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PRODUCTION POTENTIAL AND POPULATION OPTIMIZATION OF COWS IN INDIA

The average annual milk production per cow in India from 1951 through 1976 has been reduced to 150.38 kg. from 166.90 kg. The production potential of a cow plays an important role in the profitability of dairy farm enterprise. A knowledge of different causes responsible for deterioration in production potential is necessary for deciding appropriate strategy to increase milk production in India. As no information is available as to why deterioration in production potential has taken place, it was considered desirable to study the factors responsible for deterioration in production potential of average annual milk yield of a cow in relation to population optimization.

METHODOLOGY

The magnitude of cows required to maintain the number of existing cow production and unproductive cows was estimated by the technique developed by Mishra.[1] The average productivity life, age at first calving and annual mortality rate upto age at first calving is assumed to be ten years, four years and 10 per cent respectively.

Herd Stability Model

$$\text{Run} = \frac{e \times (1 - m)^n}{2} \cdot B_t$$

$$T = 2/e \times (1 - m)^n$$

where B_t = number of parental breedable stock,

Run = annual replacement rate of unproductive cows for population optimization, or total number of unproductive cows to be replaced annually,

T = average standard productive life of a cow in optimized herd,

e = annual breeding efficiency of parental stock,

n = age at first calving or lag between parental and replacement stock.

Theory

Under Indian conditions, where the input resources of feed and fodder are limited, population optimization refers to the utilization of these available resources in most efficient manner by productive cows, along with an improvement in their average annual milk production potential. This can be attained by replacing unproductive cows (Run), equal to the number of heifers entering (Rf_n) into production every year. In an optimized population, there is no unproductive animal or the number of surplus animals (unproductive) tends to be zero.

Unproductive cows:— Unproductive cows to be replaced in an optimized population refers to the cows which are neither in milk nor pregnant in a particular year.

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1. S. N. Mishra: Livestock Planning in India, Vikas Publishing House Pvt. Ltd., Bombay, 1978, Chapter 5, "A Surplus Cow Model", pp. 75-79.

Assumptions

1. Annual mortality rate of replacement stock upto age at first production and cows in production was assumed to be uniform.

2. The lag between parental breedable and replacement stock was 'n' years and during this period the size of breedable cows was assumed to be stationary.

Proof

The model was derived by taking Mishra's model[2] as base to predict the number of heifers entering into production and unproductive cows to be replaced annually for maintaining population stability along with standard productive life.

$$B_t - 1/e \frac{\frac{2(B_t)}{t}}{(1-m)^n} = 0 \quad \text{(Mishra[3])} \qquad \text{(Theory)} \qquad \ldots\ldots(1)$$

$$B_t \left(1 - 1/e \frac{2(1/T)}{(1-m)^n}\right) = 0 \qquad \ldots\ldots(2)$$

Multiple of two variables is equal to zero, where B_t is a population size which cannot be equal to zero.
The possibility is:

$$1 - 1/e \frac{2(1/T)}{(1-m)^n} = 0 \qquad \ldots\ldots(3)$$

$$\text{or } 1/e \frac{2(1/T)}{(1-m)^n} = 1 \qquad \ldots\ldots(4)$$

$$\text{or } 1/T = \frac{e \times (1-m)^n}{2} \qquad \ldots\ldots(5)$$

In a population where average productive life of a cow is T years, the cows whose age will advance from T years will retire from production, because under herd optimized conditions cows are retained in the herd till they are in productive phase. Under this condition, unproductive phase of cows is eliminated by artificial culling of unproductive cows. So under herd optimized situation, 1/T fraction of total cows will retire from production every year, due to unproductive reasons. Hence, 1/T is ideal annual replacement rate of unproductive cows (Ru) for population optimization.

$$Ru = \frac{e \times (1-m)^n}{2} \qquad \ldots\ldots(6)$$

Total cows to be replaced annually can be obtained by multiplication of equation (4) with B_t (population size).

$$Run = \frac{e \times (1-m)^n}{2} \times B_t \qquad \ldots\ldots(7)$$

2. *op. cit.*
3. *op. cit.*

The total unproductive cows (Run) to be replaced annually is composed of two components: (*a*) unproductive cows to be eliminated by artificial culling (B_t), (*b*) annual mortality rate among adult cows (m0) or total number of cows meeting their natural death in a year (m0) $\times$ (B_t).

$$Ru = bt + m_1$$

$$\triangle\, bt = (Ru - m_1) \qquad \text{......(8)}$$

So, $\triangle$ bt is fraction of total cows, should be culled from national milch herd by artificial selection every year.

The total number of unproductive cows to be culled by artificial selection can be obtained by multiplication of equation (8) by B_t:

$$\triangle B_t = B_t(Ru - m_1) \qquad \text{......(9)}$$

By putting the value of Ru from equation (6) in equation (9)

$$\triangle B_t = B_t\left(\frac{e \times (1-m)^n}{2} - m_0\right) \qquad \text{......(10)}$$

The average standard productive life of cow in optimized herd (T):
From equation (5)

$$1/T = \frac{e \times (1-m)^n}{2}$$

$$\therefore\ T = \frac{2}{e \times (1-m)^n} \qquad \text{......(11)}$$

Annual replacement stock (Rf_n):
Young heifers upto 0-1 year of age:

$$Rf_1 = \frac{e \times (1-m)^1}{2} \cdot (B_t) \qquad \text{......(12)}$$

Heifers between 1-2 years of age:

$$Rf_2 = Rf_1 \times (1 - m_1) \qquad \text{......(13)}$$

By putting the value of Rf_1 in equation (13)

$$Rf_2 = \frac{e \times (1-m)(1-m_1)}{2} \cdot B_t = \frac{e \times (1-m)^2}{2} \cdot B_t \qquad \text{......(14)}$$

$\because (1-m_1), (1-m)$ - - - Assumption (1)

$$\vdots \qquad \vdots \qquad \vdots$$

Heifers n — 2 to n — 1 years of age:

$$Rf_{(n-1)} = \frac{e \times (1-m)^{n-1}}{2} \cdot B_t \qquad \text{......(15)}$$

Heifers between n—1 to n year of age:

$$Rf_n = Rf_{(n-1)} \cdot (1-m_n) \qquad \text{......(16)}$$

By putting the value of Rf_{n-1} from equation (15) into equation (16):

$$Rf_n = \frac{e \times (1-m)^{n-1} \cdot (1-m)}{2} \cdot B_t \qquad \text{......(17)}$$

$$Rf_n = \frac{e \times (1-m)^n}{2} . B_t \qquad ......(18)$$

Note:—$(1-m)$, $(1-m_1)$, $(1-m_2)$, $(1-m_{n1})$ and $(1-m_n)$ are the mortality rates of heifers between 0-1, 1-2, $n-1$ to n year of age respectively and it is assumed to be uniform.

Hence, it is proved that the number of heifers entering into production Rf_n is equal to total number of cows to be replaced (Run) under herd optimized situation.

$$Run = Rf_n = \frac{e \times (1-m)^n}{2} . B_t \qquad ......(19)$$

Improvement in milk production potential:

$$\triangle G_t = h^2 \times \frac{S_{(f)} + S_{(m)}}{2 \times \text{Generation interval}} \quad \text{(Rice et al.[4])} \qquad ......(20)$$

Under herd optimized conditions, only females are being selected. Selection against male is not operated. Hence, $S_{(m)} = 0$.

$$\triangle G_t = h^2 \times \frac{S_{(f)}}{2 \times \text{Generation interval}} \qquad ......(21)$$

$$S_{(f)} = (\overline{B}_t - \overline{B_t - B_t})$$

By putting the value of $S_{(f)}$ in equation 21 :

$$\triangle G_t = \frac{(h^2 \times \overline{B}_t - \overline{B_t + B_t})}{2 \times \text{Generation interval}} \qquad ......(22)$$

Notations

B_t = size of breedable cows to be stabilised,

e = annual breeding efficiency of parental stock or ratio of cows in milk to total in a year,

T = average standard productive life of a cow,

m = average annual mortality rate upto age at first production,

n = age at first production or lag between parental and replacement stock,

Ru = fraction of unproductive cows to be replaced in a year,

Run = number of total unproductive cows to be replaced in a year,

$\triangle bt$ = fraction of total cows to be culled by artificial selection,

$\triangle B_t$ = total number of unproductive cows to be culled annually,

Rf_1 = number of total heifers upto 0-1 year of age,

Rf_2 = number of total heifers upto 1-2 year of age,

$Rf_{(n-1)}$ = number of heifers between $n-2$ to $n-1$ year of age,

Rf_n = number of heifers between $n-1$ to n year of age,

4. Victor Arthur Rice, Frederick Newcomb Andrews, Everett James Warwick and James Edward Legates: Breeding and Improvement in Farm Animals, McGraw-Hill Book Co., New York, 1970, pp. 260-262.

$\triangle G_t$ = annual genetic gain for milk production,

h^2 = heritability for milk production,

$S_{(f)}$ = selection differential of females (milk production).

$S_{(m)}$ = selection differential of males (milk production) (S_m = 0),

m_1 = annual mortality rate among adult cows (uncontrolled population),

m_2 = annual mortality rate in adult cows in optimized population,

T_1 = average productive life of a cow in uncontrolled population,

T_2 = average productive life of a cow in optimized population,

$\bar{B_t}$ = average annual milk production of selected cows in optimized population,

$\overline{B_t + B_t}$ = average annual milk production of cows before selection.

Optimized population

In optimized population ($\triangle B_{t2}$) cows are being annually disposed of from national milch herd by artificiacl selection. Population size of breedable cows and heifers entering into production (Rf_n) remains stationary. Annual genetic gain for milk production will be ($\triangle G_t$). In this population, the productive life of the cow (T_2) and the number of unproductive cows to be disposed of by artificial selection is dependent upon the number of heifers entering into production every year.

Uncontrolled Population

In uncontrolled population $\triangle B_{t1}$ (unproductive cows) are being retained annually in the national milch herd. In this population, average productive life (T_1) is not dependent upon the number of heifers entering into production every year. It is dependent upon the mortality rate among adult cows. The productive life of a cow in national milch herd is prolonged till she meets her natural death. So population size will increase by $\triangle B_{t1}$ annually, leading to increase in the number of heifers entering into production (Rf_n) every year. This cycle continues and the population size goes on increasing, leading to a decrease in average annual productivity as explained in the text.

Data

The data for the present investigation pertain to the Livestock Census in India from 1951 to 1976. Information on the total number of adult cows, ratio of total cows in milk to total in a year, annual milk production per cow, and average annual milk yield per cow was available at the interval of five years from 1951 to 1976. Information on human population is available at ten-year interval from 1951 to 1971.

RESULTS AND DISCUSSION

The number of adult breedable cows, ratio of cows in milk to total, total annual milk production per cow, total milk production and human population as per the Census of different years have been tabulated. The last column of (Table I) reveals that during the 25 years (1951-1976), annual milk production per cow registered a decline by 16.52 kg. or 10 per cent. The annual decrease per cow was estimated at 803 grams in spite of an increase of 19 per cent in breedable cows and 7 per cent in total cow milk production. Per capita milk consumption has gone down by 16 grams. It is because of more demand of milk by the increasing human population which has gone up 51.81 per cent in two decades (1951-1971). The decrease in average annual milk yield per cow is chiefly due to two factors, *viz.*, genetic degradation and limited feed and fodder resources available for growing cattle population.

Genetic Degradation

The genetic degradation is due to low intensity of selection. Selection among cows was practised by breeders, removing low graded unproductive cows, but these cows continued to be the part of other herds. This resulted in poorest uneconomical animals to be at a place where they could survive on natural vegetation. Table II points out that the percentage of unproductive to total cows was almost constant during 1951-1976, whereas the total number of unproductive cows increased from 11.34 to 12.69 million or by 11.9 per cent. This was because of constant natural selection intensity. Taking the average age of a cow at first production as four years and her productive life of about ten years, the selection intensity was found to be 10 per cent, as 1/10 of total cows were meeting their natural death annually. The number of unproductive cows increased because the large number of (13.12 per cent) young heifers entering into production was more

TABLE I—NUMBER OF ADULT BREEDABLE COWS, RATIO OF COWS IN MILK TO TOTAL, MILK PRODUCTION, ANNUAL MILK PRODUCTION PER COW AND HUMAN POPULATION

Year	Human population (crores)	Number of adult cows (millions)	Annual ratio of milch to total cows or breeding efficiency (per cent)	Milk production (million tonnes)	Average annual milk production per cow (kg.)
1951	36.10	46.37	40	7.74	166.90
1956	—	47.26	42	8.18	173.30
1961	43.92	51.50	40	8.75	169.90
1966	—	51.70	40	6.92	133.70
1972	54.81 (for 1971)	53.72	41	8.10	150.70
1976	—	55.19*	40	8.30	150.38
Increase or decrease (per cent)	+51.81	+19.00		+7.00	—10.00

*Estimated figure.

Source: Government of India: Indian Livestock Census (1951 to 1976); and India (1977-78).

than the number of cows meeting their natural death (10 per cent) annually. The reason for constant selection intensity of the cattle population of the country was due to non-operation of artificial selection, because of religious sacredness of cows. Irrespective of its economic value, owners have retained the cow in their herd till she meets her natural death. The problem of low graded unproductive cows was not great for those which did not reproduce, but it was increased manifold by those which left their 3-4 progenies of their type in their life span, thereby lowering the production potential of the whole population. This cycle was continued for years together and ultimately it has reduced the milk yield upto the present level.

Limited Feed and Fodder Resources

According to the National Commission on Agriculture,[5] the total availability of green fodder, dry fodder and concentrates during 1976 was 219.55, 309.00 and 11.50 million tonnes against the requirements of 343.50, 347.41 and 19.50 million tonnes respectively. In this year 12.7 and 6.18 million hectares of land were under pasture and fodder cultivation respectively.

There is not much increase in fodder resources, whereas the population size of cows has increased from 46.37 to 55.14 million (by 19 per cent) from 1951 through 1976. It has been estimated that during 1951-1976 about 44.36 to 50.76 million kg. of dry matter per day were consumed by 11.34 to 12.69 million low graded unproductive cows respectively[6] (Table II). These unproductive cows have further reduced the availability of feed and fodder for productive cows, ultimately leading to a decrease in their average annual milk productivity.

Population Optimization and Its Effect on Total Milk Output

The population size of adult cows is more than the carrying capacity of land available for fodder cultivation. From Table II, it is apparent that the level of total milk production, say in 1976, could have been maintained by 42.50 million cows instead of by 55.19 million cows which included 23 per cent of unproductive cows. According to herd stability model, the removal of 4 to 5 million unproductive cows by artificial selection every year is expected to result in annual genetic gain from 0.268 to 0.358 kg. (Table II) and this removal will help in increasing the feed and fodder availability to the productive cows.

The increase in feed and fodder supply in underfed conditions is directly proportional to the increase in milk yield as observed by Jacob *et al.*[7] and

5. Government of India: Report of the National Commission on Agriculture, 1976, Part VII: Animal Husbandry, Ministry of Agriculture and Irrigation, New Delhi, 1976, see sections on "Feed Requirements for Livestock" and "Availability of Feeds and Fodders", pp. 389-391.

6. As per the recommendations of the National Commission on Agriculture (1976) in India, on an average, an adult cow weighing 200 kg. body-weight, at the rate of 2 kg. dry matter per 100 kg. of body-weight consumes 4 kg. of dry matter per day. On the basis of this recommendation, dry matter consumption of unproductive cows was estimated.

7. T. Jacob, V. N. Amble, M. L. Mathur and Subba Rao, "Milk Production Functions and Optimum Feeding Schedules", *Indian Journal of Agricultural Economics*, Vol. XXIV, No. 2, April-June 1969.

Mishra.[8] Twenty per cent increase in feed supply tended to improve breeding efficiency by 3 per cent as reported by the Institute of Agricultural Research Statistics.[9] In the light of these observations under the situation of 1976, elimination of all unproductive cows (23 per cent) could have led to an increase of 30 per cent in feed supply, of 4.5 per cent in breeding efficiency and of 5 per cent in total milk output (Table III). Under population optimized situation, the annual elimination of 13 per cent unproductive cows, which is equal to the number of young heifers entering into production every year, could have led to an increase of 14.8 per cent in feed supply, of 2.98 per cent in breeding efficiency and of 3 per cent in total annual milk output. It is the population optimization which can control the decreasing trend of annual milk yield of Indian cows.

Nature of Different Components Affecting Growth of Annual Replacement Rate of Unproductive Cows in an Optimized Population

According to herd stability model, the growth of annual replacement rate of unproductive cows $\left(R\mu = \frac{e \times (1-m)^n}{2}\right)$ depends upon breeding efficiency (e), exponential function of age at first calving (n) with annual survival rate upto age at first calving (1 — m) and average productive life of a cow in this country. The behaviour of these components is studied and the results are presented in Table IV by taking one component at varying level into consideration and keeping others constant.

Annual replacement rate of unproductive cows was having a linear relationship with annual breeding efficiency (e), age at first calving (n) and exponential function $(1-m)^n$ of age at first calving with annual survival rate whereas the annual replacement rate had curvilinear relationship with annual survival rate (1 — m) and average productive life (T).

The partial correlation coefficient of annual replacement rate, with annual breeding efficiency (+ 1.00), age at first calving (— 1.00), exponential function of age at first calving with annual survival rate (+ 1.00), annual survival rate upto age at first calving (+ 0.95) and average productive life (— 0.95) was closer to unity when other components were held constant.

The realistic ranges of breeding efficiency of the stock was between 40-42 per cent (Table I). There was a linear relationship between unproductive cows and breeding efficiency. The correlation coefficient tends to be unity.

Improvements in the breeding efficiency, age at first calving and annual survival rate can be brought about by better managerial practices, manipulation of genetic material like introducing exotic germ plasm and selection within the population generated, which in turn may help in increasing the annual replace-

8. *op. cit.*

9. Institute of Agricultural Research Statistics: Final Report on Repeat Surveys on Milk Production in Punjab, Eastern Uttar Pradesh and Gujarat, Indian Council of Agricultural Research, New Delhi, 1969.

TABLE II—NUMBER OF ADULT COWS (B_t), NUMBER OF COWS REQUIRED TO MAINTAIN EXISTING COW POPULATION (NCREP), NUMBER OF LOW GRADED UNPRODUCTIVE COWS (R), AMOUNT OF DRY MATTER CONSUMED BY UNPRODUCTIVE COWS EVERY DAY (DM(R)), AND STANDARD PRODUCTIVE LIFE (T_2), NUMBER OF HEIFERS ENTERING INTO PRODUCTION (Rf_n), UNPRODUCTIVE COWS TO BE REPLACED (Run), UNPRODUCTIVE COWS TO BE CULLED BY ARTIFICIAL SELECTION ($\triangle B_t$), AVERAGEN ANNUAL MILK PRODUCTION PER COW AFTER POPULATION OPTIMIZATION ($\overline{B}_t$), AVERAGE ANNUAL MILK PRODUCTION PER COW BEFORE CULLING ($\overline{B_t + B_t}$), AND ANNUAL GENETIC GAIN (G_t) IN AN OPTIMIZED POPULATION

Year	B_t (million)	NCREP (million)	R (million/ per cent)	DM(R) (million kg./day)	T_2 (years)	Rf_n = Run (million)	$\triangle B_t$ (million)	$\overline{B}_t$ (kg.)	$\overline{B_t = B_t}$ (kg.)	G_t (kg.)
1951	46.37	35.33	11.34/23.80	44.36	7.62	6.08	4.69	160.90	151.45	0.330
1956	47.26	34.33	12.96/27.42	51.86	7.26	6.51	5.09	173.30	156.55	0.358
1961	51.50	39.25	12.25/23.78	49.00	7.62	7.75	5.21	169.90	154.31	0.337
1966	51.70	39.44	12.33/23.81	49.32	7.62	6.79	5.24	133.70	121.43	0.263
1972	53.72	39.39	12.78/25.65	55.12	7.43	7.22	5.19	150.70	136.75	0.298
1976	55.19	42.56	12.58/23.00	50.76	7.62	6.75	4.89	150.38	137.88	0.268

Assumed constants: Annual mortality rate in adult cows (m_1) in optimized population = 3 per cent.
Generation interval in indigenous cows (GI) = 7 years.
Heritability of milk production in cows h^2 = 0.3.

TABLE III—EFFECT OF POPULATION OPTIMIZATION OR ELIMINATION OF UNPRODUCTIVE COWS (SURPLUS) ON MILK OUTPUT

	Under present situation (1976) when all unproductive cows are eliminated				Under optimized situation when 13 per cent (R) unproductive cows are eliminated			
	Total number of cows	Ratio of cows in milk to total or annual breeding efficiency (per cent)	Annual milk yield per milch cow (kg.)	Total milk output (kg.)	Total number of cows	Ratio of cows in milk to total or annual breeding efficiency (per cent)	Annual milk yield per milch cow (kg.)	Total milk output (kg.)
Before elimination of unproductive cows	100	40.0	380	15,200	100	40.0	380.00	15,200
After elimination of unproductive cows	77	42.0	494	15,976	87	41.2	425.60	15,637
Change (per cent)	—23	+4.5	+30	+5.0	—13	+2.98	+14.8	+3

Milk output = Total number of breedable cows × Annual breeding efficiency or ratio of milch to total × Average annual milk yield/milch cow

TABLE IV—NATURE OF DIFFERENT COMPONENTS, AFFECTING ANNUAL REPLACEMENT RATE OF UNPRODUCTIVE COWS (R) IN AN OPTIMIZED POPULATION

Breeding efficiency(s) when exponential function of age at first calving (n) with annual survival rate is held constant		Age at first calving (n) when breeding efficiency and annual survival rate upto age at first calving is held constant			Annual survival rate upto age at first calving when breeding efficiency and age at first calving is held constant			Average productive life of a cow		
Annual breeding efficiency (e) (per cent)	Annual replacement rate of unproductive cows (R) (per cent)	Age at first calving (years)	Exponential function of age at first calving $(1-m)^n$ with annual survival rate upto age at first calving	Annual replacement rate of unproductive cows (per cent)	Annual survival rate upto age at first calving (per cent)	Exponential functon of age at first calving with annual survival rate $(1-m)^n$	Annual replacement rate of unproductive cows (per cent)	Productive life (T) years	Average age of a cow (T + 4) years	Annual replacement rate of unproductive cows (per cent)
10	3.28	1	0.90	18.00	10	0.0001	0.002	1	5	100.00
20	6.56	2	0.81	16.20	20	0.0016	0.032	2	6	50.00
30	9.84	3	0.77	14.58	30	0.0081	0.160	3	7	33.33
40	13.12	4	0.66	13.12	40	0.0256	0.510	4	8	25.00
50	16.40	5	0.58	11.80	50	0.0625	1.250	5	9	20.00
60	19.68	6	0.53	10.62	60	0.1296	2.590	6	10	16.66
70	22.96	7	0.48	9.56	70	0.2401	4.800	7	11	14.28
80	26.24	8	0.43	8.60	80	0.4096	8.190	8	12	12.50
90	29.52	9	0.38	7.74	90	0.6561	13.120	9	13	11.10
100	32.80	10	0.34	6.97	100	1.0000	20.000	10	14	10.00

Standard value used: Breeding efficiency (e) = 40 per cent.
Age at first calving (n) = 4 years.
Annual survival rate upto age at first calving = 90 per cent.

ment rate of low graded unproductive cows bringing optimization of population and effective improvement in milk production per cow in the country.

Policy Implications

The increasing trend of cattle population should be controlled through the technique of population optimization by annually replacing low graded unproductive cows. The use of proven exotic germ plasm and selection of half bred bulls by testing their progeny with improved management practices should be followed by drastic culling. The population optimization among cattle is a dream till socio-political and religious sentiments are attached to the cow.

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BENEFITS FROM THE HIGH-YIELDING VARIETIES PROGRAMME AND THEIR DISTRIBUTION IN AN IRRIGATED PADDY AREA†

There is a strongly held view that the benefits of the high-yielding varieties (HYVs) technology have not been shared equally between regions or amongst groups of holdings in the same area.[1] On these grounds, it is argued that the HYVP has not been successful, and involves conflict between the achievement of the objectives of growth and social justice. Comparing the performance of the new technology in Mexico, Taiwan and India, Raj[2] observed that the introduction of modern agriculture technology often creates dualism in the agricultural sector rather than modernizing traditional agriculture. In answering Raj's claim, Dantwala[3] argued in the context of the farming structure in India that, but for the high-yielding varieties programme (HYVP), they would have remained below the subsistence level for a longer time and this situation must be preferred to a more 'egalitarian stagnation'. Further, income distribution in agriculture is mainly determined not by the technology but by the Government fiscal policies and the results of defective fiscal policies reflected in more uneven income distribution.

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1. A brief, but comprehensive discussion is given in T. Byres, "Dialectics of Green Revolution", *South Asia Review*, Vol. 5, No. 2, 1972, pp. 99-116.

2. K. N. Raj, "Some Questions Concerning Growth, Transformation and Planning of Agriculture in Developing Countries", *Journal of Development Planning*, Vol. I, No. 1, 1969, pp. 15-38.

3. M. L. Dantwala, "From Stagnation to Growth: Relative Roles of Technology, Economic Policy and Agrarian Institutions", in R. T. Shand (Ed.): Technical Change in Asian Agriculture, Australian National University Press, Canberra, 1973.