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Original Research Article

Optimization of Natural Resources to Achieve Food Production Target to Feed the Growing Population

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A B S T R A C T

Agricultural growth in India has fast-tracked remarkably after green revolution, but most of this growth has been driven by rapid hybridization and mechanization which increased yield per unit area rather than by accelerating expansion of the cultivated area in rainfed as well as irrigated condition. Looking into future population growth the research was undertaken upper Krishna project (UKP) covering 210 ha under Narayanpura right bank canal command area. The results obtained the overall essential crop production by the existing cropping pattern could feed the population of 2,320, whereas the production estimated by the conjunctive use could meet the food requirements of 3,893 surface water Goal programming (SWGP) to 5,947 persons conjunctive water use goal programming (CWUGP) after meeting marketable surplus. Thus, DSS based optimum use of groundwater and surface water and associated mean effective rainfall consideration would not only be a profitable model (CWUGP) but also could feed the population of 2.56 times more people at present. This would be useful for agricultural scientists, decision makers, policy planners and researchers in agricultural crop planning to take proper crop plan decision for food security.

Introduction

The rapid growing population in India and Asia has almost doubled between 1960 and 1990 to over 1 billion to 2.9 thousand million people. This consists of nearly 55 percent of the world total. According to UN forecasts cited in several publications, the population of Asia will increase to 4.2 thousand million people by the year 2025 (Anon, 2014). The International Food Policy Research Institute estimates that due to the increase in population and changing food demands the world food production has to be doubled by the year 2020. Looking towards 2030 to meet the demand for grain and to feed a growing population on the available arable land. It is suggested that annual crop production should be increased to around 580 Mt and that yield should increase by at least 2 % annually (Mingsheng *et al.,* 2011). Crop production will become more difficult with climate change, resources scarcity.

In Multi-Objective Chance-Constrained Goal Programming model (MOCGP) rainfall is considered as stochastic parameter. The soils, land area, water availability, cropping activities and other socioeconomic parameters are used as input to get output (results) in a software-based

Decision Support System-Planning (DSS-P). The DSS is a user-friendly software, which incorporates ‘knowledge’ and ‘expertise’ within the framework of the decision support mechanism. The DSS gives information which is vital for planning, implementation, monitoring, directing and controlling operation and maintenance activities, review and evaluation (Reddy and Reddy, 2003). In the present study multi-disciplinary approach involving hydrology, agronomy, information system, system engineering and socioeconomic components were employed for evaluating the existing crops. Further, appropriate cropping pattern to arrive at planning of optimum utilization of land and water resources consistent with the returns on sustainable manner with the assistance of DSS in two selected lateral command areas of the UKP during 2012-’14. Considering the various issues discussed above, the present research work was carried out with the following objectives:

To conduct inventory of land and water resources and cropping pattern in the command area of the selected canal system.

To suggest suitable measures for improving resource management and efficient cropping pattern and achieving optimal returns using systems engineering / optimisation approach and working out the economics.

To develop a decision support system for achieving optimal productivity on sustainable basis.

Materials and Methods

Essential crop production target constraints

Any crop production planning should be oriented to meet the food demands and nutritional requirements of the people in a region, especially from the view point of the national goal of self-sufficiency in food production.

That way essential crop production requirement constraints are social constraints and assume greater importance. According to food production requirement by IWMI report (Upali, 2005) the per capita food consumption (t) of major crops is presented in Table 1. It can be stated that, the production of essential crops should be greater than or equal to the food requirements of the command area and expressed in the following standard form:

$$\sum_{ij=1}^{n} Y_i\, x_{ijkl} \geq C \;\forall\; i = 1,2,\ldots 9;\; j = 1,\ldots 7\;;\; k = 1,2;\; l = 1, 2 \quad (1)$$

Where,

C = the total production requirement (target) level of crop ‘C’

Y_{xijkl} = production of essential i^{th} crop in j^{th} FIC in season ‘k’ under lateral ‘l’, t.

The constraints associated with the target levels of nine crops are considered under the study as shown below:

Rice

$$\sum_{ij=1}^{n} Y_i\, x_{ij} \geq Rc_{kl} \;\forall\; i = 1\;;\; j = 6, 7;\; l = 1, 2;\; k = 1, 2 \quad (2)$$

Where,

R_{ckl} = the target level of rice production in season ‘k’ under lateral ‘l’.

Other cereals (maize)

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq Mz_{kl} \ \forall\ i = 1 ; j = 6,7; l = 1, 2; k =1 \quad (3)$$

Where,

M_{zkl} = the target level of maize production in season 'k' under lateral 'l'.

Pigeonpea

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq Pp_{kl} \ \forall i = 3; j =1, 2,\ldots 4; l = 1, 2; k =1 \quad (4)$$

Where,

P_{pkl} = the target level of pigeonpea production in season 'k' under lateral 'l'.

Chickpea

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq Cp_{kl} \ \forall i = 4; j = 4, 5, 6 \text{ and } 7; l = 1, 2 ; k =2 \quad (5)$$

Where,

C_{pkl} = the target level of chickpea production in season 'k' under lateral 'l'.

Groundnut

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq GN_{kl} \ \forall i = 4 ; j =1, 2\ldots 3 ; l = 1, 2 ; k =2 \quad (6)$$

Where,

GN_{kl} = the target level of groundnut production in season 'k' under lateral 'l'.

Other *kharif* vegetable (*brinjal*)

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq B_{kl} \ \forall i = 6 ; j = 1, 2, 3; l = 1, 2 ; k =2 \quad (7)$$

Where,

B_{kl}= the target level of brinjal production in season 'k' under lateral 'l'.

Rabi vegetable (tomato)

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq Tm_{kl} \ \forall i = 7; j = 1, 2, 3; l = 1, 2 ; k =2 \quad (8)$$

Where,

T_{mkl} = the target level of tomato production in season 'k' under lateral 'l'.

Chilli

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq Ch\ Tm_{kl} \ \forall i = 8; j =1, 2, 3, 4, 5; l = 1, 2 ; k =1,2 \quad (9)$$

Where,

Ch_{kl} = the target level of chilli production in season 'k' under lateral 'l'.

Cotton

$$\sum_{ij=1}^{n} Y_j X_{ij} \geq Ct_{kl} \ \forall i = 9; j = 1, 2\ldots 5; l = 1, 2 ; k =1, 2 \quad (10)$$

Where,

Ct_{kl} = the target level of cotton production in season 'k' under lateral 'l'.

Non-negative constraints

$X_{ij} \geq 0$
$TCQ_{kl} \geq 0$
$SL \geq 0$

$\forall i = 1, 2\ldots9; j = 1, 2\ldots7; l = 1, 2; k = 1, 2$

Where,

SL = slack variable,

TCQ_{kl}= the discharge in season 'k' under lateral 'l', ha m.

Estimation of population

According to the population census of Gabbur, 2011, the total population was 8272 people and the total area of Gabbur was 5392.50 ha. By considering the geographical boundaries of the study area and the total area of Gabbur, proportionate density of population was worked out for the areal extent of each reaches falling within the boundary of the command area. By using the above said data, the population of the study area and crop wise food requirement for that much population was comparatively worked out with some assumptions.

Essential Food Production Achievement in Existing Cropping Pattern Compared to Models

The essential food production achievement results obtained were presented in Table 2 and Fig. 1. It was observed that, by restricting rice crop and by considering food production requirement in head reach of the laterals there was decrease in rice production under the existing cropping pattern (343.85 t) compared to the prediction of models (244.38 to 331.52 t) except in CWUGP model, where it increased (351.29 t). But still there was over achievement in rice production when the whole command area was considered.

The essential food production achievement results showed (Table 4.26 and Fig. 4.15) by restricting rice crop and by considering food production requirement in head reach laterals there was decrease in rice production existing (343.85 t) compared with the overall mean rice production from all the optimisation models predicted was about 305.97 t. The maize production ranged from 17.71 t in CWUCCGP70 model to 68.79 t CWUGP model and the mean over achievement of maize essential food production was predicted in optimisation models was 51.12 t compared with the existing target of -3.07 t. But, there is under achievement in other cereal mean production in all the optimisation models (8.48 t). So, in future farmers are encouraged to grow short duration cereals during *rabi* season to increase the cereals production achievement which consumes very less water (1 or 2 irrigation) for the full crop period during *rabi* season. The pulses (pigeonpea) production existing (-1.26 t) there is under achievement, when compare to mean essential food production in optimisation models predicted was 9.81 t over achievement, except in CWUGP model there is under achievement of essential food production (-3.77 t). The oilseed production (groundnut) there is under achievement in mean optimisation cropping pattern models predicted -7.16 t when compared with the existing cropping pattern 0.45 t. These need to be taken care during cropping pattern design. There is under achievement of vegetables in an existing cropping pattern (-7.02 t) the same after optimisation the mean essential vegetable production was 542.08 t over achievement in all other optimisation models. The cotton fiber crop existing 58.02 t when compared with the optimisation models mean essential cotton production predicted was 12.37 t there is a decrease in cotton production after meeting cloth requirement.

Table.2 Essential food production (t) achievement obtained in existing cropping pattern compared to models

Sl. no.	Crops	Existing essential food production	SW-GP	SW-CCGP70	CWU-GP	CWU-CCGP70	Average	Remarks
1	Rice	343.85	244.38	331.52	351.29	296.69	305.97	Over achievement
2	Maize	-3.07	57.56	60.41	68.79	17.71	51.12	Over achievement
3	Other cereals	-7.68	-8.04	-7.68	-9.53	-8.68	-8.48	Under achievement
4	Pulses	-1.26	34.29	2.42	-3.77	6.30	9.81	Over achievement
5	Groundnut (Oilseed)	445.54	-6.79	-6.44	-8.05	-7.34	-7.16	Under achievement
6	Vegetables	-7.02	356.30	435.53	669.80	706.67	542.08	Over achievement
7	Cotton	58.02	13.26	9.86	13.99	12.38	12.37	Over achievement
8	Which can be fed Population	2320	3893	4556	5947	5608		

Fig.1 Existing food production target compared to SW-GP/CCGP and CWU-GP/CCGP Models

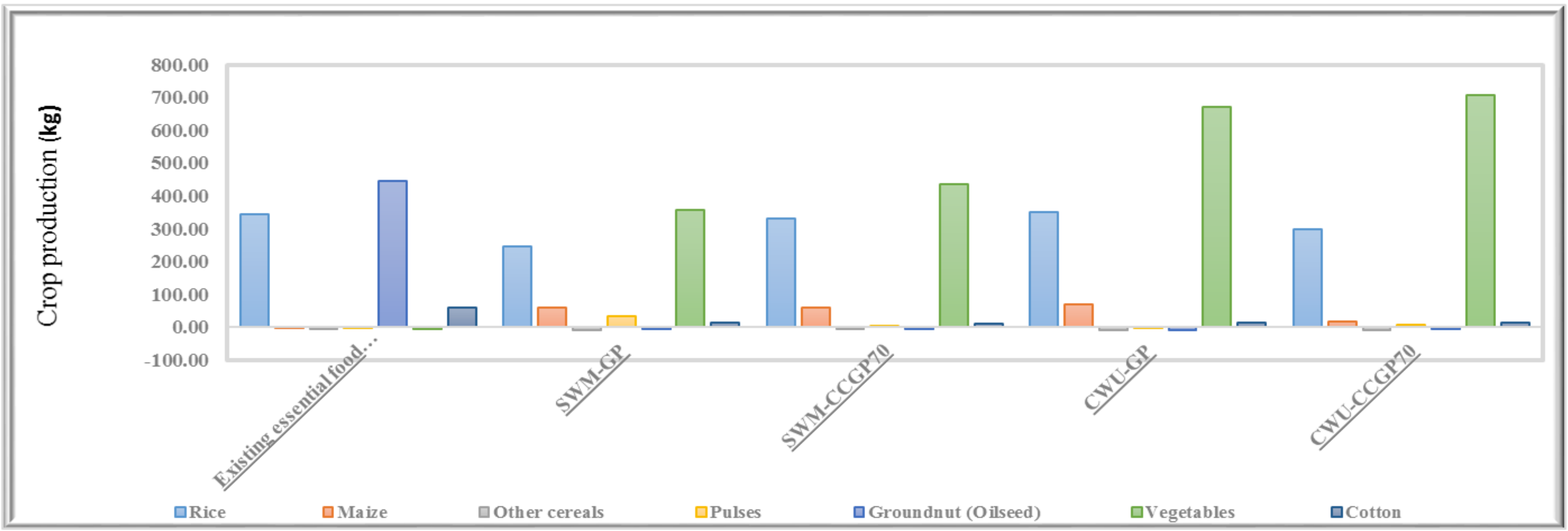

Table.1 Per capita food consumption of major crops

Crops	Unit	1995		2015		2025	
	kg d^{-1}	Per day	Per year	Per day	Per year	Per day	Per year
Rice	,,	0.21	77.38	0.21	78.11	0.22	78.84
Wheat	,,	0.17	60.59	0.17	63.51	0.18	66.43
Maize	,,	0.02	8.03	0.02	8.03	0.02	8.03
Other cereals	,,	0.06	20.08	0.06	20.08	0.06	20.08
Pulses	,,	0.04	12.78	0.03	12.59	0.03	12.41
Oilseed crops (equivalent)	,,	0.04	15.70	0.05	16.97	0.05	18.25
Vegetables	,,	0.15	55.48	0.16	59.68	0.18	63.88
Roots and tubers	,,	0.06	20.81	0.06	22.45	0.07	24.09
Sugar (raw equivalent)	,,	0.10	35.04	0.10	37.78	0.11	40.52
Fruits	,,	0.09	34.31	0.10	36.87	0.11	39.42
Cotton	(kg yr^{-1})	-	2.36	-	2.36	-	2.36

So in future study area is restricted for cotton in all reaches after achieving yearly cloth requirement and restricting rice in head reach command area.

The overall essential crop production analysis indicates that, the existing cropping pattern can feed the population volume of 2320 people when compared with the optimisation models it increase from 3893 to 5947 people by using the conjunctive use model (CWUGP) after meeting marketable surplus. Considering the fact that, optimum use of ground water and surface water conjunctively at mean standard weekly rainfall in the study area will be successfully make a decision to feed the population of 5947 people with profitable model. The results are in line with the finding of Yi and Liping (2014) developed a main function of ‘CropIrri model’ was pre-sowing and real-time irrigation management decision support system, simulation of soil water dynamics in the root zone, evaluation of the effect of certain irrigation plan on the crop yield and database management. Similar observation of increase in crop production after optimisation was found by (Dwitikrishna, 2009; Bhabagrahi *et al.*, 2006; Chaplinsky *et al.*, 2006).

Maize food production varied from 17.71 to 68.79 t, but there was under achievement in other cereal production in all the models (-7.68 to -9.53 t). In case of existing pulses (pigeonpea) production there was under achievement (-1.26 t) compared to prediction of models which varied from 2.42 to 34.29 t resulting in over achievement, except in CWUGP model, there was under achievement of essential food production (-3.77 t). The existing oilseed (groundnut) production was 0.45 t compared to suggestion of models and there was under achievement (-8.05 to -6.44 t) of oilseed production. This need to be taken care in existing cropping pattern. There was under achievement of vegetable production in the existing cropping pattern (-7.02 t) against 356.30 to 706.67 t predicted by the models resulting in over achievement. The existing cotton crop production was 58.02 t compared to prediction of the models (9.86 to 13.99 t). There was a decrease in the cotton requirement predicted by the models after meeting cloth per capita marketable surplus.

The overall essential crop production by the existing cropping pattern could feed the population of 2,320, whereas the production estimated by the conjunctive use could meet the food requirements of 3,893 (SWGP) to 5,947 persons (CWUGP) after meeting marketable surplus. Thus, DSS based optimum use of groundwater and surface water and associated mean effective rainfall consideration would not only be a profitable model (CWUGP) but also could feed the population of 2.56 times more people at present.

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