OPTIMAL RICE/COLOCASIA CROPPING SYSTEMS IN THE ASHANTI, EASTERN AND CENTRAL REGIONS WITHIN THE SEMI-DECIDUOUS FOREST ZONE OF GHANA

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ABSTRACT
This study is a follow-up survey to investigate the economic viability of the Rice/Colocasia cropping systems introduced by the Root and Tuber Improvement Project (RTIP)/Ministry of Food and Agriculture in the year 2000. It explores the possibility of improving the net earnings of farm families through appropriate farm plans. A Linear Programming model was developed to optimize net income from the Rice and Colocasia enterprises subject to land and labour constraints. The model selected the inter-cropping system as the optimal enterprise in relation to the resources available and allocated 1.2 ha for this cropping system out of the 3 ha available to the typical farm household. The maximum net income obtained from the inter-cropping system for the model farm was ¢ 4,454,726 ($543.26). There was a binding labour constraint for the first weeding of the farming activities with a shadow price of ¢14.65. Due to labour bottlenecks in certain times of the year, farmers paid unrealistic labour wages of up to ¢8,000 which resulted in low labour productivity in the study area. About 56% of the farmers were females with the younger generation forming the majority (58.9%).

Keywords: Economic viability, linear programming models, farm plans, Rice/Colocasia enterprises, shadow prices.

INTRODUCTION

Rice and Taro *(Colocasia esculenta)* are generally grown by smallholder farmers for their own needs. They are traditionally found to be producing low-value crops they are familiar with and this accounts for the low land and labour productivity. For production to increase and to be able to meet the food requirements of farmers and the ever growing non-farming urban population, it is essential that farmers are assisted to produce more to meet demand.

Taro (*C. esculenta)* is cultivated in West Africa, being particularly important subsistence staples in Ghana, Cameroon and Gabon (Karikari, 1980). In some areas such as Asia, they are the dominant root crops in terms of production (Lyonga, 1980; Knipscheer and Wilson, 1981; Purseglove, 1972).

Due to the potential of the two crops being very important in diversified farming aimed at contributing to food security, the Root and Tuber Improvement Project (RTIP)/Ministry of Food and Agriculture in the year 2000, introduced the Rice/*Colocasia* cropping systems. The technology combined an early maturing and a high yielding rice variety (Sikamo) with the local varieties of *Colocasia* and cultivated under three main cropping systems (sole *Colocasia,* sole rice, and inter-cropping). The two crops were cultivated on the same piece of land but they required different overlapping labour time and amounts, and competed for this resource with other crop enterprises and domestic non-farm labour demanding activities.

This paper determines which rice/*Colocasia* cropping system gave the optimum profit. Specifically, the objectives of this paper are: to estimate the yield of *Colocasia* and rice by enterprise type, to estimate the gross margins of *Colocasia* and rice by enterprise type and to recommend prototypical optimum combinations of the Rice/*Colocasia* cropping systems based on resource availability constraints.

The research is justified because it can serve as a useful basis for the development of effective production plans. The effective cultivation of rice and *Colocasia* has the potential to put the lowlands to efficient use.

Many of the resources available to the farmer are not strictly fixed but can be varied because they can be supplemented through hiring or renting of additional units. For example, if the fixed supply of family labour is critical, the farmer might hire additional workers and similarly, land can be rented (Hazell and Norton, 1986). Jaeger and Matlon, (1990) found land and labour to be relatively abundant in both the Sahel and North Guinean zones in their study of utilization of animal draft power for farming. Labour-land ratio was also found to be significantly lower among households equipped with animal traction and higher among households without animal traction in these zones. Majority (65.75%) of farmers in the two regions of Ruvuma and Kilimanjaro in Tanzania were willing to expand their food crop farms in response to a structural adjustment policy which engendered greater resource management and trade liberalization (Sankhayan, 1995). The decision to expand was based on the availability of production factors, mainly land, labour and capital. It is therefore hypothesized that, the resources available to the typical farm household in the study area are sufficient to undertake all three enterprises of Rice and *Colocasia.*

MATERIALS AND METHODS

Data types, sources and analysis

To achieve the objectives of the study, both primary and secondary data were used. The data types included survey data (primary) and farm experimental data on the adaptive research trial farms (yields and level of input use) and other sources of information such as books, journals and both published and unpublished research works. The analytical tool was Linear Programming, which is a mathematical programming technique for the construction of constrained optimization problems whose objective function and constraints are assumed linear (Dorfman *et al,* 1958; Agrawal *et al,* 1972; Beneke and Winterboer, 1973). Such a model was developed to optimize net incomes from a set of the rice and Colocasia enterprises subject to land and labour constraints. The data which pertained to enterprise capacities, prices and resource availabilities was incorporated into the Linear Programming model. The Simplex algorithm was the method used for solving the model.

Sample selection and sampling technique

Sampling leading ultimately to the choice of a prototypical farm within the study area was done as follows.

The selection of five districts (viz. Afigya Sekyere, Kumasi, Ahafo Ano South, Kwaebibirem and Asikuma Odobin Brakwa) and subsequently, the towns and villages (Jamasi, Mankranso, Kunsu, Beposo, Appiadu, Deduako, Gyinyase, Breman Benin and Okumaning) was purposive. This was so because the adaptive research trial farms and farmers were located in these areas where the RTIP project was on-going and monitored.

Selection of the representative farm

In practice, it is not feasible to model each individual farm. For this reason, a representative farm was used for the five districts.

Because the RTIP adaptive research farmers cultivated the same land size in all the districts, the only variation that was considered in the selection of the representative farm was the yield. A cluster analysis was conducted to classify sample farms into homogeneous groups to reduce aggregation bias. The cluster analysis grouped all the farms into one category, indicating homogeneity in yield for the farmers in the study area. Due to this homogeneous nature, and because the mean and the median values were found to be very close, the arithmetic mean farm was used and considered as a single large farm for the construction of the Linear Programming model.

The linear programming model

The linear programming model maximizes the net income from the three enterprise types of sole rice, sole *Colocasia* and rice/*Colocasia* combination subject to land and labour constraints. The farm plan has activity levels of *Colocasia* and rice represented by X_i, where i = 1 up to n and n denotes the number of enterprises. In this case n = 3.

The average land holding per household for cultivation in the study area (i.e. both cultivated and uncultivated) was found to be a little over 3ha.

In view of the above, some operational assumptions were made as follows:

a) Only 3 ha of land were available to the farm household.
b) Rice and *Colocasia* are the most profitable food crops grown by farmers in the study area.
c) Fixed costs such as the cost of hoes and cutlasses were not considered (i.e. fixed costs were assumed to be zero) for the study period.
d) Family labour was used and paid for at the going rate per man-day in the study area.
e) Decisions taken by the farmers were timely and appropriate at any one stage of their farming activities.
f) All conditions of climate and soil on a piece of land were considered everywhere the same and that one specific method of cultivation was applied.
g) Farmers took their holidays in off-peak periods (Barnard and Nix, 1994).
h) All the farmers were willing to produce and sell *Colocasia* and rice (*sikamo*).
i) The same technology is applied by all farmers.

The simplex method was used to obtain the optimal solution after explicitly identifying the constraints and their relevant coefficients. The farm plan must have the largest possible net revenue (profit) Z that does not violate any of the fixed resource constraints. One planning period was considered and that consisted of the growing seasons for rice and *Colocasia*. The farmers took major decisions like land preparation, planting, weeding and harvesting at various time periods of the growing season. The growing season was divided into T equal periods (i. e. in months) and grouped into the various farming activities or operations and numbered j = 1, 2 ,..., T (Hazell and Norton, 1986).

The objective function and constraint equations for the basic programme are as follows:

The objective function

Maximize $Z = S^{n}_{i=1} P_i a_i X_i - C_i b_i X_i$ (1)

$= S^{n}_{i=1} (P_i\, a_i - C_i b_i)\, X_i$

Where, Z is the net revenue (profit) from the n–enterprises.

X_i is the number of ha for each enterprise.

P_i is the price per unit of output (cedis).

a_i is the yield per ha (bags).

C_i is the cost per unit of input (cedis).

b_i is the amount of inputs per ha.

The constraint inequalities

The land and labour constraint inequalities are as follows:

$S^{n}_{i=1}\, k_i X_i \pounds K$ (2)

$S^{n}_{i=1}\, l_{ji} X_i \pounds L_i$ (3)

Where K and L_i respectively represent land and labour input levels.

With regard to the three general expressions above, equation (1) is maximized subject to constraint inequalities (2) and (3).

More explicitly, we may state the linear programming problem as follows:

Maximize $Z = S^{n}_{i=1} (P_i a_i - C_i b_i) X_i$

Subject to

$S^{n}_{i=1}\, k_i X_i \pounds K$ (4)

$S^{n}_{i=1}\, l_{1i} X_i \pounds L_1$ (5)

$S^{n}_{i=1}\, l_{2i} X_i \pounds L_2$ (6)

$S^{n}_{i=1}\, l_{3i} X_i \pounds L_3$ (7)

$S^{n}_{i=1}\, l_{4i} X_i \pounds L_4$ (8)

$S^{n}_{i=1}\, l_{5i} X_i \pounds L_5$ (9)

$S^{n}_{i=1}\, l_{6i} X_i \pounds L_6$ (10)

$S^{n}_{i=1}\, l_{7i} X_i \pounds L_7$ (11)

where, k_i in expressions (2) and (4) denotes the coefficient related to land required for each enterprise and K is the available land in ha for the cultivation of rice, *Colocasia* and the two most important other food crops (i.e maize and cassava).

L_1 and l_{1i} correspond to available and required labour respectively for land preparation for February/March.

L_2 and l_{2i} correspond to available and required labour respectively for planting in April.

L_3 and l_{3i} correspond to available and required labour respectively for first weeding and

fertilizer application in May.

L_4 and l_{4i} correspond to available and required labour respectively for second weeding in June.

L_5 and l_{5i} correspond to available and required labour respectively for birds scaring

and harvesting of rice in July/August.

L_6 and l_{6i} correspond to available and required labour respectively for third weeding in September on the *Colocasia* farm.

L_7 and l_{7i} correspond to available and required labour respectively for harvesting *Colocasia* in November/December.

The labour available in a year for rice and *Colocasia* cultivation was divided equally among the 12 months and later grouped according to farm activities as indicated above (Hazell and Norton, 1986).

Sensitivity Analysis

Stability is tested under *ceteris paribus* conditions, whereby the effect of a change in a single coefficient is considered with all other coefficients held constant. This stability of the final solution refers to the degree of variation in a particular coefficient that could be absorbed by the model before a change in the basis could occur (Johnson, 1985). In agriculture most technologies are sensitive to changes in four principal areas. These include price, delay in implementation, cost over run and yield (Gittinger, 1984).

RESULTS AND DISCUSSION

As preliminary results, we present some demographic and social characteristics of the Study Area.

Age distribution

The demographic data revealed that the average age of the farmers was 43.9 years, in a range of

Table 1: Age distribution of respondents

Age of farmer (years)	Freq.	Percentage	Cum. Percentage
16-25	2	5.9%	5.9%
26-35	7	20.6%	26.5%
36-45	11	32.4%	58.9%
46-55	9	26.4%	85.3%
56-65	4	11.8%	97.1%
Over 65	1	2.9%	100.0%
Total	34	100.0%	

Source: Field Survey – 2002

22-78 years and standard deviation of 11.75. Table1 shows that majority (58.9%) of the farmers age fell within the age range of 16 – 45 years. This shows that younger and more energetic farmers are engaged in rice and *Colocasia* production in the study area, indicating that the production of these crops is laborious. Many older farmers seem to avoid the cultivation of rice and/or *Colocasia* because of their high demand on labour.

Gender distribution

The majority of the farmers (56%) were women (Table 2). The involvement of more women in the production of *Colocasia* in particular shows that it is grown as a food security crop because women are more concerned when it comes to food security matters (Anda, 1978; Boampong, 1989; Bortei-Dorku, 1990).

Table 2: Gender distribution and the type of crop cultivated

Sex	Frequency	Percent Frequency
Male	15	44.1%
Female	19	55.9%
Total	34	100.0%

Source: Field Survey – 2002

The Land tenure arrangement

Very few of the farmers (11.8%) hired land for cultivation because of the land acquisition arrangement problems associated with *Colocasia* in particular. In that arrangement, the landowners usually take their land back after the first year of cultivation. This type of land title arrangement discourages the farmer from cultivating large portions of *Colocasia* and for that matter its combination with rice as the farmer benefits more in the subsequent years of cultivation through ratooning. The farmer in the subsequent years has an additional benefit of selling out *Colocasia* suckers to other interested farmers to earn extra revenue.

Table 3: Land tenure system

Tenure system	Freq.	Percent Frequency	Cum. Frequency
Own land	19	55.9%	55.9%
Family land	9	26.4%	82.3%
Cash hire	4	11.8%	94.1%
Others	2	5.9%	100.0%
Total	34	100.0%	

Source: Field Survey – 2002

Farm size

The same farm sizes (0.2ha) in all the five districts were put under cultivation of each of the cropping systems of sole rice, sole *Colocasia* and rice/*Colocasia* combination by the RTIP research trail farmers. Due to this, the only variation considered for classification was the yields.

Yields of rice and *Colocasia*.

Due to the homogeneous nature in yield as stated earlier, and because the mean and the median yield values were found to be very close, the arithmetic mean yield was used to classify the various cropping systems into single large farms (Table 4).

Table 4: Average Yields of rice and *Colocasia*.

Cropping system	Average Yield (tons/ha) – Model Farm
Sole Rice	2.050
Sole *Colocasia*	21.894
Rice/*Colocasia*	1.160 (12.514)

Source: Field Survey – 2002

Note: Figure in parenthesis is the average yield for *Colocasia*

Gross margin estimation

The average figures in Table 4 above were used for the calculation of the gross margins as shown in Table 5 and subsequently used in the Linear Programming model.

Table 5: Summary of the gross margins by enterprise

Cropping system	Gross margins-Model Farm
Sole Rice	¢2,344,750.00 ($285.95)*
Sole *Colocasia*	¢3,572,500.00 ($435.67)*
Rice/*Colocasia*	¢3,956,500.00 ($482.50)*

Source: Field Survey – 2002

**Dollar rate at the time of the study was $1=¢8,200*

Optimum combination of the three enterprises

The land and labour inputs determined were used in addition with the gross margins as shown in Table 5 to analyze the LP problem.

Formulation of LP model and Solution by the Simplex method

The model was developed in the face of the earlier mentioned operational assumptions. The explicit expressions for the resulting LP model are as follows:

Maximize Z

$$= 2,344,750\ X_1 + 3,572,500\ X_2 + 3,956,500\ X_3$$

Subject to

$$X_1 + X_2 + X_3 \leq 3 \quad (12)$$

$$160,000\ X_1 + 160,000\ X_2 + 160,000\ X_3 \leq 352,000 \quad (13)$$

$$80,000\ X_1 + 64,000\ X_2 + 80,000\ X_3 \leq 272,000 \quad (14)$$

$$264,000\ X_1 + 248,000\ X_2 + 270,000\ X_3 \leq 304,000 \quad (15)$$

$$248,000\ X_1 + 248,000\ X_2 + 256,000\ X_3 \leq 296,000 \quad (16)$$

$$255,000\ X_1 + 120,000\ X_3 \leq 243,000 \quad (17)$$

$$240,000\ X_2 + 120,000\ X_3 \leq 224,000 \quad (18)$$

$$360,000\ X_2 + 150,000\ X_3 \leq 320,000 \quad (19)$$

Where Z is the profit and X_1, X_2 and X_3 are the allocation of land to sole rice, sole *Colocasia* and rice/*Colocasia* combination respectively. The coefficients of X_1, X_2 and X_3 were drawn from the gross margin table (Table 5).

Interpretation of the Final Simplex Tableau

Optimality test

Since all the entries in the last row are at most zero, it follows from the final tableau that optimality had been reached (Table 6). It can be seen from Table 6 that the programme selected the inter-cropping system as the optimal enterprise (Figure 1 in the forth row of the third column is indicative) with a corresponding land allocation of approximately 1.2ha (figure 1.155926 in the fourth row of the last column is also indicative). This was as a result of the benefits usually associated with inter-cropping or diversified farming which provides greater yield per unit area (Dayal *et al*, 1967; Fisher, 1977). It however determined zero land allocation to the cultivation of sole rice and sole *Colocasia.* The values corresponding to the crop (real) activities (i.e.1523828 and 61618.62) in the first and second columns of the last row indicate by how much the per ha gross margins of sole rice and sole *Colocasia* respectively would have to be increased before they could be introduced into the farm plan without reducing Z.

Shadow prices

The values (entries) in the last row of the final tableau (Table 6) corresponding to the slack ac-

Table 6: The final simplex tableau

2.222222E-02	8.1481E-02	0	1	0	0	-3.703704E-06	0	0	0	0	1.844074
3555.555	13037.03	0	0	1	0	-0.5925926	0	0	0	0	171851.9
1777.778	-9481.483	0	0	0	1	-0.2962963	0	0	0	0	181925.9
0.977778	0.9185185	1	0	0	0	3.703704E-06	0	0	0	0	1.155926
-2311.111	12859.25	0	0	0	0	-0.9481481	1	0	0	0	7762.970
137666.7	-110222.2	0	0	0	0	-0.4444444	0	1	0	0	107888.9
-117333.3	129777.8	0	0	0	0	-0.4444444	0	0	1	0	88888.89
-146666.7	222222.2	0	0	0	0	-0.5555555	0	0	0	1	151111.1
-1523828	-61618.62	0	0	0	0	-14.6537	0	0	0	0	-4454726

THE BIGGEST UNIT YIELD IS: 0 AND THE COLUMN NUMBER IS: 3
THE MAXIMUM YIELD IS: ¢4,454,726

tivities or variables (S) are the shadow prices. Shadow prices are the valuations derived from the amount of the increase in contribution that would have arisen if one more unit of a scarce resource were made available. For resources that are not completely used, this value is zero (Kay and Edwards, 1994). It must be noted here that, in maximization problems, the shadow and the dual prices are the same. The value for the slack variables in the last row (i.e. columns 4,5,6,8,9,10 and 11) of the solution in Table 6 is zero and that for column 7 of the same row is -14.6537 (shadow price). Each of the slack variables is associated with a particular constraint of the problem. From the final tableau, the slack variables S_1, S_2, S_3, S_5, S_6, S_7 and S_8 have spare capacities of labour as shown in the last column of Table 6 and so the corresponding constraints were not scarce resources. This means that no value is gained in the objective function by altering these constraints. On the other hand, labour available for first weeding had been completely used up and is thus a scarce resource. Labour migration creates labour bottlenecks in certain parts of the year resulting in higher labour cost in the study area. This phenomenon results in low labour productivity which does not commensurate the average labour cost of ¢8,000 in the study area. The ¢14.65 in practice is what the farmer would be willing to pay for one more unit of labour.

Post Optimality Analysis

Range of optimality of the objective and the constraint function coefficients

The following changes are the ranges in which the basis of the final tableau will be unchanged. The usual sensitivity analysis for linear Programming involves computing ranges (i. e. range of optimality) for the objective and the constraint function coefficients. As long as the actual value of the objective function and the constraint coefficients are within the range of optimality, the current basic feasible solution will remain optimal.

Table 7: Change in the objective function coefficients

Enterprise	Initial objective function coeff.(A)	Allowable coef. increase (B)	Allowable coef. decrease (C)	Range of optimality
Sole Rice	¢2,344,750	¢1,523,828	¢2,344,750	¢0*£X_1£¢3868578.00**
Sole *Colocasia*	¢3,572,500	¢61,618.62	¢ 489,226	¢0*£X_2£¢3634118.62**
Rice/*Colocasia*	¢3,956,500	¢ 489,226	¢59,346.50	¢3897152.50*£X_3£¢4454726**

Source: Field Survey – 2002
**Lower bound figure =A-C*
***Upper bound figure = A+B*

From Table 7, the gross margins of sole rice and sole *Colocasia* could be increased up to ¢1,523,828 and ¢61,618.62 or decreased to zero Cedis respectively without the optimal solution being affected. In the case of rice and *Colocasia* combination, a reduction of profit by ¢59,346.50 (1.5%) did not affect the optimal solution.

Table 8: Change in the Right Hand Side (RHS) of the constraint

Constraint	Initial const. Figures (A)	Allowable increase (B)	Allowable decrease (C)	Range of optimality
Land (K)	3 ha	Up to 20 ha	By 1.5 ha	1.5*≤K≤23
Labour (L_1)	¢352,000	infinity	20 man-days (¢160,000 ***	¢192,000*≤ L_1 ≤ infinity**
Labour (L_2)	¢272,000	infinity	22 man-days (¢176,000)***	¢96,000*≤ L_2 ≤ infinity **
Labour (L_3)	¢304,000	1 man-day	None	¢304,000*≤L_3≤¢305,000**
Labour (L_4)	¢296,000	infinity	7 man-days (¢56,000)***	¢240,000* ≤ L_4 ≤ infinity**
Labour (L_5)	¢243,000	infinity	13 man-days (¢104,000)***	¢139,000*≤ L_5 ≤ infinity**
Labour (L_6)	¢224,000	infinity	10 man-days (¢80,000)***	¢144,000*≤ L_6 ≤ infinity**
Labour (L_7)	¢320,000	infinity	19 man-days (¢152,000)***	¢168,000*≤ L_7 ≤ infinity**

Source: Field Survey – 2002
**Lower bound figures = A-C*
***Upper bound figurese = A+B*
**** Figures in parenthesis are the values of the corresponding labour man-days*

From Table 8, it will be economically unwise for any farmer in the study area to increase labour on the rice/*Colocasia* farm at the going average rate of ¢ 8,000 per man-day.

CONCLUSION AND RECOMMENDATIONS

The Linear Programming model selected the rice/*Colocasia* inter-cropping system as the optimal enterprise. The LP model determined zero land allocation to both sole rice and sole *Colocasia* enterprises and 1.2ha for the rice/*Colocasia* inter-cropping system out of the 3ha available to the typical farm household. Since the model selected only one enterprise (Rice/*Colocasia* inter-cropping system) based on the resources available, it is concluded that the resources available to the farm household are insufficient to undertake all three enterprises. Hence, the expectation (hypothesis) that the resources available to the typical farm household were sufficient to undertake all three enterprises was rejected. The most critical constraint selected by the model corresponded to the labour available for first weeding. Farmers in the study area pay more than the economic rate for labour due to the existence of labour bottlenecks in certain parts of the year as a result of some labour emigration. The farmers, in practice, should be paying only ¢14.65 per unit of labour instead of the exploitative average rate of ¢ 8,000 per man-day which account for the low labour productivity. It is therefore recommended that RTIP and supporting Agricultural Extension Agents (AEAs) educate farmers on the importance of production diversification (inter-cropping) and of the efficient use and allocation of land and labour resources in producing high-value crops in order to improve both land and labour productivity since a suitable farm plan had been provided by this study.

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APPENDIX A

The computer output of the LP programme

TABLE AU: 1

1	1	1	1	0	0	0	0	0	0	0	3
160000	160000	160000	0	1	0	0	0	0	0	0	352000
80000	64000	80000	0	0	1	0	0	0	0	0	272000
264000	248000	270000	0	0	0	1	0	0	0	0	304000
248000	248000	256000	0	0	0	0	1	0	0	0	296000
255000	0	120000	0	0	0	0	0	1	0	0	243000
0	240000	120000	0	0	0	0	0	0	1	0	224000
0	360000	150000	0	0	0	0	0	0	0	1	320000
2344750	3572500	3956500	0	0	0	0	0	0	0	0	0

THE BIGGEST UNIT YIELD IS: 3956500 AND THE COLUMN NUMBER IS: 3

TABLE AU: 2

2.222222E-02	8.148146E-02	0	1	0	0	-3.703704E-06	0	0	0	0	1.844074
3555.555	13037.03	0	0	1	0	-.5925926	0	0	0	0	171851.9
1777.778	-9481.483	0	0	0	1	-.2962963	0	0	0	0	181925.9
.9777778	.9185185	1	0	0	0	3.703704E-06	0	0	0	0	1.155926
-2311.111	12859.25	0	0	0	0	-.9481481	1	0	0	0	7762.970
137666.7	-110222.2	0	0	0	0	-.4444444	0	1	0	0	107888.9
-117333.3	129777.8	0	0	0	0	-.4444444	0	0	1	0	88888.89
-146666.7	222222.2	0	0	0	0	-.5555555	0	0	0	1	151111.1
-1523828	-61618.62	0	0	0	0	-14.6537	0	0	0	0	-4454726

THE BIGGEST UNIT YIELD IS: 0 AND THE COLUMN NUMBER IS: 3
THE MAXIMUM YIELD IS: 4454726

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