PERFORMANCE BASED LAND AND WATER ALLOCATION WITHIN IRRIGATION SCHEMES: 2. APPLICATION

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ABSTRACT

The Area and Water Allocation Model (AWAM) which uses simulation-optimization technique for optimum allocation of land and water resources to different crops cultivated in different allocation units of the irrigation scheme was modified to include both productivity and equity in the process of developing the allocation plans for optimum productivity and/or maximum equity. This paper illustrates the potential of this approach with the help of a case study on Nazare medium irrigation scheme in India. The allocation plans were developed for optimization of different performance parameters (productivity and equity) for different management strategies based on irrigation amount and irrigation interval and cropping distribution strategies of free and fixed cropping. The results indicated that the two performance objectives productivity and equity conflict with each other and in this case, equitable water distribution may be preferred over free water distribution at the cost of a small loss in productivity. Though these results relate to one case study, they show the value of the approach of incorporating productivity and equity in the allocation process with the help of the simulation-optimization model described in the companion paper.

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INTRODUCTION

For canal irrigation systems it is necessary to consider the heterogeneity in soils and climate, the complexity of the water distribution network and the limited water supply while preparing allocation plans for distribution of land and water resources to different crops up to tertiary or farm level, and the corresponding water delivery schedules (Gorantiwar and Smout, 2003 and Unal et al 2004). Further, it is also important to allocate water both efficiently and equitably (Chambers, 1988). In the past, several methodologies have been developed to prepare the allocation plans during the planning process. These are reviewed by Gorantiwar et al (2005).

Most of these studies focused only on the optimization of the productivity while developing the allocation plans. Though some of the studies addressed the issue of equity, its consideration was limited to allocating water to previously cultivated area or equitable water allocation was estimated outside the allocation process. However the local situations may need maximizing equity, while optimizing the productivity. Equity has multidimensional aspects (Abernethy 1989) and often conflicts with the other important performance measures (Gorantiwar 1995; Kalu et al. 1995; Onta et al. 1995 and Small and Rimal 1996). Therefore inclusion and analysis of equity in the allocation process needs emphasis on all dimensions of equity. Gorantiwar et al (2005) presented the procedure for including the performance measure such as productivity and equity in the allocation process. The procedure uses simulation-optimization model-AWAM (Gorantiwar 1995 and Smout and Gorantiwar 2005) for developing the allocation plans and incorporates the appropriate objective function and constraints for including performance measures of productivity and equity in allocation plans. This paper describes the utility of this procedure by developing the allocation plans for different strategies with a case study of one irrigation scheme in India.

THE APPLICATION OF MODEL

Irrigation Scheme

The "Nazare Medium Irrigation Scheme" in a semi-arid region of Maharashtra State in India was selected for the purpose of case study. The irrigation season of this scheme starts from the 15th October and ends on 14th October of next year. There are three distinct crop seasons within the irrigation season. These are Rabi (winter), summer and Kharif. As little rainfall is received in Rabi season, the crops grown in this season are supplied with irrigation water for their growth. In summer season no rainfall is received but it is characterized with high evapotranspiration. The irrigations are given to a limited area in the summer season. Most of the rainfall is received in Kharif (monsoon) season. Therefore crops grown in this season need one or two irrigations (protective irrigations) only. The irrigations during Kharif season are of little interest in this study as the reservoir fills during the Kharif season. Therefore for this scheme in this study, the irrigation season was considered to spread over Rabi (winter) and summer crop seasons. Normally the irrigation interval in Rabi season is 21 days and in summer season is 14 days.

The gross reservoir capacity and dead storage capacity of the reservoir are 22.31 and 5.68 Mm^3, respectively. One main canal originates from the headworks. The full supply discharge and length of the main canal are 1.53 m^3/s and 3.05 Km, respectively. One distributory canal emerges from the main canal, the length of which is 11.75 Km.

The carrying capacity of the distributory canal is 1.53 m^3/s. The cultural command area (CCA) of the irrigation scheme is 3539 ha. There are 28 direct outlets (4 on main canal and 24 on distributory canal) and four minors (all on distributory canal). There are 9 outlets on the minor. The details of the outlets on the minors could not be obtained. Therefore CCA of all 28 outlets and 4 minors were considered as allocation units, resulting in 32 AUs. The data related to allocation units interms of different efficiencies (application, distribution and conveyance), soil types etc were obtained from different sources (Stofkoper and Tilak, 1992 and IRD, 1992).

The climatological data was collected from the daily records of the Meteorological Observatory of the nearest agricultural university (Mahatma Phule Agricultural University, Rahuri). The same data series was used for the reservoir (for estimating the water evaporation) and command area (for estimating the reference crop evapotranspiration and bare soil evaporation). The climate over the entire command area was assumed as uniform. Thus there was only one 'Region' (using the terminology in Gorantiwar et al 2005). The command area is characterized with four different types of soils. In the present study two crop seasons formed the irrigation season and gram, sorghum, onion, wheat (Rabi crops), groundnut and sunflower (summer crops) were considered in the analysis.

Strategies

The procedure developed by Gorantiwar et al (2005) was applied to the case study described above for developing allocation plans for different management, performance and cropping distribution strategies. These strategies are described below.

Management strategies: The allocation plans at planning stage and the water delivery schedules were developed for the following two different management strategies.

Irrigation amount: The following three different alternative strategies were considered while developing the allocation plans. These are irrigation policies described by Gorantiwar et al (2005).

1. Full irrigation: The irrigations were applied to bring the root zone soil moisture to the field capacity.
2. Fixed depth irrigation: The fixed depth of irrigation, which was same for all irrigated fields in the scheme and over the irrigation season, was applied.
3. Optimized deficit irrigation: The irrigations were applied in different combinations of the depths between full irrigation and no irrigation.

Irrigation interval: The AWAM model operates on a uniform irrigation interval for all regions, crops and soils in a particular scheme. This interval can be varied over the planning period or irrigation season, but this is known or decided before developing the allocation plan for crop area and water. In fact the allocation plans are developed for the particular known set of irrigation intervals. The water delivery interval might be different to the irrigation interval in case of optimized deficit irrigation approach (due to skipping of irrigation) so that different regions, soils and crops may have different water delivery intervals, but only by addition of consecutive irrigation intervals. These water delivery intervals are the results of optimized deficit irrigation. The following sets of irrigation interval were chosen for this study.

1. 14 days (I-14)
2. 21 days (I-21)
3. 28 days (I-28)
4. 21 days in winter season and 14 days in summer season (I-21-14)

5. 28 days in winter season and 21 days in summer season (I-28-21)

6. 35 days in winter season and 28 days in summer season (I-35-28)

Performance strategies: The allocation plans were developed for the following three performance strategies. These strategies are based on the distribution of available water in the irrigation scheme to different allocation units.

1. Maximum productivity: The allocation plans were developed by distributing available water in the irrigation scheme to different allocation units for maximum net benefits from the irrigation scheme.
2. Maximum equity (seasonal): In this case allocation plans were developed for maximum equity over the entire irrigation season in the water distribution to different allocation units.
3. Maximum equity (per irrigation) (IEWD in figures): The irrigation-wise equity in distribution of water to different allocation units is often considered for example in the Warabandi system in Northern India and Pakistan (Malhotra, 1982). Hence in this case the allocation plans were developed for maximum equity per irrigation in the water distribution to different allocation units.

Cropping distribution strategies: The following two cropping distributions were considered.

1. Free cropping distribution: In this cropping distribution no restrictions were put on the allocation of area or water or output to be obtained from the different crops. The model is therefore free to select any crops depending on which crops produce maximum total net benefits from the irrigation scheme.

2. Fixed cropping distribution: Restricting the area under different crops according to a particular requirement is referred to as the fixed cropping distribution. Based on the previous practice in the irrigation scheme, the fixed cropping distribution of (gram-25%, sorghum-20%, onion-10% and wheat-15 % in Rabi and Sunflower –10 % and groundnut-20% in summer season) was assumed.

Development of Allocation Plans

The allocation plans were developed for different scenarios resulting from the combination of management, performance and cropping distribution strategies for each set of irrigation interval with the help of AWAM model described in the companion paper (Gorantiwar et al 2005). As the irrigation scheme is characterized with same climate and consists of four different soils and as the six different crops are proposed to be cultivated, there are 24 CSR units. There is only one irrigation strategy corresponding to each CSR unit for the irrigation policies of ‘full irrigation’ and ‘fixed depth irrigation’. However for deficit irrigation, several irrigation strategies were generated by varying the value of deficit ratio in the range of 0 (no irrigation) to 1 (full irrigation) at an interval of 0.2 (Phase:1 of AWAM as described in the companion paper). For example for wheat cultivated on Soil-2, 46,656 irrigation strategies were generated for the irrigation interval of 21 days. Each of these irrigation strategies specifies the magnitude of deficit to be provided for each irrigation. The irrigation programs were developed for each irrigation strategy using SWAB and CRYB sub models (Phase:2 of AWAM). Finally for the irrigation policy of optimized deficit irrigation, specified number irrigation programs (maximum 10 programs in this case) based on optimality and efficiency criteria were selected (Phase:3 of AWAM). The detail procedure for the selection of programs is described by Gorantiwar and Smout

(2003). Note that for other irrigation policies only one irrigation program was developed for each CSR unit. In this way irrigation programs were finalized for all CSR units for a specified set of irrigation interval.

These irrigation programs were then transferred for each crop-soil (CS) unit of each allocation unit (AU) by modifying the irrigation programs of the corresponding CSR unit developed in Phase:3, with consideration to distribution and conveyance efficiencies (Stage:1 of Phase:4). In this irrigation scheme, as each AU is characterized with one soil and as six different crops can be cultivated, there were 6 CS units for each AU. Thus 32 AUs of the irrigation scheme has resulted in up to 1860 decision variables in objective function for the irrigation policy of optimized deficit irrigation (32 AU; 6 CS units in each AU and 10 selected irrigation programs for each CS of AU. Note that for some CS units, less than 10 irrigation programs were selected, especially for crops cultivated in summer season on light soils). Similarly there are 192 decision variables (32 AU; 6 CS units in each AU and one irrigation program for each CS of AU) for other irrigation policies. The total number of constraints varied according to the different requirements and the irrigation interval. For example for this case study for the irrigation interval of 21 days, there were 327 constraints for the scenario of fixed cropping distribution, variable depth irrigation and seasonal equity in water distribution. These include 192 constraints for fixed cropping distribution and 32 for seasonal equity in water distribution in addition to the constraints related to the resource limitations, intrsaseasonal water supply, canal capacity etc. The optimum solution was obtained by solving the resource allocation model by linear programming for the specified irrigation interval (Stage:2 of Phase:4). The output was the allocation of areas for irrigation for different crops cultivated on different soils of allocation units and the corresponding irrigation programs. This irrigation program provides the information about the water to be delivered at each irrigation and the resulting crop yields and net benefits. This enabled estimation of the total water deliveries and net benefits for each allocation unit. This information was used for the computation of productivity and equity.

For the management strategy of fixed depth irrigation, the same depth needs to be applied at each irrigation for all CSR units. However this depth varies in the range of minimum to maximum possible irrigation depths. In this case these depths were 50 mm and 150 mm per irrigation, respectively. Therefore the irrigation depth that gives maximum output needs to be decided. This was identified by applying the AWAM model successively for all the depths in this range (with the depth interval of 10 mm) and the depth that gives the optimum output is finalized as the depth for the policy of fixed depth irrigation. For example for irrigation interval of 21 days, the irrigation depths of 70 mm per irrigation in winter season and 140 mm in summer season were found as the fixed irrigation depths producing the optimum output. The detailed procedure is presented by Smout and Gorantiwar (2002).

COMPUTATION OF PERFORMANCE MEASURES

The performance measures of productivity and equity were estimated for allocation plans developed by AWAM model for different scenarios and by following the procedure described below.

Productivity

The productivity is the ratio of the total net benefits of the scenario to the total net benefits of the scenario which gives maximum total net benefits amongst all the scenarios considered for comparison. The scenarios resulting from fixed and free cropping distributions were considered separately for the purpose of computation of the productivity.

Equity

Modified inter quartile allocation ratio (equations 1-4) (Gorantiwar 1995) was used as the measure of equity

$$E = \frac{\overline{R^{pq}}}{\overline{R^{bq}}} \qquad (1)$$

$$R_a = \frac{\lambda x_a}{\lambda d_a} \qquad (2)$$

$$\lambda d_a = \frac{\Delta d_a}{\sum_{a=1}^{na} \Delta d_a} \qquad (3)$$

$$\lambda x_a = \frac{\Delta x_a}{\sum_{a=1}^{na} \Delta x_a} \qquad (4)$$

where

E = modified inter quartile allocation ratio

$\overline{R^{bq}}$ = average of allocation ratios of the best quarter

$\overline{R^{pq}}$ = average of allocation ratios of the poorest quarter

R_a = allocation ratio of a^{th} allocation unit

λx_a = actual allocation proportion for a^{th} allocation unit

λd_a = desired allocation proportion for a^{th} allocation unit

Δd_a = CCA of a^{th} allocation unit (ha)

na = total number of allocation units

Δx_a = value of parameter by which equity is measured, computed for a^{th} allocation unit

Δx is water allocated for the equity in water allocation and benefits generated for the equity in benefits generation. These are computed by equations (6) and (7).

$$\Delta x_a = V_a * A_a \quad (6)$$

$$\Delta x_a = Nb_a * A_a \quad (7)$$

A_a = Area allocated for irrigation or irrigated of a^{th} allocation unit (ha)

V_a = Volume of water allocated or delivered to the a^{th} allocation unit (ha-m)

Nb_a = Total net benefits expected or generated from a^{th} allocation unit (currency units)

RESULTS AND DISCUSSION

The productivity and equity values obtained for allocation plans developed for different management strategies (irrigation depth) and performance strategies (productivity/equity) for different sets of irrigation interval are presented in Figs 1 to 6 for free cropping distribution and in Figs 7 to 12 for fixed cropping distribution. These are compared for productivity and equity.

Productivity

Figs 1 to 6 show that the productivity varies with the irrigation interval. For free cropping distribution, the productivity is maximum with the irrigation interval of 21 days for all the management strategies (irrigation depth) and performance strategies (productivity/equity). Amongst the management strategies, the optimized deficit irrigation produces greater benefits than fixed depth irrigation and full irrigation. This is due to the fact that in case of optimized deficit irrigation the irrigations were applied optimally in variable depths ranging from zero depth (skipping irrigation) to full irrigation depth whereas in case of full irrigation and fixed depth irrigation, there was no flexibility in applying irrigation depths. For the management strategy of optimized deficit irrigation, the performance strategy of maximum productivity produced greater benefits than performance strategies of maximum equity. This is obvious from the fact that when the performance strategy was maximum productivity, the allocations were prioritized to more efficient allocation units. Therefore this strategy has resulted in greater productivity than the performance strategy of maximum equity, when the resources were allocated also to allocation units which were not efficient.

Similar results were obtained for fixed cropping distribution, except that the irrigation interval of 14 days produced greater benefits for the management strategy of optimized depth irrigation, and the irrigation interval of 21-14 days produced maximum benefits for the management strategies of fixed depth irrigation and full irrigation. However there are no marked differences amongst the productivity values of lower irrigation intervals (I-14, I-21-14 and I-21).

Equity in water distribution

The equity values presented in Figs 1 to 6 for free cropping distribution and in Figs 7 to 12 for fixed cropping distribution are compared below for different performance strategies.

Maximum productivity: In this case the water is allowed to be allocated freely. Figs 1 to 12 show that the equities are zero or very low (very low for irrigation interval of 28-35 days for optimized deficit irrigation, when cropping distribution is free) when the performance strategy is maximum productivity and the water distribution is free (shown as FWD in figures). When water was allowed to be allocated freely, the most efficient allocation units (allocation units near to headworks and with favorable soil properties) got priority in water allocation, to meet the overall objective of benefit maximization. This has resulted in inequitable allocation of water and therefore the equity values in seasonal water distribution and irrigation-wise distribution are zero or very low for the performance strategy of maximum productivity. This has also resulted in zero or very low equity in benefits generated.

Maximum equity (Seasonal) (SEWD in figures): In this case the equity in seasonal water distribution is enforced in water allocation to different allocation units and hence the equity in seasonal water distribution is maximum i.e. one, for all the management strategies, irrigation intervals and cropping distributions. However the productivity values are less than those obtained with free water distribution. The figures also show that seasonal equitable water distribution does not produce equity in irrigation-wise water distribution in optimized deficit irrigation and full irrigation. In optimized deficit irrigation, the irrigation water may be allocated in different depths for different irrigations and for different Crop-Soil-Region (CSR) units for maximization of total net benefits. Hence there may not be irrigation-wise equitable distribution of water. For full irrigation, the depth of full irrigation varies for each irrigation and for each CSR unit and therefore there is no irrigation-wise equity, even though the equity in seasonal water distribution is enforced. For fixed depth irrigation, as the irrigations are applied in fixed depth for all irrigations and for all CSR units, the equity in seasonal water distribution also leads to the equity in irrigation-wise water distribution.

Maximum equity (per irrigation) (IEWD in figures): The results are also obtained for irrigation-wise equity in distribution of water to different allocation units (Figs 1 to 6 for free cropping distribution and Figs 7 to 12 for fixed cropping distribution). For full irrigation, as there is only one full irrigation depth and as this full irrigation depth varies for different irrigations, the solutions for irrigation-wise equitable distribution of water could not be obtained. Whenever water is allocated equally over all irrigations to different allocation units, there is also equitable distribution of water over the season to all allocation units. Hence the values of both irrigation-wise equity and seasonal equity are one when the water was allocated for equity in irrigation-wise distribution. It is observed from Figs 1 to 12 that the values of productivity are lower for irrigation-wise equitable water distribution than seasonal equitable water distribution. When the irrigation-wise equity is enforced, it is possible that for some CSR units, the water will be allocated in excess of that required, for some irrigations. The allocation of this excess water may lower the productivity in the case of irrigation-wise equitable water distribution.

Equity in benefits generated

As the total net benefits combines the influence of the yields of different crops to a single monetary value, it is considered as the convenient indicator of productivity in a multi crop situation. Similarly in this study it is proposed to consider the equity in net benefits generated to different allocation units as one of the indicators of equity. This indicator not only combines the effect of different crops but also considers the more or less efficient allocation units due to their relative positions with respect to headworks, soil types, efficiency of distribution network etc. The values of equity in benefits generated for different strategies are shown in Figs 1 to 12. As expected there is no equity in benefits generated to different allocation units for free water distribution scenarios. The equity in benefits generated is higher for smaller irrigation intervals and lower for larger irrigation intervals for different management and performance strategies. The values of equity in benefits generated are almost the same for the performance strategies of seasonal equity and irrigation-wise equity in water distribution. However as the productivity is higher for seasonal equitable water distribution than irrigation-wise equitable water distribution, the performance strategy of seasonal equitable water distribution may be preferred over irrigation-wise equitable water distribution strategy.

Productivity and equity

The productivity is maximum for the irrigation interval of 21 days and optimized deficit irrigation for free cropping distribution, and for the irrigation interval of 14 days and the management strategy of optimized deficit irrigation for fixed cropping distribution. However the equities are zero for both these cases. For the maximum equity of one in seasonal or irrigation-wise water distribution, the productivity is maximum for the irrigation interval of 21 days for free cropping distribution, and for the irrigation interval of 14 days for fixed cropping distribution, for the performance strategies of seasonal or irrigation-wise water distribution. As the productivity is higher for seasonal water distribution than for irrigation-wise water distribution and as there are no marked differences between equities in net benefits generated between seasonal and irrigation-wise water distribution strategies, the equitable seasonal water distribution strategy is preferred over the irrigation-wise equitable water distribution strategy. Thus for maximum equity, suitable allocation plans are obtained with the equitable seasonal water distribution strategy for the irrigation interval of 21 days for free cropping distribution, and for the irrigation interval of 14 days for fixed cropping distributions. However the free cropping and fixed cropping distributions reduce the productivity values by 12% and 16% over the free water distribution strategy.

It is clear from the Figs 1 to 12, and the above discussion that productivity and equity have an inverse relationship. In earlier studies, Kalu et al (1995) found that the policy emphasizing the system efficiency is not optimal with respect to equity and likewise the most equitable policy is not the efficient one. Onta et al (1995) and Small and Rimal (1996) also found the inverse relationship between net benefits and equity under water shortage. Therefore the case study was used to develop the relationship between productivity and equity for the irrigation interval of 21 days for free cropping distribution and 14 days for fixed cropping distribution. The relationships between productivity and seasonal water distribution equity, between productivity and irrigation-wise water distribution equity, and between productivity and equity in net benefits generated are shown in Figs 13 (a) to (c) for free cropping distribution and equitable seasonal water distribution strategy, and in Figs 14 (a) to (c) for free cropping distribution and equitable irrigation-wise distribution strategy. Similarly the relationships between productivity and seasonal water distribution equity, between productivity and irrigation-wise water distribution equity and between productivity and equity in net benefits generated are shown in Figs 15 (a) to (c) for fixed cropping distribution and equitable seasonal water distribution strategy, and in Figs 16 (a) to (c) for fixed cropping distribution and equitable irrigation-wise distribution strategy. It is observed that with the increase in equity, the productivity decreases. The productivity is high when equity is low because in this case the water is not allocated to less productive units such as units at tail end and units with less productive soils. However for high equity, water spreads proportionally over all the units, thus making water allocation to less productive units also. This is in contrast to Abernethy (1986), Khepar et al (2000) and Evans et al (2003) who argued that the equitable distribution of water is also necessary for maximizing productivity. Their argument was that the farmers at the head of a canal apply more water than needed for potential yield and excess water will not improve the productivity but will reduce it. Had that excess water been diverted to other parts of the scheme which received less water than needed to produce potential yields, the production would have increased. This fails to take account of efficiencies however and when water is scarce and managed optimally, the productivity and equity are conflicting issues, as found in this study.

The relationships in Figs 13 to 16 also indicate that the equity is very sensitive at higher values of productivity. For example, for the free cropping distribution and equitable seasonal water distribution strategy, the seasonal water distribution equity dropped from 1 to 0.4 when productivity increased from 0.87 to 0.91, and for the fixed cropping distribution and equitable seasonal water distribution strategy, the seasonal water distribution equity dropped from 1 to 0.2 when productivity increased from 0.68 to 0.70. These observations lead to the conclusion that when both productivity and equity are performance objectives, equitable water distribution may be preferred over free water distribution at the cost of small loss in productivity.

CONCLUSIONS

It was possible to develop the allocation plans and the water delivery schedules for different performance parameters such as productivity and equity, from the methodology and model developed in the companion paper. The inclusion of these performance parameters while developing the optimum allocation plans enables the irrigation authorities to select the appropriate allocation plans depending on the local situation and to match the performance of the irrigation scheme to the objectives/goals of the irrigation scheme. The results of the model obtained with one case study on an irrigation scheme in central India for different management strategies of irrigation amount and irrigation interval and free and fixed cropping distributions, indicated that the performance parameters of productivity and equity conflict with each other, if the water resources are allocated optimally. It was also found that the equity is more sensitive than productivity and that major improvements in equity could be achieved for a small loss of productivity in this case study. Thus this study highlights the importance of considering both productivity and equity while developing the allocation plans and water delivery schedules for an irrigation scheme with limited water supply.

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Captions of figures (figures are arranged in order)

Fig. 1. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 14 days for free cropping distribution.

Fig. 2. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 21-14 days for free cropping distribution.

Fig. 3. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 21 days for free cropping distribution.

Fig. 4. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 28-21 days for free cropping distribution.

Fig.5. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 28 days for free cropping distribution.

Fig. 6. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 35-28 days for free cropping distribution.

Fig. 7. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 14 days for fixed cropping distribution.

Fig. 8. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 21-14 days for fixed cropping distribution.

Fig. 9. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 21 days for fixed cropping distribution.

Fig. 10. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 28-21 days for fixed cropping distribution.

Fig. 11. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 28 days for fixed cropping distribution.

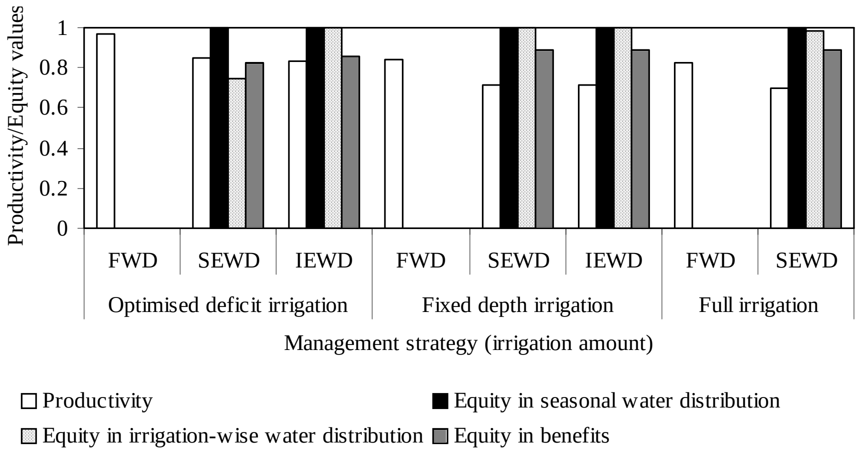
Fig. 12. Productivity and equity for different management strategies of irrigation amount and performance strategies for irrigation interval of 35-28 days for fixed cropping distribution.

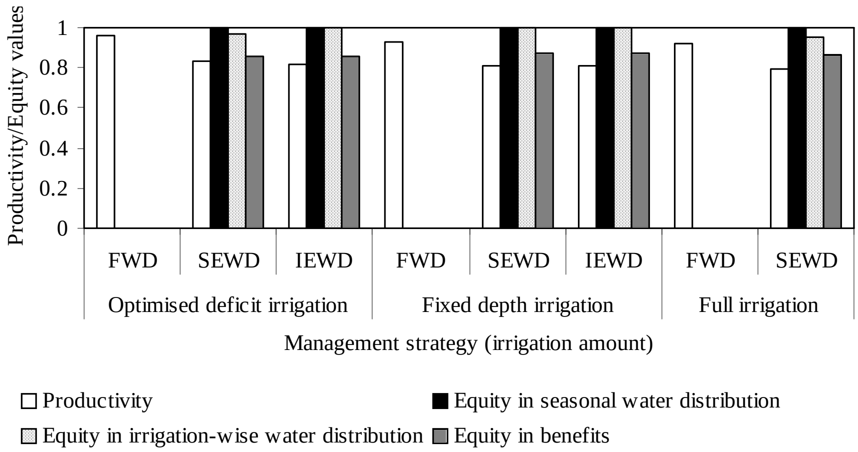
Fig. 13. The relationship between productivity and equity for irrigation interval of 21 days for free cropping distribution and irrigation-wise equitable water distribution strategy.

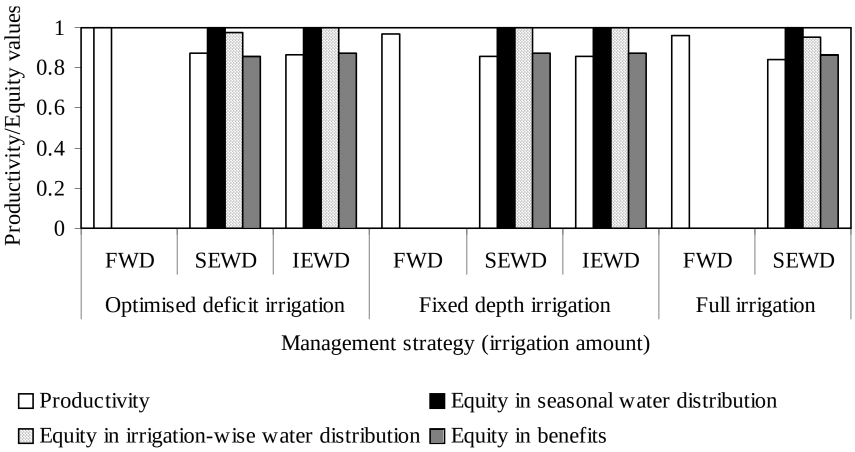
Fig. 14. The relationship between productivity and equity for irrigation interval of 21 days for free cropping distribution and seasonal equitable water distribution strategy.

Fig.15. The relationship between productivity and equity for irrigation interval of 14 days for fixed cropping distribution and irrigation-wise equitable water distribution strategy.

Fig. 16. The relationship between productivity and equity for irrigation interval of 14 days for fixed cropping distribution and seasonal equitable water distribution strategy.


Productivity/Equity values
1
0.8
0.6
0.4
0.2
0
FWD
SEWD
IEWD
FWD
SEWD
IEWD
FWD
SEWD
Optimised deficit irrigation
Fixed depth irrigation
Full irrigation
Management strategy (irrigation amount)
Productivity
Equity in seasonal water distribution
Equity in irrigation-wise water distribution
Equity in benefits


Productivity/Equity values
1
0.8
0.6
0.4
0.2
0
FWD
SEWD
IEWD
FWD
SEWD
IEWD
FWD
SEWD
Optimised deficit irrigation
Fixed depth irrigation
Full irrigation
Management strategy (irrigation amount)
Productivity
Equity in seasonal water distribution
Equity in irrigation-wise water distribution
Equity in benefits



Productivity/Equity values
1
0.8
0.6
0.4
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FWD
SEWD
IEWD
FWD
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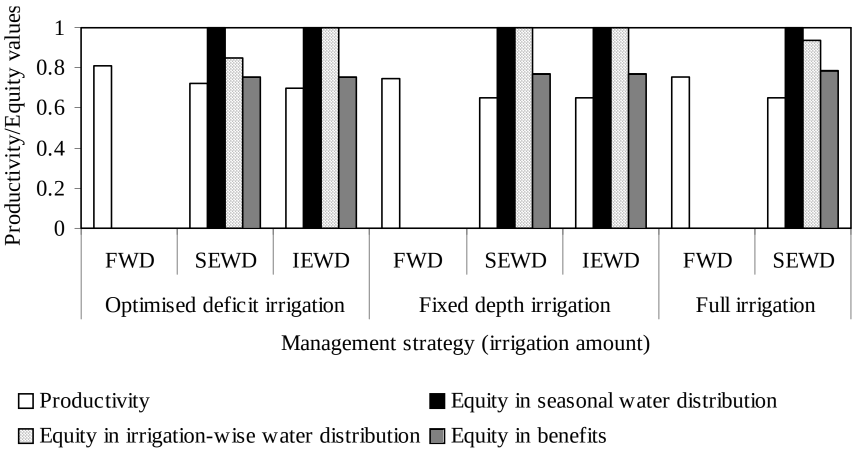
IEWD
FWD
SEWD
Optimised deficit irrigation
Fixed depth irrigation
Full irrigation
Management strategy (irrigation amount)
Productivity
Equity in seasonal water distribution
Equity in irrigation-wise water distribution
Equity in benefits



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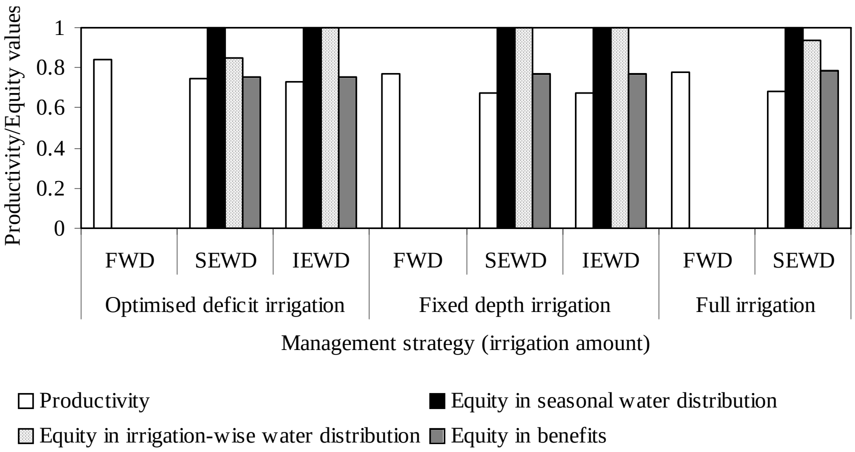

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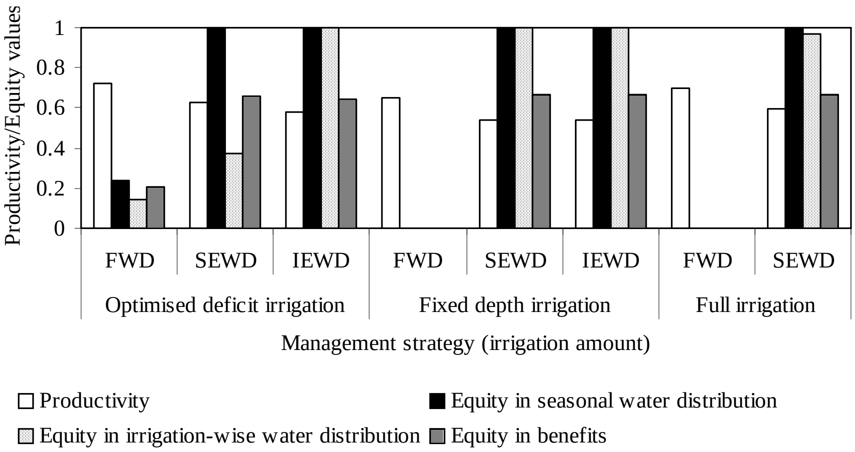
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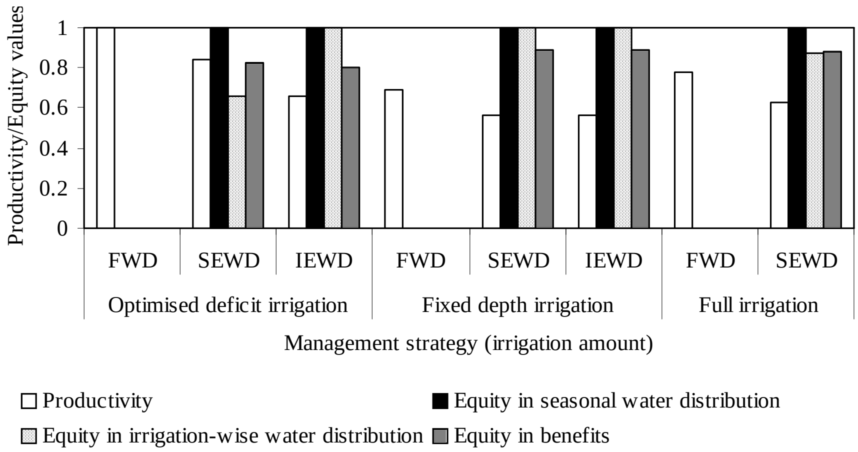

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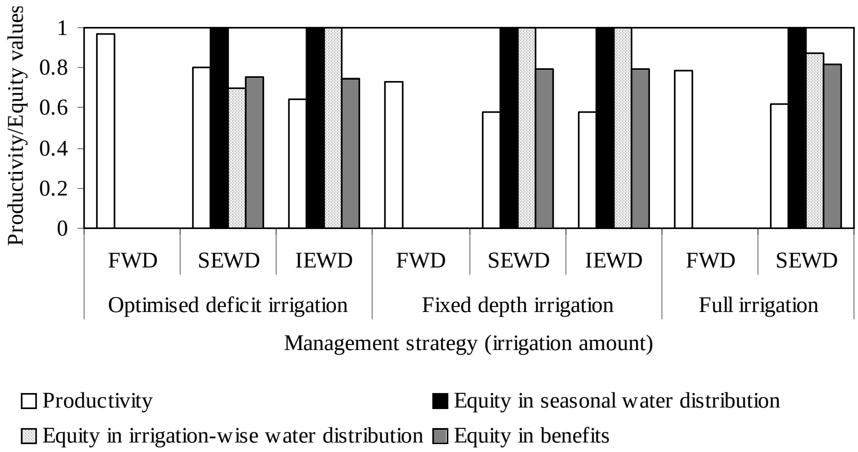
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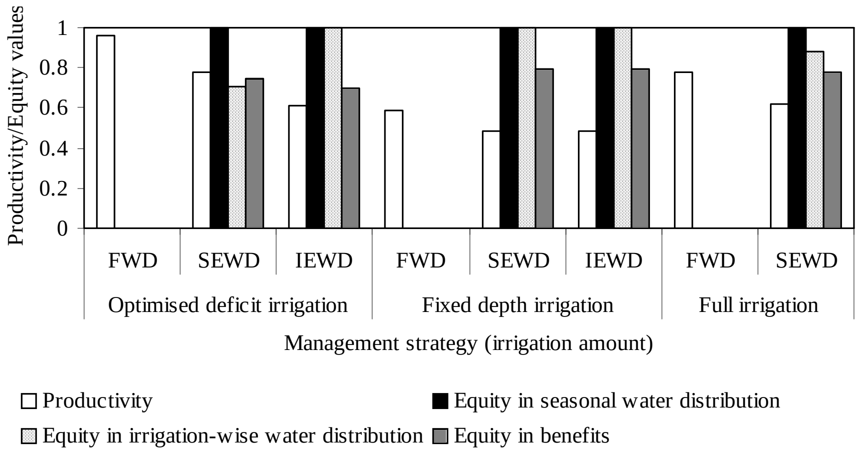

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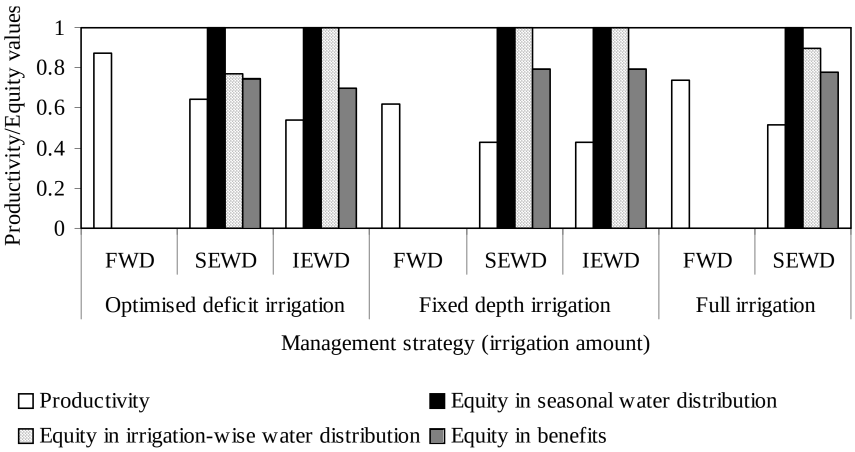
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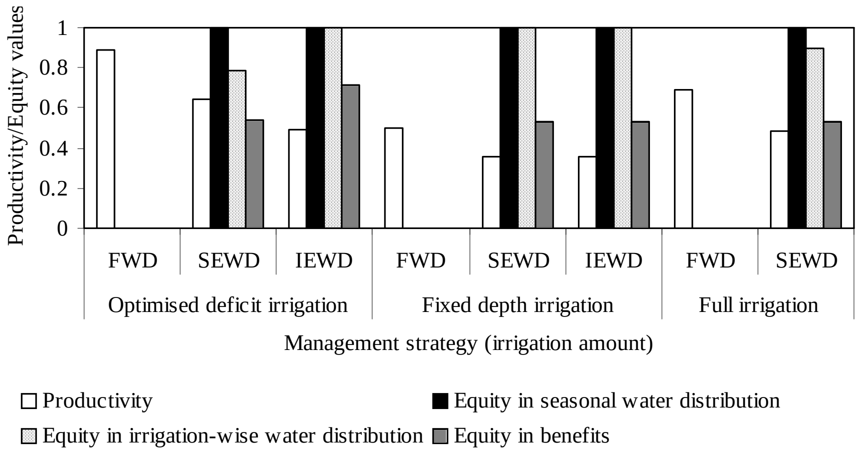
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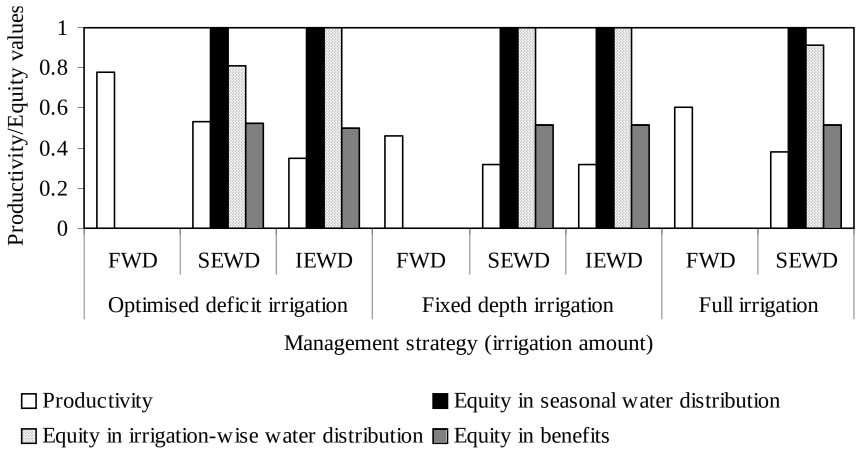
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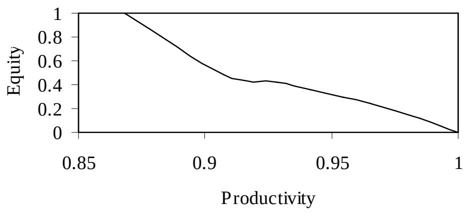
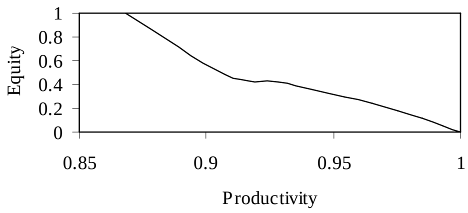
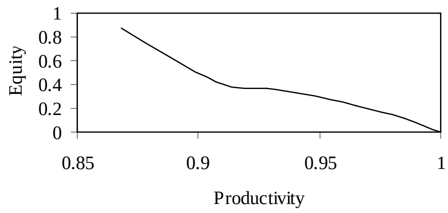


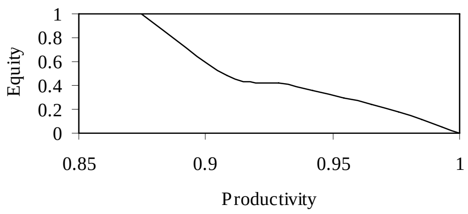
(a) Seasonal equity



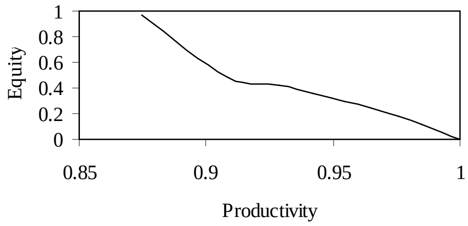
(b) Irrigation-wise equity



(c) Benefits generated



(a) Seasonal equity



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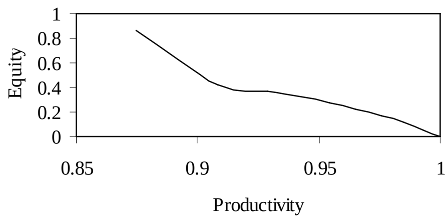

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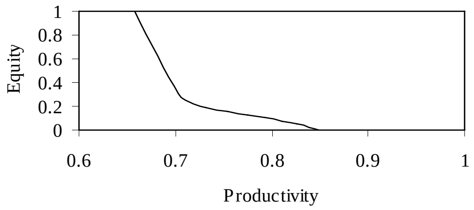
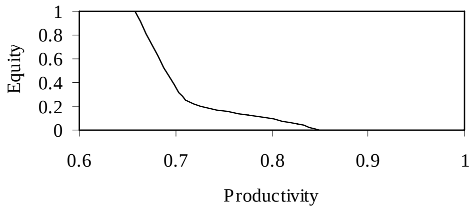


(a) Seasonal equity



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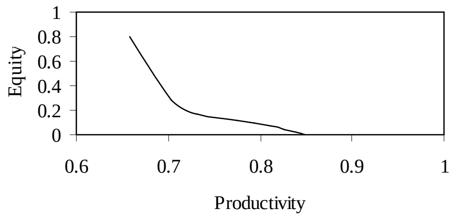

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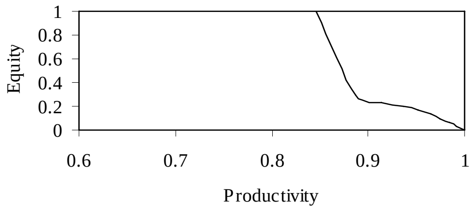

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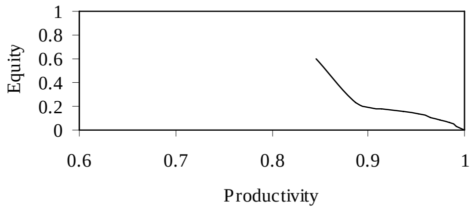
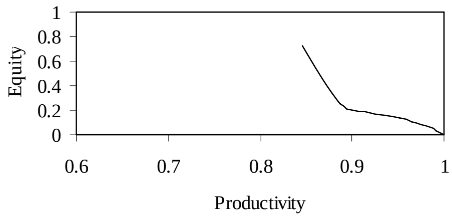


(b) Irrigation-wise equity



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