

References: The references should be made by means of author's names and year in the text. The artifice "Leading author et al." may be used for multiple authorship papers if desired. At the end of paper, there should be a section headed "References" in which the full references should be quoted in alphabetical order including the names of all the authors, year, the title in the original language (and translation, where available), publication, volume, issue number (in parentheses) and page numbers, in that order.

Proprietary Products: In general, it is not desirable to give the names of products, instruments and equipment, model designations, or the names of their manufacturers; exceptions may be allowed, where detailed descriptions can be avoided by indicating the make, etc., or where considerations of accuracy and precision make it desirable that the particular product should be known. Mention of any proprietary product in this way implies no endorsement by this journal.

Refereeing: All papers will be refereed by at least two referees. The Editors collate the referees' reports and add their own comments. Final decisions on papers are made by the Editors.

Proofs: Authors will receive proofs for checking. Proofs will be sent to one author only. These proofs, clearly marked with the corrections, should be returned to the Editor with minimum delay.

Reprints: A total of 20 reprints will be supplied free of charge. Additional reprints can be ordered at current printing prices.

Page charges: To cover the printing and electronic submission process, there is a page charge of US$ 25 per printed page. Upon paper acceptance, the author should pay the charge.
Please make payment either by credit card or by bank draft/cheque in favor of "*ASIAN INST. OF TECH. (AAAE)*" and mail to:

AAAE Secretariat
c/o Agricultural Systems and Engineering
Asian Institute of Technology
P. O. Box 4, Klong Luang, Pathumthani 12120, Thailand
Tel: (66-2) 524-5479, 5450, 5488
Fax: (66-2) 524-6200, Telex: 84276TH

Submission: The original manuscript and two copies should be submitted to the Editor, Inter-national Agricultural Engineering Journal, c/o Agricultural Engineering Department, 218B Davidson Hall, Iowa State University, Ames IA 50011, U.S.A. First submission in electronic form is also encouraged (e-mail: aaae@ait.ac.th).

<u>MEMBERSHIP APPLICATION FORM</u>

Affix Photo here

ASIAN ASSOCIATION FOR AGRICULTURAL ENGINEERING (AAAE)

I wish to become a member of the AAAE
Membership Categories: (Mark the appropriate box)

☐ LIFE MEMBER	As per the age of a member (minimum US$ 400)
☐ REGULAR MEMBER	US$ 25 within Asia & US$ 35 outside Asia per calendar year*
☐ CORPORATE MEMBER	US$ 100 minimum annually (for industries only)

<u>PERSONAL DETAILS</u>

NAME (Prof./Dr./Mr./Ms.)..

DATE OF BIRTH : ....

TITLE/POSITION : ....

ORGANIZATION : ....

Mailing Address : ....

....

Phone: .... Email: ....

Fax:...

QUALIFICATIONS ATTAINED:

....

Number of years of professional experience: ....

....

Special field(s) of interest:..

Affiliation with other society or association: ....

....

Please make payment either by credit card or by bank draft/cheque in favor of "*ASIAN INST. OF TECH. (AAAE)*" and mail to:

AAAE Secretariat
c/o Agricultural Systems and Engineering
Asian Institute of Technology
P. O. Box 4, Klong Luang, Pathumthani 12120, Thailand
Tel: (66-2) 524-5479, 5450, 5488, Fax: (66-2) 524-6200, Telex: 84276TH

<u>For Office Use Only</u>... Date received...

Secretariat Acknowledged .... Verification of National Affiliation ....

Membership Grade Approved.. Membership Number ....

Membership Plaque/Certificate/Card issued ....

* Inclusive of US$ 10 for air mailing of journal and other materials

JOURNAL SUBSCRIPTION FORM

ASIAN ASSOCIATION FOR AGRICULTURAL ENGINEERING (AAAE)

Subscription form for the INTERNATIONAL AGRICULTURAL ENGINEERING JOURNAL published by AAAE.

Subscription rates are as follows:

☐ OUTSIDE ASIA	US$ 150* per annum (four issues)
☐ ASIA	US$ 135* per annum (four issues)
	* Including postage

Please make payment either by credit card or by bank draft/cheque in favor of "ASIAN INST. OF TECH. (AAAE)" and mail to:

AAAE SECRETARIAT
c/o Agricultural Systems and Engineering
Asian Institute of Technology
P. O. Box 4, Klong Luang, Pathumthani 12120, Thailand
Tel: (66-2) 524 5479/5450 Fax: (66-2) 524 6200

SUBSCRIBER DETAILS

NAME:..

TITLE/POSITION: ....

ORGANIZATION: ....

Address: ....

....

....

Phone:..

Telex:.. Fax:..

We wish to subscribe for the International Agricultural Engineering Journal for next …………… year(s). We have made arrangements for the subscription fee, a sum of ……….. (USD), by Credit card or Bank cheque/Bank draft/Other.

Office Use Only

Date received:...

Secretariat Acknowledged: ....

Verification of Location (Asia/Outside Asia): ....

Subscriber Registration Number: ....

Asian Association for Agricultural Engineering (AAAE)

The Association was established on December 5, 1990 with the objectives, (i) To strengthen the profession of Agricultural Engineering by promoting information exchange, improving communications, minimizing duplication of activities, and optimizing use of resources. (ii) To publish an international peer-reviewed journal, supervised by an editorial board. (iii) To formulate, establish, and promote voluntary academic, professional and technical standards of relevance to the profession of Agricultural Engineering in Asia. (iv) To support, at the international level, the activities of national Agricultural Engineering societies or related associations and to maintain liaison among them. (v) To coordinate and assist in organizing timely international meetings in cooperation with national societies/associations within the region.

Membership Categories: (i) Life Member: Based on the age of the member (Minimum US$ 400); (ii) Regular Member: US$ 25 within Asia and US$ 35 outside Asia per calendar year; (iii) Corporate Member (mainly for industries, institutions or organizations): US$ 100 minimum per calendar year. Payment should be made either by credit card or by bank draft /check in favor of the "Asian Inst. of Tech. (AAAE)" and is to be mailed to the secretariat.

Association Officials:

- Prof. Nobutaka Ito, President, Japan
- Prof. Chen Zhi, Vice President, China
- Dr. Agung Hendriadi, Vice President, Indonesia
- Dr. Tanya Niyamapa, Vice President, Thailand
- Dr. Linus U. Opara, Vice President, Oman
- Prof. Jin Tong, Vice President, China
- Mr. Yoshisuke Kishida, Director, Public Relations, Japan
- Dr. Peeyush Soni, Secretary-General, Thailand
- Dr. Hemantha P.W. Jayasuriya, Treasurer, Thailand

Country Representatives on AAAE Board:

- Prof. B. R. Mulik – India
- Dr. Ida Bagus Suryaningrat – Indonesia
- Prof. Mikio Umeda – Japan
- Mr. Felipe Butlig – Philippines
- Prof. Lu-Quan Ren – P. R. China
- Dr. Somposh Sudajan – Thailand

Service to Members:

The following valuable services will be provided by the AAAE to its membership. The Association will publish an "International Agricultural Engineering Journal" regularly. Announce a calendar of events, report on events, people and professional activities, and noteworthy product releases from agro-industry through AAAE Newsletter, published four times a year.

For further information write to: The AAAE Secretariat, c/o Agricultural Systems and Engineering, Asian Institute of Technology, P. O. Box 4, Klong Luang, Pathumthani 12120, Thailand. Tel: (66-2) 524 5450, 524 5479; Fax: (66-2) 524 6200, 516 2126. E-mail: aaae@ait.ac.th

Abstracted in: ***Agricultural Engineering Abstract by CAB International, EI Compendex Plus, Pollution Abstracts, Applied Mechanics Review, Engineering Information Inc., Elsevier Bibliographic Databases.***

Published by

The Asian Association for Agricultural Engineering (AAAE)