PERFORMANCE ASSESSMENT OF IRRIGATION SYSTEM IN RICE-WHEAT CROPPING ZONE USING MODERN TECHNIQUES

EVALUATION DE LA PERFORMANCE DU SYSTEME D'IRRIGATION UTILISANT LES TECHNIQUES MODERNES DANS LA ZONE AGRICOLE RIZ-BLE

Muhammad Arshad[1] and Rai Niaz Ahmad[2]

ABSTRACT

Performance assessment of irrigation systems is regarded as the pivotal element for improving irrigation management. This paper presents the impacts of irrigation system improvement on the crop water productivity in the rice-wheat cropping zone of Khurrianwala distributary command area, Rechna Doab, Punjab, Pakistan. The performance indicators, such as relative water supply (RWS), water use efficiency (WUE) and conveyance efficiency were calculated. The results indicated that after the improvement of irrigation system, the increase in rice and wheat area was 34.71 and 13.22 %, respectively. The WUE ranged from 13.07 to 18.37 kgha^{-1}mm^{-1} for wheat and 3.49 to 5.71 kgha^{-1}mm^{-1} for rice crop for flat sowing system. Similarly, in raised bed system WUE ranged from 27.20 to 33.54 kgha^{-1}mm^{-1} for wheat and from 6.41 to 10.05 kgha^{-1}mm^{-1} for rice crop. Almost 51.3% water saving was observed in bed system as compared to flat system. It was concluded that the water applied was not equitably distributed, the head getting more than the tail end. It was also found that a greater application of water did not result in higher crop vigor. Less water applied to the bed was more affective as its WUE value was higher than flat system. Greater yield was recorded in bed system as compared to flat system. It is recommended that GIS capability is the most appropriate source to provide the better understanding of soil variability. Thus, the integration of RS data and GIS tools to regularly compute performance indices could provide irrigation managers with the means for efficiently managing the irrigation system .

Key words: *Rice-wheat cropping system, Irrigation system performance, Khurrianwal distributary, Wheat and rice yield.*

1 Associate Professor, Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan. E-mail: arsmrz@yahoo.com, Tel +92-419200194.

2 Professor, Dean, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad, Pakistan. E-mail: niazrai@yahoo.com, Tel +92-419200194

RESUME

L'évaluation de la performance des systèmes d'irrigation est constatée comme un élément crucial dans l'amélioration de la gestion d'irrigation. Cet article présente les impacts de l'amélioration du système d'irrigation sur la productivité de l'eau dans la zone agricole riz-blé du périmètre irriguée secondaire de Khurrianwala à Rechna Doab au Pendjab (Pakistan). Les indicateurs de la performance tels que l'approvisionnement en eau relatif (RWS), l'efficience d'utilisation de l'eau (EUE) et l'efficience de transport ont été calculés. Les résultats ont indiqué qu'après l'amélioration du système d'irrigation, l'augmentation de la superficie du riz et du blé était de 34,71 et 13,22% respectivement. Le WUE variait de 13,07 à 18,37 kgha^{-1}mm^{-1} pour le blé et 3,49 à 5,71 kgha^{-1}mm^{-1} pour le riz pour le système de semis à plat. De même, dans le système de bande élevée, le WUE variait de 27,20 à 33,54 kgha^{-1}mm^{-1} pour le blé et de 6,41 à 10,05 kgha^{-1}mm^{-1} pour le riz. Environ 51,3% d'économie d'eau a été constatée dans le système de bande élevée par rapport au système de semis à plat.

Il a été conclu que l'eau appliquée n'était pas distribuée de manière équitable. On a également constaté qu'une plus grande application de l'eau n'a pas abouti à l'augmentation des cultures agricoles. L'application de moins d'eau à la bande était plus efficace car sa valeur WUE était plus élevée que celle du système à plat. Un rendement élevé a été enregistré dans le système de bande par rapport au système à plat. Il est recommandé que la capacité du SIG soit la source plus appropriée à fournir une meilleure compréhension de la variabilité du sol. Ainsi, l'intégration des données RS et des outils SIG pour calculer régulièrement les indices de la performance pourrait fournir aux gestionnaires de l'irrigation des moyens de gérer efficacement le système d'irrigation.

Mots clés: *Système agricole riz-blé, performance du système d'irrigation, Khurrianwal secondaire, rendement du blé-riz.*

1. INTRODUCTION

The rice-wheat cropping system has been practiced by farmers in Asia for more than 1000 years. It has since expanded and is currently estimated at 23.5 million hectares (Mha). It is one of the most essential cropping pattern for food self security in the region. It covers 13.5 Mha in South Asia: India, 10.0 Mha; Pakistan, 2.2 Mha; Bangladesh, 0.8 Mha and Nepal, 0.5 Mha. This system is found in the fertile, hot semi-arid to hot sub-humid regions of the Indus and Indo-Gangetic Plains (IGP) of Bangladesh, India, Nepal and Pakistan (Hobbs and Gupta, 2001). More than 150 million people support themselves by growing rice in rotation with wheat in 13.5 Mha of land in the IGPs of these three countries. Indeed, the livelihoods of millions of farmers and workers are dependent on this system (RWC-CIMMYT, 2003). Rice is generally grown in the wet summer (May/June to October/November) and wheat in the dry winter (November/ December to February/March). The rice-wheat growing areas in Pakistan are primarily situated in central Punjab (main districts include Gujranwala, Sheikhupura, Narowal and Sialkot) followed by Sindh, over an estimated area of 1.6 Mha. In the system, rice is conventionally grown by transplanting 25-35 days old seedlings in well-puddled and continuously flooded field (Mann and Ashraf, 2001). Wheat crop is also badly affected by flood irrigation due to poor drainage of paddy soils. Consequently, the productivity of the system remains far below the potential yield levels of modern cultivars.

The rice-wheat cropping system has higher water demand, as rice needs more water compared to other crops (Jehangir et al., 2004). Irrigation is generally used to stabilize the productivity of this system using canal and tubewell water. Competition for water will be a foremost challenge for agriculture and it is necessary that this scarce resource is used efficiently. New technologies for water saving, e.g., alternate drying and wetting, raised beds and direct seeding are being tested for rice cultivation in South Asia (Bhuiyan and Tuong, 1995; Guerra et al., 1998; Vander et al., 2001). Similarly, laser land leveling and zero till wheat sowing are seen as interventions to improve efficiency of water resources for wheat (Hobbs, 2001; Ahmad and Iram, 2009).

Performance assessment is regarded as the pivotal element for improving irrigation management. Irrigation performance indicators range from water distribution to agricultural, economic, social, and environmental aspects (Bos et al., 1994). Performance is assessed for a variety of reasons i.e. to improve system operations, to appraise progress towards strategic goals, as an integral part of performance-oriented management, to assess the general health of a system, to evaluate impacts of interventions, to diagnose constraints, to better understand the determinants of performance, and to compare the performance of a system with others or with the same system over time. Many authors have proposed indicators to measure irrigation system performance (Molden and Gates, 1990; Rao, 1993; Bos et al., 1994; Beyribey and Çakmak, 1996; and Molden et al., 1998). Much of the work in irrigation performance assessment has been focused on the internal processes of irrigation systems. Many internal process indicators relate performance to management targets such as timing, duration, and flow rate of water, area irrigated, and cropping patterns. A major purpose of this type of assessment is to assist irrigation system managers in improving water delivery service to the users. Other performance indicators are external and are used to relate outputs from a system to the inputs into that system. These indicators help policy makers and managers making long-term and strategic decisions, and researchers searching for relative differences between irrigation systems (Molden et al., 1998).

The use of modern technologies like RS and GIS for the performance evaluation of irrigation systems has been slow in most developing countries and especially in rice-wheat systems despite the advantages they offer. GIS is a special type of information system in which the database consists of observations on spatially distributed features and procedures to collect, store, retrieve, analyze, and display such geographic data. The application of RS and GIS technology in agriculture sector and water resource management includes crop classification, estimation of crop yield, determination of soil conditions, resource management, surface water areas, soil moisture and ET, delineation of irrigation fields and fresh water reservoirs (lakes). Therefore, there is a pressing need to evaluate the performance of irrigation system using these modern technologies.

2. MATERIALS AND METHODS

Description of Study Area

The research was conducted in the rice-wheat area of Faisalabad, at Khurrianwal distributary. The area lies between 30° 45’ to 31° 45’ N latitude and 72° 43’ to 73° 32’ E longitude (Fig. 1).

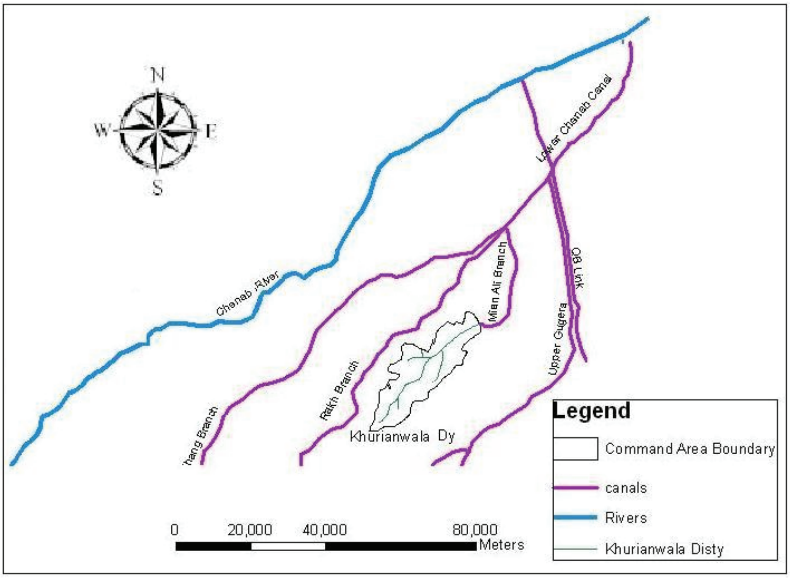

Fig. 1. Command area of Khurrianawala distributary

The texture of Khurrianwala distributary command area soil is loam to clay loam, which is good for growing all types of crops, vegetables and fodder. The soil pH ranges from 7.5 to 8.2. The soil is good in organic matter content. In some parts of the area salinity problem is observed. The climate of the region is semi-arid subtropical continental. Mean annual rainfall ranges from 200 to 430 mm, two third of which is received in the form of high intensity shower during monsoon. The mean annual, summer and winter temperatures are 23.9°C, 32.3°C and 13.3°C, respectively. The physiographic position of the area is level plains with well drained structures. The elevation of the study area is 187 m above sea level.

Main crops of the area are wheat, rice, sugarcane, maize, fodder etc. Surface irrigation is sufficient for 70% to 75% cropping intensity. A large number of tubewells have been installed in the area, to have additional water supplies that have increased the cropping intensity to about 130-150%, despite the high cost of running these tubewells. About 2% of land is lying barren because of shortage of irrigation water and/or salinity/sodicity. A part of the barren land is under reclamation effort. Good irrigated land covers 17020 ha. Yields of most of the crops in the area are moderate. Moderate to good yields of most common crops can be obtained with modern management.

Watercourse Improvement

The partial lining was done from main channels to the field channels to enhance smooth water flow as a new approach rather than full lining of the watercourse. Brick lining was selected because it is more durable and economical as compared to slab lining. To calculate the water losses of the each selected watercourse, the total length of watercourse was divided into three portions i.e. head, middle and tail. Discharge measurements were made within each portion by further selection of three points in each section by cut throat flume. Overall conveyance efficiency at the downstream of watercourse at Khurrianwala site was 67%.

Discharge and conveyance efficiency at head, middle and tail position was also measured in the watercourse and was compared with conveyance losses.

Mapping the Study Area through GPS

A detailed survey of the study area was conducted to mark the coordinates of the fields and the corresponding water course through GPS in degree decimal system. The water course surveyed points were marked at three different points i.e. head middle and tail. These coordinates were converted into Universal Transverse Mercator (UTM) system.

Satellite Images

Available satellite images of LandSAT ETM+ for the year 2001 and 2006 were used for the classification of soil, cropping pattern and performance evaluation of the Khurrianwala Disty.

Meteorological Data

Monthly average temperatures, daytime wind speed, sunshine hours and minimum relative humidity were collected from the Meteorological Department of University of Agriculture, Faisalabad, Pakistan. Weather data were used to compute reference crop evapotranspiration using the FAO-24 modified Blaney–Criddle method (Allen and Pruitt, 1986). Watercourse level canal discharge values were also collected.

Cropped area was estimated using a supervised classification approach. Crop condition assessment was done by computing the normalized difference vegetation index (NDVI) values of crop pixels by using the equation 1.

$$NDVI = [(NIR - RED) / (NIR + RED)] \quad \ldots (1)$$

Where, RED and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually hence, they take on values between 0.0 and 1.0. By design, the NDVI thus varies between -1.0 and +1.0.

Performance Indices

The irrigation system was evaluated using three performance indices under different categories. The indices for adequacy and equity describe the water delivery system, while the last index, agricultural productivity, describes the irrigated agriculture system.

Adequacy

The adequacy indicator shows to what extent is the quantity of water provided sufficient for the crop growth needs (Abernethy, 1989). The relative water supply (RWS), defined by Levin (1982), describes the adequacy of water supply. Equation 2 shows the mathematical equation for calculating RWS.

RWS = [(IR = RN) / (IRG)] … (2)

Where, IR is the irrigation water supply, RN the rainfall and IRG the gross irrigation requirement. The major rainfall season, for this region, is June–October, with little rainfall in November–February (*Rabi*, or the winter cultivation season).

The gross irrigation requirement (IRG) was computed as the net irrigation requirement (IRN) divided by irrigation efficiency. Net irrigation requirement (IRN) was computed using Equation 3.

IRN = (ETc – Pe) … (3)

Where, ETc is the crop evapotranspiration and Pe is the effective rainfall (WTC, 1983).

For the present study, the information about the amount of irrigation water supply was collected from watercourse of 53-RB. The crop evapotranspiration (ET) value was computed using the crop coefficients values.

Agricultural Productivity

Agricultural production performance indicators include cropping intensity, ratio of area planted and area harvested, annual yield, productivity of land and water (Rao, 1993). In the present study, an attempt has been made to estimate the productivity of water. Productivity of water or water use efficiency (WUE) is expressed in Equation 4.

WUE = (CY) / (WS) … (4)

Where, CY is the crop yield and WS total water supplied.

Equity

Levin and Coward Jr. (1989) have suggested that a system that is considered fair by most farmers is more efficient than the one that the Water Authority has designed on the basis of productivity and efficiency but which is considered unfair by the farmers. Any irrigation distribution system, which practices equity in water allocation and distribution, will have uniformity in the cropped area along the distribution system. However, if there is a large and consistent difference in the cropped area and between the head and the tail ends of the distributaries, the distribution system can not be considered to be practicing equity. To assess equity, command area of watercourse no. 53-RB of the distributary was studied. The cultivated cropped area (CCA) of the watercourse is 143.26 ha. The command area of the watercourse was divided (from head to tail) into three regions and for each region; cropped area (as % of geographical area) was computed using interpolation technique in ArcMap (GIS).

Conveyance Efficiency

It is calculated for the watercourse no. 12022/R before lining and after lining by using Equation 5.

Conveyance Efficiency (%) = [(Downstream Discharge) / (Upstream Discharge)](100) … (5)

3. RESULTS AND DISCUSSION

Irrigation Water Saving in Wheat Crop

Water saving was measured for each irrigation (1st, 2nd, 3rd and 4th) in terms of time saving for irrigating one acre (0.4047 ha) of wheat with the same stream size both for bed and conventional planting at various farm fields of site (Figure 2). The timings were observed in determining the percentage of water savings on bed-furrow and conventional planting systems. The water saving per acre varied from 46.51 to 56.5% of time. The disparity in water saving is due to various soil types, leveled and unleveled fields and farmers' approach towards appropriate water application according to their crop water requirement. The average range of irrigation water saving at site was 51.37%, which provides evidence of 50% water saving in bed planting.

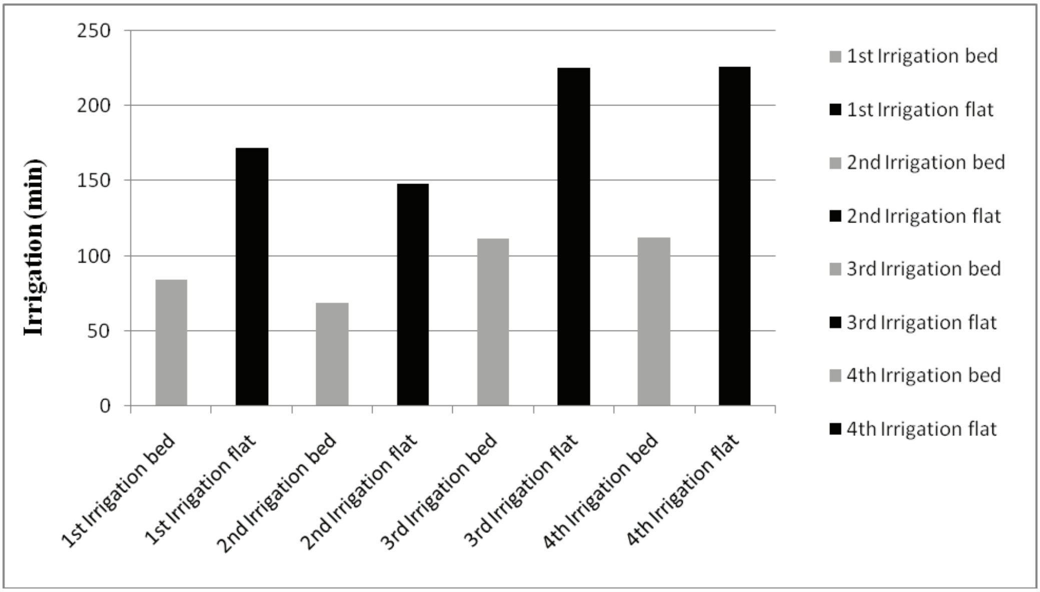

Fig. 2. Average irrigation time in bed and flat (1st, 2nd, 3rd, 4th)

Irrigation Water Saving in Rice Crop

The range of water saving is 28.91 to 45% which happens due to over irrigation even in bed planting by same farmers. Irrigation timing in rice crop at different farms is shown in Figure 3.

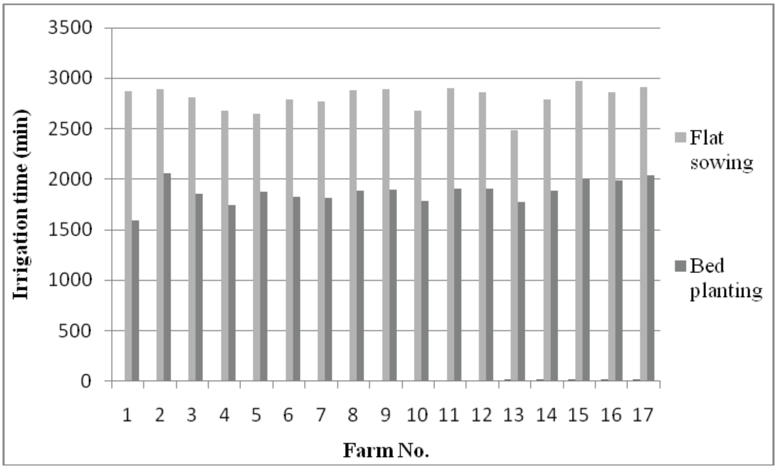

Fig. 3. Irrigation timing in rice crop at different farms

Wheat and Rice Yield

Highest percentage (29.4 %) of increase in yield of rice on raised bed was observed at farm no. 2 while comparing it with the traditional sowing technique. Minimum percent (9.09 %) increase of rice yield on raised bed was obtained at farm no. 8. Results showed that on an average 22.27 % increase in yield was obtained from bed planted rice (Figure 4) in comparison with traditionally flooded fields of rice.

Increased wheat yields (Figure 5) under bed planting are encouraging for adoption of this newly introduced technology. In fact, increased yield under bed planting is more than blessing since bed planting is primarily being adopted to focus on water savings (Figures 6 & 7).

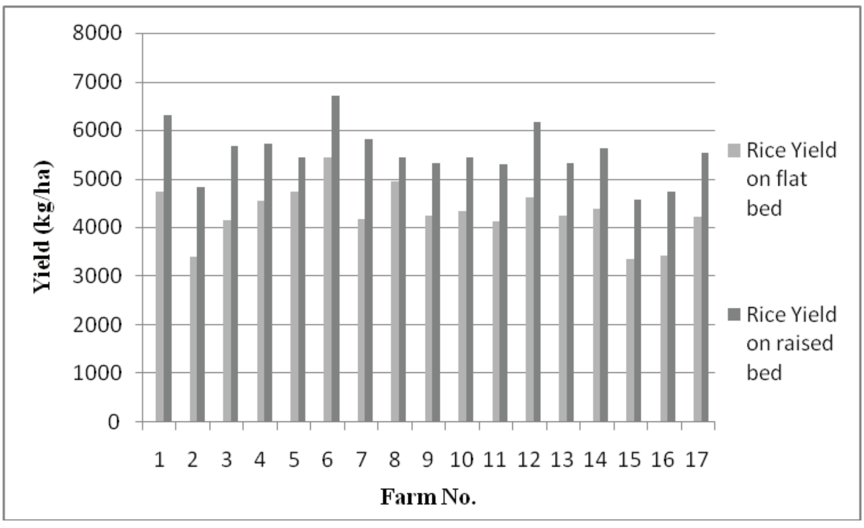

Fig. 4. Rice yield at different farms

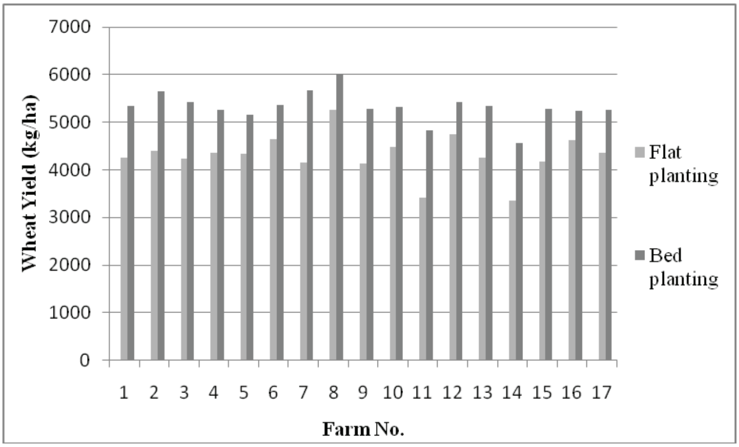

Fig. 5. Wheat Yield at different Farms

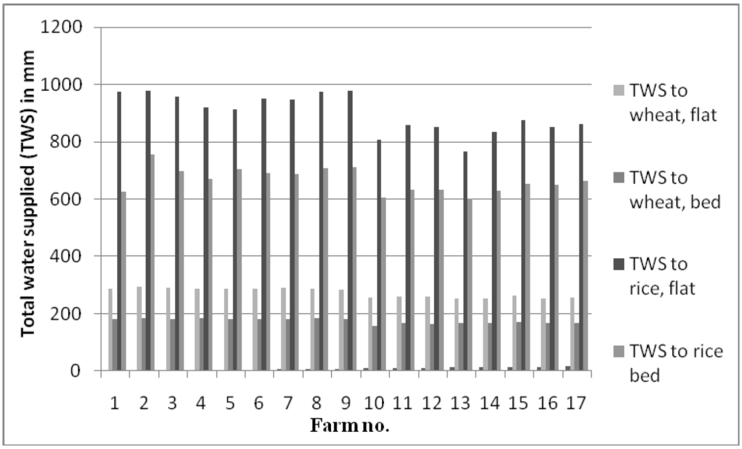

Fig. 6. Comparison of total water applied in wheat and rice crop on flat and bed system

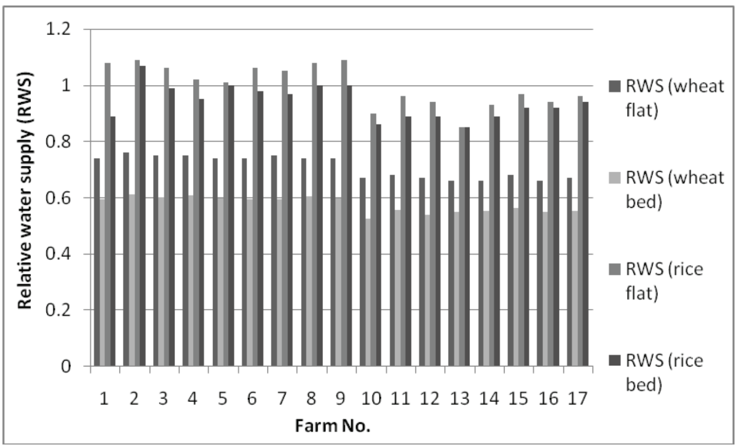

Fig. 7. Comparison of RWS in wheat and rice crop on flat and bed system

Water Use Efficiency

The agricultural productivity or the efficiency of water to produce crop growth ranged from 13.07 to 18.37 kg/ha/mm in wheat flat while in wheat bed it ranges from 27.20 to 33.54 kg/ha/mm (Figure 8). In rice crop it ranges from 3.49 to 5.71 kg/ha/mm in flat system while in bed system it ranges from 6.41 to 10.05 kg/ha/mm (Figure 9).

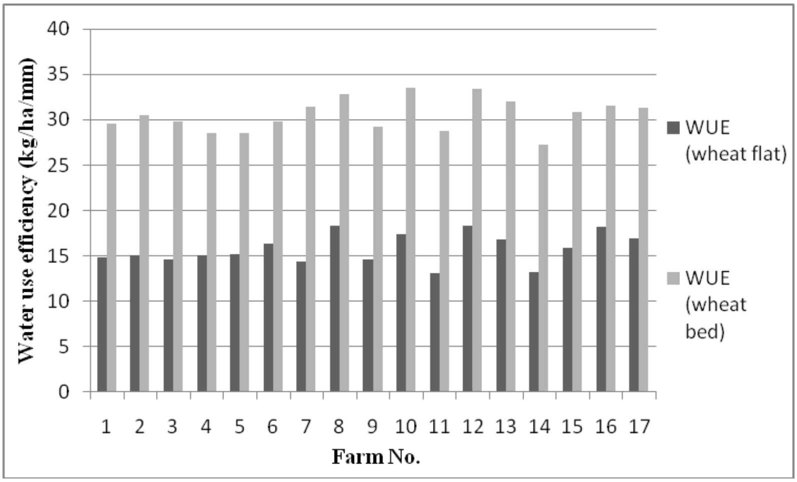

Fig. 8. Water use efficiency of wheat on flat and bed system

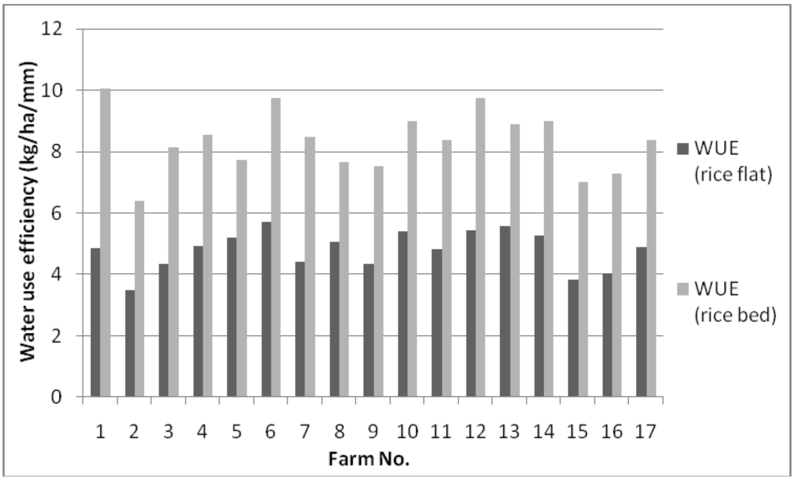

Fig. 9. Water use efficiency of rice on flat and bed system Equity/Head-to-Tail Difference

Difference in cropped area and crop vigor between head and tail zones of the watercourse was studied. The command area was divided into three nearly-equal zones from head to tail. It was found that the cropped area decreased from 58% to 41% from head to tail. It was also found that the crop vigor, as expressed by the average NDVI values, was lower in zones towards the tail end of both distributaries.

Conveyance Efficiency

The calculated conveyance efficiency of watercourse no.12022/R before lining came out 60% while, after lining it was 85%. Lining has increased 25% conveyance efficiency (Figure 10) and if we lined all other watercourses not only conveyance efficiency will be improved but will also help in equal water distribution among farmers and will increase the command area of that watercourse.

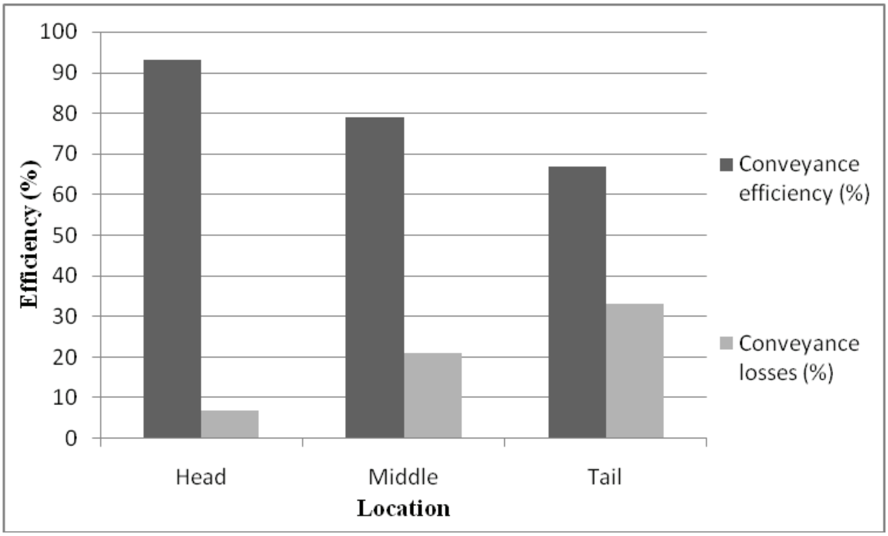

Fig. 10. Comparison of conveyance efficiency and losses

4. CONCLUSIONS

The overall impact of the Khurrianwala distributary has been two to three-fold increases in the gross cropped area and average crop yield and the generation of a high net additional income for the region. However, in the last 40 years, there has been an increase in the problems of water logging and salinity (Desai et al., 1994). This has been due to non-uniform distribution system of irrigation water. The present performance analysis showed that performance indicators could identify the problem, an intensively managed and studied irrigation system. The water applied is also not equitably distributed, the head getting more than the tail end. It has also been found that a greater application of water does not result in higher crop vigor. Less water applied to bed is more affective as its WUE value is higher than flat system where more water is applied in both seasons. Similarly, RWS values show that maximum water deficit while minimum area is getting adequate water supply. Greater yield is recorded in bed system as plant per sq. meter is more in bed system in comparison of flat system Inverse distance weighted (IDW) Interpolation was found suitable for mapping of soil and water characteristics. GIS capability is the most appropriate source to provide the better understanding of soil variability. Thus, the integration of RS data and GIS tools to regularly compute performance indices could provide irrigation managers with the means for managing efficiently the irrigation system.

REFERENCES

Abernethy, C.L. 1989. Indicators of the performance of irrigation distribution systems.

In: Proceedings of the Symposium on the Performance Evaluation of Irrigation Systems. International Irrigation Management Institute (IIMI), Colombo, 23 November 1989.

Allen, R.G. and W.O. Pruitt. 1986. Rational use of the FAO Blaney–Criddle formula.

J. Irr. Drain. Engg. Div.ASCE, 112: 139–155.

Bos, M. G., D. H. Murray-Rust, D. J. Merry, H. G. Johnson and W. B. Snellen. 1994.

Methodologies for assessing performance of irrigation and drainage management. Irr. Drain. Systems, 7: 231-261.

Hobbs, P.R. and R.K. Gupta. 2001. Rice-Wheat Cropping Systems in the Indo-

Gangetic Plains: Issues of Water Productivity in Relation to New Resource Conserving Technologies. Paper presented at a Water productivity workshop held at IWMI. November 15-16th, 2001. Colombo, Sri Lanka.

Jehangir, W. A., H. Turral and I. Masih. 2004. New directions for a diverse planet:

Proceedings of the 4th International Crop Science Congress

Brisbane, Australia. Sep. 26 – Oct. 1, 2004. (Available online at http://www.cropscience.org.au.htm)

Levin, G. 1982. Relative water supply: An explanatory variable for irrigation systems.

Technical report no. 6, Cornell University, Ithaca, New York, USA.

Levin, G. and E.W. Coward Jr. 1989. Equity considerations in the modernization of

irrigation systems. ODI-IIMI Irrigation Management Network paper 89/2b, International Irrigation Management Institute, Colombo, SriLanka.

Mann, R.A., W.A. Jehangir and I. Masih. 2004. Improving Crop and Water

Productivity of Rice-Wheat System in Punjab, Pakistan. New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress. 26 Sep – 1 Oct, 2004. Brisbane, Australia.

Molden, D. 1997. Accounting for Water Use and Productivity SWIM Paper 1.

International Irrigation Management Institute (IIMI), Colombo, Sri Lanka.

Rao,P.S. 1993. Review of Selected Literature on Indicators of Irrigation Performance,

International Irrigation Management Institute, Colombo, Sri Lanka. Pp: 75.