ENERGY SUPPLEMENTATION AND PRODUCTIVITY OF GUATEMALAN SUGAR-CANE CUTTERS: A LONGITUDINAL APPROACH[1]

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SUMMARY

A long-term energy supplementation program was carried out to determine its effect on the productivity of agricultural workers in Guatemala. The program provided, free of charge, a low-energy (24 Kcal) and a high-energy (350 Kcal) bottled, orange-flavored soft drink to two groups of long-term resident sugar-cane cutters who worked on the same plantation, located in the Pacific Coast.

Previous to, and periodically thereafter during implementation of the program, data relative to energy intake and anthropometry were collected. Through data obtained from payroll lists, a longitudinal series of average productivity (tons of sugar cane cut and loaded per day) covering 48 weeks of pre-supplementation, 90 weeks of supplementation ,and 21 weeks post-supplementation, was constructed. Control of the supplement consumption was daily observed. Random assignment of workers to the high-energy supplement (HES) and the low-energy (LES) groups, was not possible.

Prior to supplementation both groups presented the same characteristics in terms of age, energy intake level, weight, height, tricipital adiposity and daily productivity.

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Little variation was found throughout the time the supplement was consumed by the HES Group. Energy intake of workers increased significantly in absolute terms in relation to the LES Group, except towards the end of the 28 months' supplementation period. Energy balance was maintained by workers throughout the study period.

A time series of the difference in mean productivity of the two supplement groups (Y_t) was modeled using the ARIMA techniques. No auto-regressive term was present in the Y_t series. The ARIMA (0,0,1) model was fitted and expanded with different intervention components.

None of the estimated parameters of the intervention components were statistically significant. It was therefore concluded that no abrupt, or gradual and sustained energy supplementation effect on productivity was present.

INTRODUCTION

This paper reports the results of a study carried out to assess the effects of long-term energy supplementation on the productivity of rural workers in Guatemala. Much of the evidence of the effect of deficient energy intake and nutritional status of workers in developing countries on their productivity comes from cross-sectional studies. Body composition parameters have been shown to be associated with work performance in different occupational groups and in different settings (1-5). Physical working capacity of rural workers in developing countries, particularly of sugar-cane cutters, appears to be positively associated with their daily productivity (2, 6, 7).

There is little empirical evidence relative to long-term energy supplementation and its impact on worker productivity. An earlier study in Guatemala retrospectively demonstrated significant productivity differences in groups of agricultural workers after one group had been supplemented for two-and-a-half years (5). However, the productivity levels of both groups before supplementation in one group was started,were not known. Two small groups of rice farmers in India who were maintained on daily energy intake levels of 3,000 and 2,400 Kcal, respectively, showed no difference in work performance after 90 and 112 days (8). A recent study with rural road workers in Kenya reported a mean increase in daily productivity of 12.5% after an average of 53 days of energy supplementation, an increase which was only statistically significant at the 0.10 level (9).

The issue as to under what conditions (if any) energy supplementation results in higher worker productivity directly relates to the measurement of functional consequences of marginal malnutrition (10), and to the definition of energy requirements for economically active population groups. A great deal of additional evidence will be required, however, before specific pronouncements can be made.

MATERIAL AND METHODS

The study setting, research design and supplementation program have all previously been described in some detail (11). Two groups of resident sugar cane cutters who worked on the same plantation were included in the study. The sugar cane harvesting season is normally extended from the middle of November until July. During this period the workers cut and loaded cane and were paid a piece rate per ton of cane delivered. They decided on their own working hours during cane harvesting when work availability is generally unrestricted. A food ration was earned in addition to the monetary wage for each day worked. The workers were long-term residents of two plantation communities. Both groups of workers were consistently assigned to separate cane fields. Because of within-group interaction, workers could not be randomy assigned to a high-energy supplement (HES) group (n = 95) and a low-energy supplement (LES) group (n = 63). The non-random assignment of workers to either group may potentially pose a threat to the internal validity of the research design.

The high energy supplement consisted of a bottled, orange-flavored soft drink which was delivered 11 times a week twice a day Monday through Friday, and once on Saturday. When consistently consumed, supplementation provided 550 Kcal/day over a seven-day period. The low energy supplement was identical in appearance, but was sweetened with a low caloric synthetic sweetener, and provided 24 Kcal/day over a whole week. Each supplement contained vitamin A (3.7 mg/350 ml) and vitamin C (16 mg/350 ml). The experiment was conducted in double-blind fashion. Both supplements were offered at no charge to the workers with a high acceptance of both throughout the supplementation period. The program was started in April 1974 and was terminated 28 months later (August 1976).

Data collection was initiated in January 1974, and for certain data, did not terminate until May 1977. The productivity data (tonnage of sugar cane cut and loaded) were obtained from company payroll records, and cover (a) a pre-supplementation period of 48 weeks (for which data were retrospectively obtained); (b) the supplementation period of 90 weeks, and (c) a post-supplementation term of 21 weeks. Daily supplement intake by each worker was continuously monitored, and supplements were consumed under direct supervision of project staff at about 8:00-9.00 a.m and at 12 noon. Periodically, the dietary intake of the workers was obtained using the one-day recall method. Anthropometric measurements (body weight, height, mid-upper arm and leg circumferences, and triceps skinfolds) were also periodically taken.

Rigorous statistical techniques to analyze time series data have recently been developed. Reference is made to a class of stochastic process models called Auto-regressive Integrated Moving Average or ARIMA models originally developed by Box and Jenkins (12). A comprehensive treatment of these models may be found in McCleary and Hay (13). The general approach is to estimate the process that underlies the data series, and to analyze the auto-regressive, integrated and moving average components of the model. Next, impact assessment models can be defined to analyze whether: (a) there was an abrupt shift in the series at the time the intervention was introduced, (b) a gradual and permanent shift, or (c) a gradual and temporary shift. The ARIMA technique has the advantage over regression analysis in that if the series represents a stochastic process rather than a trend, the latter technique can lead to incorrect conclusions about the impact of the intervention.

We first analyzed statistically the effect of energy supplementation on the total energy intake of the HES Group workers during the complete supplementation period. Next, the time series of the productivity data was submitted to the ARIMA technique to estimate the underlying stochastic process as explained above. In order to confirm our interpretation of the pattern of auto-correlations and partial auto-correlations as to the stochastic process, a second technique recently developed by Pandit and Wu was applied (14). This technique does not rely on curve fitting, but instead uses a reiterative process to estimate an n^{th} order differential equation which completely describes the dynamic system that underlies the data series. We used the sub-routine BMDP2T of the BMDP Statistical Package to estimate the parameters of the ARIMA models herein presented.

RESULTS

General characteristics of the workers have been previously reported in some detail (11). Their median age was 31 yr with a range of 17 to 73 years. Mean height was 159.5 (SD ± 5.6) cm, mean weight 53.3 (SD ± 5.9) kg and mean daily energy intake 2,951 (SD ± 689) Kcal prior to supplementation. Triceps skinfolds ranged from 2.7 to 11.8 mm, with a mean of 4.7 (SD ± 1.6) mm which is below the fifth percentile of norms reported by Frisancho (15), thus providing further evidence of low energy stores in these workers. Mean daily productivity before supplementation was 1.22 (SD ± 0.14) tons with a range of 0.90 to 1.55 tons/person/day which was low compared to daily productivity levels notified for sugar cane cutters in other developing countries (2, 4, 6, 7). These workers were thus generally lean and muscular and demonstrated low daily productivity levels. The two supplement groups were well matched before the supplementation program was started. There were no significant differences in mean age, mean daily energy intake, mean height, weight and triceps skinfold, and mean daily productivity (Table 1). Mean daily energy intake per kg body weight did not differ significantly between the two groups.

Throughout the supplementation period, there was little inter-temporal variation in the median supplement intake in the HES Group (Figure 1). The median supplement intake as per cent of the total times offered was 91.8º/o for the 1973/74 harvest period, and 90.9º/o and 91.7º/o for the 1974/75 and 1975/76 harvest period, respectively. Half of the HES Group workers consistently obtained at least 500 Kcal/day from the supplement during each harvest period. Thus, any significant variation in net increase in daily energy intake of the HES Group during the supplementation period was most likely the result of a significant change in home energy intake.

Previously presented results for the first half of the supplementation period demonstrated that a net increase in total energy intake of the HES Group resulted with some substitution for home energy intake. Averaged over this period, the net increase amounted to 300 Kcal/day (11). Dietary intake surveys were conducted during the 19th, 22nd, 24th and 27th months of supplementation (Figure 2). The increase (over-presupplementation levels) in total energy intake by the HES Group workers remained significant during the 19th and 22nd supplementation months, but decreased to zero during the last months. No significant differences in changes in total energy intake between the two groups occurred during

TABLE 1

SAMPLE CHARACTERISTICS OF THE TWO SUPPLEMENTATION GROUPS. PRE-SUPPLEMENTATION PERIOD
($\bar{x}$ SE)

Sample Characteristic	High Energy Supplement (HES) Group (n = 95)	Low Energy Supplement (LES) Group (n = 63)
1. Age (yr)	35 5	34.4
	(1.2)	(1.3)
2. Energy intake (Kcal/24 hr)	2,899.0	3,048.0
	(88 0)	(105 0)
3. Body weight (kg)	53.5	52 6
	(0.9)	(0.9)
4. Height (cm)	159.0	160.4
	(0.9)	(0.9)
5. Triceps skinfold (mm)	4.8	4.6
	(0.2)	(0 3)
6. Sugar cane cut and loaded (ton/person/day)	1 23	1.21
	(0.02)	(0.02)

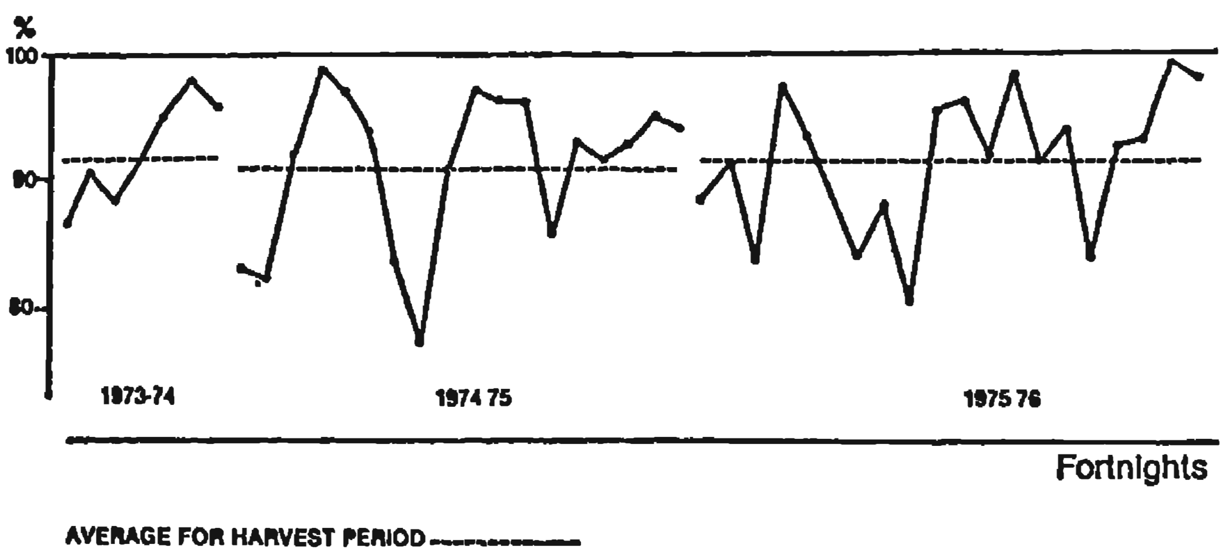

FIGURE 1

Median time supplement was consumed as per cent of total time offered fortnight — HES Group workers

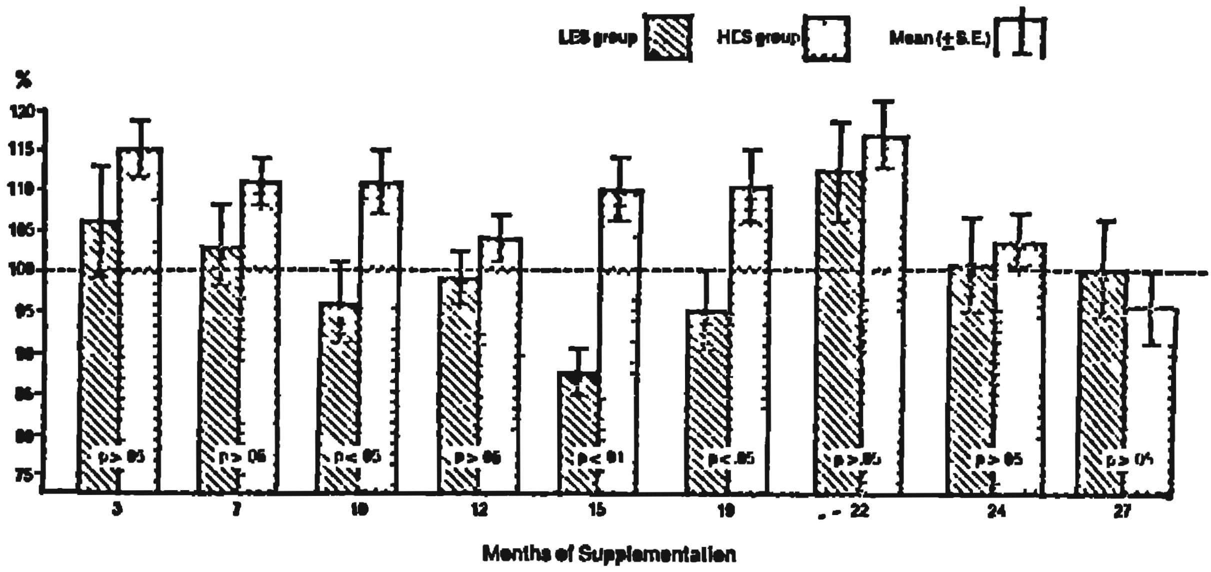

FIGURE 2

Total energy intake during selected supplementation months, expressed as per cent of pre-supplementation intake levels, by supplement group

the 1975/76 harvest season (= supplementation months 22, 24, and 27).

Periodic measurements of body weight and triceps skinfold were taken in order to monitor whether the HES Group workers maintained energy balance during supplementation relative to LES Group workers. The latter group demonstrated more inter-temporal variation in body weight than the HES Group (Figure 3). With the exception of weight measurements at 21 months, there were no significant differences in mean weight changes between the two groups. The mean increase in body weight of the HES Group workers during the 13th and 18th supplementation months amounted to 2.1% (= 1.1 kg) and 2.5% (= 1.3 kg), respectively. Supplementation months 6 and 18 fell in between harvest periods, when work availability was restricted.

Skinfold measurements have a greater inherent error than weight measurements, a fact which may account for the greater inter-temporal variation in the former. The triceps skinfold measurements taken during supplementation months 3, 13 and 25 showed decreases, especially among the HES Group workers. The loss in tricipital adiposity reflects most likely the intensification of cane harvesting activities towards the end of the harvest period. Nevertheless, the magnitude of the absolute changes in the skinfold measurements is so small, that they are not reflected in the body weight measurements. In any event, none of these data provided evidence that there was a consistent pattern of increased energy stores with supplementation among the HES Group workers.

We conclude that up to the 22nd month of supplementation the HES Group workers significantly increased their total energy expenditure level. During the last months of the supplementation period, the level of substitution of energy from the supplement for home energy intake approx-

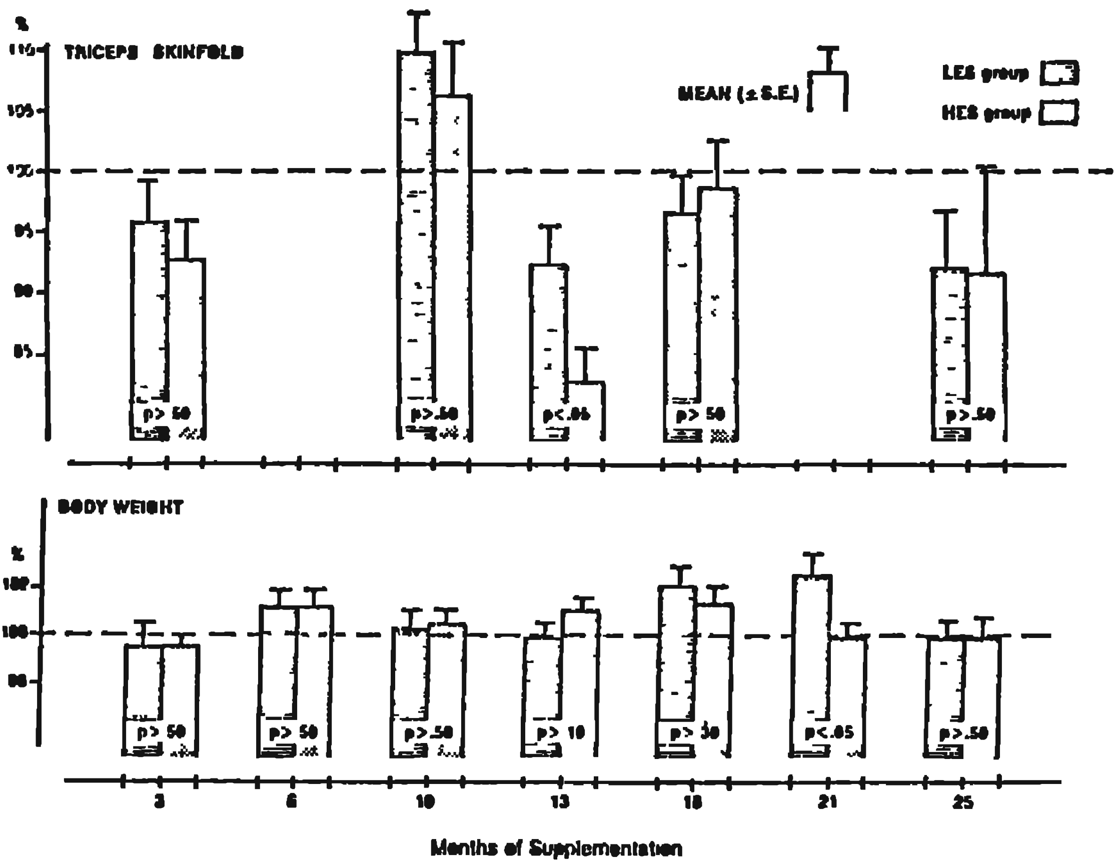

FIGURE 3

Body weight and triceps skinfold during selected supplementation months, expressed as per cent of pre-supplementation levels

imated 100°/o. The total energy intake by both groups returned to approximate pre-supplementation levels at the end of supplementation

The productivity series fot the two supplementation groups during pre- and post-supplementation are presented in Figure 4 The observations represent group means of daily output calculated over weekly periods. Visual inspection of the graph suggests that. (a) during the 1972/73 and 1973/74 harvest seasons the HES Group mean exceeded the LES Group mean as often as the opposite was true, (b) during the 1974/75 harvest the LES Group mean more often exceeded the HES Group mean, while the reverse was true during the 1975/76 harvest season. Observations during the post-supplementation period are further excluded from the time-series analysis because there are too few data points to provide a valid test of the effect of *withdrawal* of the supplements on productivity.

In applying the ARIMA time series techniques, the LES Group means were substracted from the HES Group means to generate one single series (Y_t)[7]. The analysis then proceeds in two steps: first, we modeled the underlying process of the series, and then determined whether either a shift or an asymptotic change took place in the series at the time the supplements were introduced. A number of assumptions are made. 1) both groups did not significantly differ prior to supplementation in attributes (age, body composition, energy intake), which was indeed the case, as previously stated; 2) the productivity of both groups was affected in the same way by extraneous factors over the measurement period, a weak assumption, and 3) the underlying process of the two group series is the same (in which case the Y_t series is a direct function of the difference in the random errors assumed to be normally distributed in the two series).

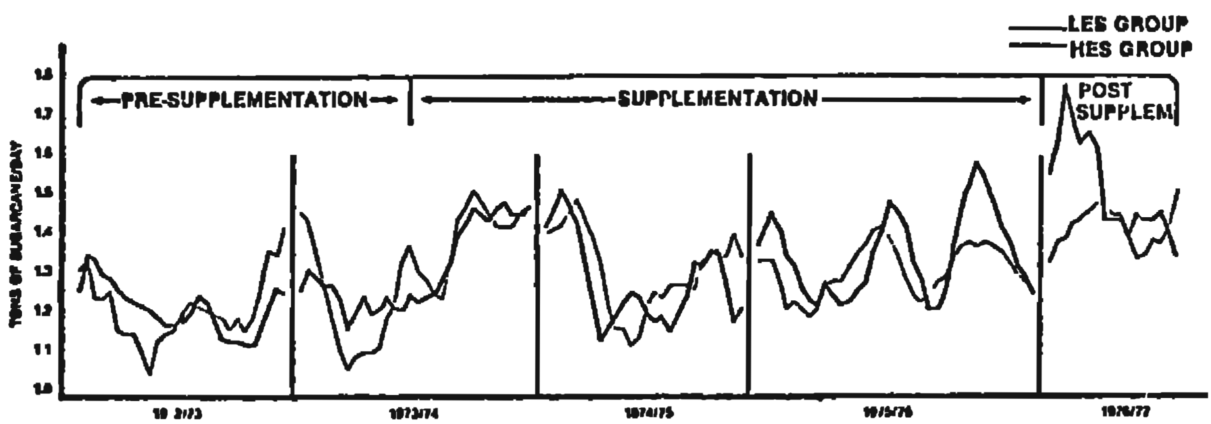

FIGURE 4

Mean daily supply of work units (tons of sugar cane) of the two supplement groups during pre-and post-supplementation (five-week moving average)

In order to establish a pre-intervention base, the Y_t series for the presupplementation period was modeled by the Box-Jenkins approach (12). Examination of the auto-correlation and partial auto-correlation patterns in the Y_t series suggested a moving average model The absence of any auto-regressive terms in the Y_t series became clear when examining the R-S array and the pattern of generalized partial auto-correlations This model specification was later confirmed when applying the systems dynamics approach to process identification of Pandit and Wu (14). Thus, the ARIMA (0,0,1) model was fitted:

$$Y_t = e_t - \Theta e_{t-1} \quad (1)$$

or

$$Y_t = (1 - \Theta B)e_t \quad (2)$$

7 The alternative would have been to analyze solely the HES Group series, since software to test for statistical differences in the underlying process and in the impact of an intervention on two different but comparable series, is not available.

where.

Y_t = $CANE_t^{hes} - CANE_t^{les}$ $t = 1, ..., 48$
CANE = weekly group means of cane/day (tons)
Θ_i = the i^{th} moving average parameter
B = the backward shift operator
e_t = the t^{th} random shock of a white noise process

The moving average parameter which was estimated was statistically significant. The ARIMA (0,0,1) model is then.

$$Y_t = e_t - (-.4303)e_{t-1} \quad (3)$$

The standard error of Θ is .1334, and the t-statistic equal to −3.22 ($p < .01$). The residuals after fitting the model were white noise (= series of normally distributed, independent random shocks)[8].

The next step is to apply the intervention analysis, by introducing an intervention component into eq. (1). The model was estimated with three different intervention components which test for: (a) abrupt, permanent change, (b) gradual, permanent change, and (c) abrupt, temporary change The impact assessment models were estimated for the whole supplementation period ($t = 88$) as well as for the first half of this period ($t = 48$) because of the insignificant supplementation effect on the total energy intake of the HES Group during the second half. The results did not differ statistically. The results for the first half of the supplementation period are herein presented.

Abrupt, permanent change. The zero-order transfer function is the first impact assessment model which was estimated. The model is

$$Y_t = e_t - \Theta\, e_{t-1} + \omega_0 (I_t) \quad t = 1, ..., 96 \quad (4)$$

where.

$\omega_0(I_t)$ = the intervention component, with $I_t = 0$ when $t < t_0$, and $I_t = 1$ when $t \geq t_0$; where t_0 equals the point in time when the energy supplementation program was introduced.

The parameter ω_0 is the 0^{th} order input parameter which tests for an abrupt and sustained change in the level of the process A statistically significant estimate of ω_0 is evidence of an immediate supplementation effect on the mean productivity of the HES Group. The parameters of the model were estimated as:

Θ: −.2286, SE: .1004; t-statistic: −2.27 ($p < .02$)
ω_0: −.5385, SE: .6710, t-statistic: −0.80 ($p > .20$)

8 Unless the underlying model is non-linear and we have misspecified the model. We examined for non-linearity in the model applying a technique whereby the model residuals are squared and auto-correlated. No non-linear patterns could be detected. For further discussion on non-linear models see Granger and Anderson (16).

With the ω_0 parameter estimated to equal zero, no immediate and positive supplementation effect was present.

Gradual, permanent change. A first-order transfer function, which tests for a gradual and sustained supplementation effect was estimated next. This impact assessment model is specified as:

$$Y_t = e_t - \Theta e_{t-1} + \frac{\omega_0}{(1 - \delta_1 B)} (I_t) \tag{5}$$

$$t = 1,\ldots, 96$$

where:

δ_1 = the first-order output parameter, with $-1 < \delta_1 < 1$.[9]. Thus, ω_0 and δ_1 are the parameters of the intervention component of the model to be estimated. When the model was fitted to the present Y_t series, the following parameter estimates were obtained

Θ.	− .2245; SE:	.1016, t-statistic	−2 21	($p < .02$)
ω_0:	−2 1056, SE.	3.5017; t-statistic	−0 60	($p > .25$)
δ_1:	− .3706, SE:	1.4227, t-statistic·	0 26	($p > .50$)

With δ_1 equal to zero, eq. (5) becomes equal to eq (4), and with ω_0 equal to zero, the intervention component of the model equals zero No gradual and sustained supplementation effect on the mean productivity of the HES Group can thus be demonstrated.

Abrupt, temporary change. The last intervention model tested was:

$$Y_t = e_t - \Theta e_{t-1} + \frac{\omega_0}{(1 - \delta_1)B} (1-B) I_t \tag{6}$$

with all the parameters defined as before. The parameter estimates are as follows·

Θ:	− 2262, SE:	.1004, t-statistic:	−2.25	($p < .02$)
ω_0:	−2 5942, SE:	3 080, t-statistic.	−0 84	($p > .20$)
δ_1:	.5144; SE.	.7311, t-statistic:	0.71	($p > .25$)

Thus the intervention component of the model is equal to zero, and no abrupt and temporary shift in the Y_t series was present.

DISCUSSION

Findings may be summarized as follows. The energy supplementation

9 The closer δ_1 is to unity, the slower the asymptotic change takes place.

program was effective in significantly raising the total energy intake of the HES Group workers, except towards the end of the program. The evidence further suggests that the workers generally maintained energy balance, and that the HES Group workers initially increased their total energy output. Under conditions of incentive wages an immediate or a gradual and permanent increase in the daily productivity of the HES Group workers would be expected. Either impact pattern could not be demonstrated over an extended period of energy supplementation.

We have previously speculated as to the reason(s) why an effective increase in daily energy intake did apparently not result in higher productivity among these workers (17). Possible reasons include: (a) purposeful behavior on the part of the workers to avoid setting a precedent of higher productivity level given the short-term nature of the study; (b) measurement errors in the estimates of energy intakes of individuals in part due to day-to-day variation in food intake, so that the actual increase in energy intake of the HES Group was less or equal to zero; (c) prior to supplementation, the study subjects existed on energy intake levels above the average for Guatemalan agricultural workers, and thus, were not representative; (d) the non-random assignment of workers to the two supplement groups which introduced a weakness in the study design.

We heavily discounted reasons (a), (b) and (c) as valid explanations. Post-supplementation interviews revealed that the majority of the workers felt that no minimum work load was imposed upon them. The one-day recall method has been shown to provide valid and reliable mean estimates of energy intake, and measurement errors can be assumed to have affected the mean energy intake estimates over time the same way. The fact that energy supplementation of the HES Group did not initially result in 100°/o substitution of supplement energy for home energy intake, suggests that these workers were at least marginally energy deficient. Reason (d) given above, does provide a rival hypothesis so that the effect of energy supplementation was confounded by the effect(s) of extraneous factors. The ARIMA time serie analysis just presented does not control for extraneous variables. Multivariate ARIMA models have been derived which would allow the introduction of extraneous variables (13). Nevertheless, at present we lack the computer software required to estimate these models.

Elsewhere we have argued that functional parameters such as worker productivity must be included when diagnosing marginal energy-protein malnutrition (10) The results from this study demonstrate that even though a nutrition intervention has the expected biological outcome, the impact on certain functional parameters is uncertain, as biological processes interact with behavioral and environmental factors. For example, workers' motivation, managerial and organizational factors as well as the workers' relative preferences for leisure versus income, may have resulted in workers expending the additional energy in after-work activities. This in turn calls for a broader definition of productivity to include performance in work and non-work activities when assesing the functional consequences of improvements in energy intake levels and nutritional status.

RESUMEN

EFECTO DE LA SUPLEMENTACION ENERGETICA SOBRE LA PRODUCTIVIDAD DE TRABAJADORES AGRICOLAS: UN ENFOQUE LONGITUDINAL

Se llevó a cabo un programa de suplementación energética de largo plazo para determinar su efecto en la productividad de trabajadores agrícolas en Guatemala. El programa suministraba, sin costo alguno, una bebida embotellada, sabor a naranja, baja en calorías (24 Kcal) y alto en calorías (350 Kcal), a dos grupos de cortadores de caña, residentes permanentes de una finca situada en la costa Sur del país.

Previo a, y periódicamente a través de la implementación del programa, se recolectaron datos relacionados con la ingesta energética y de antropometría. A través de datos obtenidos de planillas de trabajo, se construyó una serie longitudinal de productividad promedio (tonelaje de caña cortada y cargada por día), que cubrió 48 semanas de pre suplementación, 90 semanas de suplementación y 21 semanas post-suplementación. Diariamente se llevó un control del consumo de suplemento. No fue posible la asignación al azar de trabajadores, al grupo que recibió el suplemento alto en calorías (HES) y al que consumía el suplemento bajo en calorías (LES).

Previo a la suplementación, ambos grupos acusaron las mismas características en términos de edad, nivel de ingesta energética, peso, talla, adiposidad tricipital y productividad diaria. Se encontró poca variación a lo largo del tiempo en cuanto al consumo del suplemento por el grupo HES. Su ingesta energética aumentó significativamente en términos absolutos y en relación al grupo LES, salvo a finales del período de suplementación de 28 meses. Los trabajadores de ambos grupos se mantuvieron en balance energético durante la suplementación.

Se construyó una serie longitudinal de la diferencia en productividad media de ambos grupos de suplemento (Y_t), serie que fue modelada siguiendo la técnica analítica denominada ARIMA (auto-regresiva, integrada, promedio móvil). Se encontró que el modelo escolástico mejor representativo de la serie era el del promedio móvil porque no había ningún término auto-regresivo. El modelo ARIMA (0,0,1) se ajustó y fue ampliado con diferentes componentes de intervención.

Los resultados revelaron que ninguno de los parámetros de los componentes de intervencion estimados eran estadísticamente significativos. Se concluyó, por lo tanto, que la suplementación energética no tuvo ningún efecto sobre la productividad, ya fuese repentino o gradual y sostenido.

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