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THE USE OF RICE CROP RESIDUES AS A NON-COMMERCIAL ENERGY SOURCE IN THE DEVELOPING WORLD: THE ENERGY AND ENVIRONMENTAL IMPLICATIONS

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ABSTRACT

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The potential biomass energy that can be derived from the harvest of rice crop residues is calculated for three methods of crop production. The potential energy available amounts to 3.70×10^{10} J ha^{-1} year^{-1} for traditional methods, 7.93×10^{10} J for the labor-intensive and 8.36×10^{10} J for the capital-intensive methods. The net energy benefits available for cooking, heating and biogasification are calculated on a per hectare basis taking into account the costs of collection, transportation and processing. The amounts of energy available for cooking and heating range from 3.70×10^9 to 8.33×10^9 J ha^{-1} year^{-1}, and the amounts of energy for methanol use range from 1.85×10^9 to 4.17×10^9 J ha^{-1} year^{-1}.

The ecological problems associated with soil erosion, nutrient loss and pesticide use are evaluated in terms of the compensatory energy costs involved, and the resultant net energy balance for each method of rice production is calculated. The net energy available per hectare for the traditional method is 3.43×10^{10} J, for the labor-intensive method, 7.25×10^{10}J and for the capital-intensive method, 7.02×10^{10} J. The harvest of rice crop residues in the developing world could provide up to 5.80×10^{18} J year^{-1}.

The use of rice crop residues is investigated within the context of the rural village energy system. The prospects for the use of rice crop residues are evaluated in relation to alternative energy sources and it is concluded that regional residue harvest programs should be implemented cautiously, integrating soil management and environmental planning procedures where appropriate.

INTRODUCTION

As the availability of oil, coal and natural gas to rural village communities in the developing world becomes less certain due to price fluctuations and supply dislocations, greater emphasis is being placed on the use of non-commercial sources of biomass energy such as firewood, cattle dung and crop residues.

Firewood remains the main energy source in the developing world for a majority of the rural poor. Over 1400 million tons of firewood are used annually, representing an equivalent of 313 million tons of oil (Anon., 1981). The reliance on firewood as a primary source of energy cannot continue indefinitely because in many regions of the third world, the supply of firewood is quickly becoming depleted (Anon., 1979). The United Nations Conference on New and Renewable Sources of Energy reported that 100 million rural poor are currently facing severe firewood scarcity and over one billion people live in areas of growing deficits (Anon., 1981).

One possible alternative energy source is cattle dung. Currently, over 150 million tons of animal dung, with a heat of combustion equivalent to 41 million tons of oil, are being used annually for cooking and heating (Anon., 1981). This amount represents about 12% of the firewood utilization rate. The potential expansion of the use of dung has been estimated to be as high as 368 million tons of oil equivalent a year (Anon., 1981).

THE ENERGY POTENTIAL OF CROP RESIDUES

The other alternative energy source in the rural areas of the developing world is crop residues. Crop residues presently supply 7 million tons of oil-equivalent energy per year, which is 2% of the firewood utilization rate (Anon., 1981). Less than 20% of the crop residues are used for cooking and heating in most countries of the developing world (Revelle, 1976). Historically, crop residues have either been left on the field or used as animal feed.

With the intensification of agricultural production in the tropics, a greater amount of crop residue could be made available for cooking and heating. Since 1970, agricultural production, primarily cereal cultivation, has been increasing at an average annual rate of 2.8% per year in the developing world (Anon., 1979). If long-term development strategies are successful, increases in agricultural production should continue at comparable rates. The amount of available crop residue should expand in direct proportion to improvements in food output.

Currently, estimates vary considerably concerning the amount of energy that can be derived from crop residue sources. The figures depend on estimates of future yield potentials, arable land projections and agricultural planning scenarios predicted by international development agencies. The estimate most often cited is the Food and Agricultural Organization of the United Nations (Anon., 1981) projection of between 500 and 1500 million tons of oil equivalent per year. These figures are based on an original estimate published over a decade ago (Starr, 1971). Even at the lower end of the range, it is likely that crop residues will surpass cattle dung as the non-commercial energy source that can substitute for firewood as supplies dwindle.

Agricultural residues can be used as an energy source in a variety of ways. The plant wastes can be used directly in the home for cooking or heating. Crop residues can also be used to produce alcohol, usually in the

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form of ethanol, through a process of fermentation and distillation. Alcohol must have a high degree of purity to be used as fuel, requiring complex distillation processes and special additives. Rural third world use will be limited to specific regional locations where modern equipment is available. Pyrolysis, a process in which plant material is heated in the absence of oxygen to produce various liquid and gaseous forms of hydrocarbons, would also have limited applicability in the third world.

Biogasification offers the most potential for use in the tropics. The crop residue is broken down (decomposed) by anaerobic bacteria into organic compounds that can be directly converted into methane. The production of biogas (approximately 65% methane and 35% carbon dioxide) is particularly well suited to rural village application. Small-scale methane conversion digesters can process 1 ton of dry biomass into about 3.29×10^9 J of methane. Methane gas can be stored under pressure for use in the rural agricultural community and represents a convenient source of energy. While a typical family will not be able to derive all its energy needs from biogas, the energy from crop residues can be used as an energy supplement for cooking, lighting and heating in the home, for water lifting and pumping, for dry ice refrigeration, and as fuel for both stationary and mobile farm equipment.

RICE CROP RESIDUE POTENTIAL

The calculations of crop residue energy potential previously reported in the literature have been based on historical national crop yield data and have tended to provide a 'bottom line' figure of biomass output that can be reasonably expected given constraints on collection, transportation and yield (Makhijani and Poole, 1975; Revelle, 1976; Smil, 1979). A more detailed assessment of future crop residue potential can be derived using current maximum sustainable yield data for different cultivation methods presently being used in the developing world.

In order to demonstrate the potential of crop residues as an alternative energy source ice production in the developing world will be analyzed. Rice is the major cereal crop grown in the tropics and its cultivation has benefited from large-scale modification efforts that have been underway in many third world regions since the mid 1960s.

Three different methods of crop production will be considered in this study (Freedman, 1980). The first method is the traditional, in which the techniques used to grow crops have not undergone any modification since the 1950s. The seeds grown are varieties indigenous to the area, and irrigation systems, if present, are primitive. No auxiliary inputs are utilized except for organic fertilizers such as manure.

The second method is the labor-intensive style of production. Traditional technologies are modified, but the changes largely involve increased or refined labor inputs. Modern ploughs are used to till the land, locally bred seeds are sown and irrigation operations, primarily gravity type, are improved by greater attention to the timing and delivery of water. If agricultural chemicals are used, they are manually broadcast onto the fields. Harvesting and threshing are accomplished by hand, using refined implements and procedures.

The capital-intensive method is the third method, usually referred to as the 'Green Revolution' style of agriculture. Modified operations center around the adoption of high-yielding cereal varieties which are dependent on substantial inputs of fertilizers, insecticides, herbicides and modern irrigation techniques to produce the high yields. The land preparation, seeding, harvesting and threshing operations are improved, and where possible tractors and threshers are used to perform the operations that were once done manually (see Freedman (1980) for specific operational energy input requirements).

Rice production yields for the developing world have been calculated for each method of cultivation by averaging weighted maximum yields at various locations throughout the Philippines from 1968 to 1973 for both wet and dry seasons (Freedman, 1980). The average yield for the traditional rice production method is 1250 kg ha^{-1}, for the labor-intensive method, 2700 kg ha^{-1}, and for the Green Revolution method, 4440 kg ha^{-1} (Anon., 1976a; Freedman, 1980). Each kilogram of rice is assumed to contain 1.52×10^7 J of digestible energy (Pimentel et al., 1974). The average yield per hectare per growing season, expressed in terms of energy output, is 1.90×10^{10} J for traditionally grown varieties, 4.07×10^{10} J for the labor-intensive method and 6.69×10^{10} J for the Green Revolution method.

It is possible to estimate the energy content of the residue by using the straw-to-grain ratio initially provided by the Fertilizer Association of India (Saolapurkar and Balkundi, 1969). The residue coefficient is the ratio of the weight of dry matter of residue to recorded harvested weight of the seed at field moisture. Crop yield to residue proportions vary with the variety of seed, but the coefficients provided by the Fertilizer Association of India for both early and late maturing varieties have formed the basis for most estimates of crop residue energy reported in the literature (Makhijani and Poole, 1975; Revelle, 1976; Pimentel et al., 1981). For the local seeds planted using traditional and labor-intensive methods, the residue coefficient is 1.25. Crop residue coefficients for rice reported in the literature range from 1.25 for modern high-yielding varieties (Makhijani and Poole, 1975) to 2.95 for husked indigenous varieties (Makhijani and Poole, 1975; Revelle, 1976). The rice crop residue coefficients used in this paper are derived from early- and late-maturing variety data reported by Makhijani and Poole (1975) and closely conform to recent average estimates of rice crop residue coefficients reviewed by Revelle (1976) and calculated (coefficient = 1.55) by Pimentel et al. (1981). Multiplying the yield data by the residue coefficient, the amount of potential energy per hectare from crop residues is 3.70×10^{10} J for the traditional method, 7.93×10^{10} J for the labor-intensive, and 8.36×10^{10} J for the Green Revolution method.

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In the developing world, the expanded production of the rice crop can lead to a considerable increase in the supply of crop residue. Currently, rice is cultivated on more than 100 million hectares of farmland each year in the developing world (Plucknett and Smith, 1982). Taking into account the estimated crop average supplied by Plucknett and Smith for both indigenous and high-yielding varieties, the energy potential from rice crop residues in the developing world could amount to 6.51×10^{18} J $year^{-1}$.

If the crop residue is to be used as an energy source it must be stacked, collected and transported to the home or a processing location. The amount of energy required to collect 1 ha of rice residues is estimated at 5.10×10^7 J ha^{-1} for traditional methods, 1.10×10^8 J for labor-intensive methods and 1.80×10^8 J for Green Revolution methods (Pimentel et al., 1981; Freedman, 1982a). This estimate is calculated assuming collection and stacking costs of 40 814 J kg^{-1} harvested (Freedman, 1980; Pimentel et al., 1981).

Transportation costs can increase the energy input requirements for each method of production by 3.10×10^7 J ha^{-1} if the crop residue is collected for biogasification purposes (Freedman, 1980). Energy estimates of transportation costs are based on an assessment carried out by the Food and Agricultural Organization for rice production in the Philippines (Anon., 1976b). Transportation costs can equal or exceed the costs of collection if the residue is carried to a village more than 20 km away (Pimentel et al., 1981).

Once the crop residue is collected and transported to the home, it can be burned for cooking or heating purposes (see Table I). The combustion efficiency of open, slow-burning, three-stone fires is extremely low. The average efficiency for the conversion of crop residue into heat energy using primitive stoves is estimated to be between 6 and 10% (Revelle, 1976; Smil, 1979; Harris, 1981). For this analysis, the 10% estimate will be used to take into account some possible improvements in cooking procedures and stove design (see Table I) (Harris, 1981).

As discussed earlier, the crop residue can also be converted to methane and stored under pressure. There have been several estimates of biogas conversion efficiency reported in the literature. For this analysis a net energy return of 5% will be used, based on the most recent reported estimate (see Table I) (Pimentel et al., 1981). The earlier calculations did not completely account for the processing energy required (Makhijani and Poole, 1975).

ENVIRONMENTAL CONSTRAINTS ON THE USE OF CROP RESIDUES IN THE TROPICS

The major problem associated with the expanded use of crop residues in the developing world is the environmental degradation that could result from the removal of the soil cover. The plant left on the field after harvest protects the soil from erosion and serves to minimize the loss of top soil.

TABLE I

Potential energy available for household use (× 10^6 J per hectare planted per year)

	Method		
	Traditional	Labor intensive	Green Revolution
Potential energy output	37 038	79 341	83 573
Stacking and collection costs[a]	51.02	111.20	179.58
Energy available for household use	36 987	79 231	83 394
Potential heat and cooking energy available[b]	3 699	7 923	8 339
Potential methanol energy available[c]	1 849	3 962	4 170

[a]Assuming collection and stacking costs of 40 814 J per kilogram harvested (Freedman, 1980; Pimentel et al., 1981).
[b]Assuming 10% conversion efficiency (Harris, 1981).
[c]Assuming 5% conversion efficiency (Pimentel et al., 1981).

Although wind and water erosion are seldom problems during the growing season, expanding the use of rice crop residues may increase erosion between cropping periods.

Another potential environmental problem associated with the use of crop residues in the tropics is the increased amount of chemical pesticides that will be required to reduce crop loss after harvest (Spilker, 1981). Chemicals are now being used in the tropics to control pests during the growing season. To minimize losses of crop residue due to insect infestation and micro-organism degradation after the harvest, spraying and dusting will have to continue until the residues are collected and transported from the fields. The rural poor in most regions can barely afford pre-harvest pest control and for many the costs required to protect crop residues would be prohibitive.

ENERGETIC COSTS OF COUNTERACTING UNDESIRABLE ENVIRONMENTAL EFFECTS

As calculated for the Green Revolution method of rice production, the amount of potential energy available from crop residues can be as high as 8.36×10^{10} J ha^{-1}. Even after the costs of collection, transportation and processing are taken into account, the net potential energy for the developing world is considerable (Table I). The environmental degradation that might result would reduce the available energy over the long term and therefore large-scale crop residue harvest programs should be implemented cautiously.

The soil erosion problems associated with the removal of the crop cover could significantly reduce the crop residue yield potential with time and also diminish food production per hectare. Pimentel et al. (1981) have calculated that the removal of crop residues under conventional tillage conditions (as opposed to conservation or no-tillage) will lead to an average soil loss of approximately 12 cm over 30 years. This average figure is fairly consistent for a variety of cereal crops and was calculated taking into account differences in soil type, soil depth, slope of the land and rainfall (Pimentel et al., 1976). Using the compensatory energy input data provided by Pimentel et al. (1981) for conventional tillage management systems, it was calculated that on average a 37% increase in energy is necessary to offset the effects of soil degradation over a 30-year period. Most of this energy is required for additional ploughing, tilling, trampling and other intercultivation techniques that can partially alleviate a general deterioration in soil quality. Assuming a similar 37% increase in energy input to compensate for the effects of soil erosion over a 30-year period, the energy required for rice production per hectare each year would amount to 5.08×10^8 J for traditional methods, 2.27×10^9 J for labor-intensive methods and 8.51×10^9 J for Green Revolution methods (Table II) (see Freedman (1980) for 'on-field' energy input calculations for each method of rice production).

Aside from the erosion that would result, soil deterioration would require the additional use of chemical fertilizers. Assuming that nitrogen represents 1% of the weight of the crop residue, phosphorus 0.1%, and potassium 0.9%, the amount of fertilizer required to offset the depletion of nutrients that would be supplied by crop residues can be estimated for each method of rice prouduction (Leach and Slessor, 1973; Freedman, 1980). For the traditional method, the energy required to replace the macronutrients in the crop residue would amount to 2.03×10^9 J ha^{-1} $year^{-1}$ for the transitional method, 4.39×10^9 J $year^{-1}$ and for the Green Revolution method, 4.58×10^9 J (Table III). These values do not take into account the micro-nutrient loss that would result from the elimination of the crop residue cover.

The harvest of crop residues usually limits their usefulness as fertilizers because their nutritive value is largely destroyed when they are burned for fuel. Chemical fertilizers would then have to be applied to compensate for the loss of nutrients. However, the nutritive component of crop residue is not significantly reduced if it is converted into methane using the biogasification process described earlier. The residuum of undigested crop material that is left in the digester after the methane is processed can be returned to the land with little of the nutritive value destroyed provided that the 'residue soup' is injected or covered with soil (Makhijani and Poole, 1975; Anon., 1979).

TABLE II

Net energy available from rice crop residues with environmental costs considered ($\times 10^6$ J ha^{-1} year^{-1})

	Method		
	Traditional	Labor intensive	Green Revolution
Soil erosion[a]	507.87	2 267.83	8 510.38
Soil deterioration[b]	2 031	4 388	4 584
Pesticide requirement[c]	124.24	124.24	124.24
Resultant net energy available	34 324	72 451	70 176
Resultant net energy available for cooking and heating[d]	3 432	7 245	7 018
Resultant net energy available (methanol)[e]	1 716	3 622	3 508

[a] Assuming an overall 37% increase in energy input over a 30-year period (Pimentel et al., 1981). The yearly inputs were calculated based on total initial energy inputs for all agricultural operations per hectare per year: 1.37×10^9 J for the traditional method, 6.13×10^9 J for the labor-intensive method and 2.29×10^{10} J for the Green Revolution method (Freedman, 1980).
[b] See Table III.
[c] Application rate of 1.12 kg ha^{-1} (Pimentel et al., 1974; Jones, 1975).
[d] Assuming 10% conversion efficiency (Harris, 1981).
[e] Assuming 5% conversion efficiency (Pimentel et al., 1981).

The use of pesticides to spray crop residues can also be expressed in energy terms. Assuming an application rate of 1.12 kg ha^{-1} (Pimentel et al., 1974; Jones, 1975), the additional energy required would amount to 1.24×10^8 J. (The energy required to produce 1 kg of pesticide totals 1.11×10^8 J (Jones, 1975).)

The potential environmental costs, expressed in energy terms, and the resultant net energy balance for each method of rice production is presented in Table II. The net energy available per hectare for the traditional method is 3.43×10^{10} J, for the labor-intensive method, 7.25×10^{10} J and for the Green Revolution method, 7.02×10^{10} J. The total non-commercial energy that can be derived from the harvest of rice crop residues in the developing world would amount to 5.80×10^{18} J (Table IV). This represents an equivalent of 184.7 million tons of oil per year, which is more than half of the current firewood utilization rate. The F.A.O. estimates that between 500 and 1500 million tons of oil equivalent per year can eventually be derived

TABLE III

Fertilizer application requirements to compensate for removal of crop residue (ha^{-1} $year^{-1}$)[a]

Method of production	Ave. yield (kg)	Residue coefficient	Crop residue yield (kg)
Traditional	1250	1.95	3437
Labor intensive	2700	1.25	5265
Green Revolution	4400	1.25	5500

Traditional	Fertilizer requirement (kg)		Energy requirement ($\times 10^6$ J)
Nitrogen	24.4		1795.4
Phosphorus	2.4		33.6
Potassium	21.9		202.0
		Total	2031.0
Labor intensive			
Nitrogen	52.7		3879.2
Phosphorus	5.3		72.6
Potassium	47.4		436.4
		Total	4388.2
Green Revolution			
Nitrogen	55.0		4052.0
Phosphorus	5.5		75.7
Potassium	49.5		455.9
		Total	4583.6

[a] 73.63×10^6 J to produce 1 kg nitrogen; 13.77×10^6 J to produce 1 kg phosphorus; and 9.21×10^6 J to produce 1 kg potassium (Leach and Slessor, 1973).

TABLE IV

Total net energy potential of rice crop residues in the developing world

Method of production	Potential net energy ($\times 10^6$ J ha^{-1} $year^{-1}$)	Land area planted (ha $\times 10^6$)[a]	Total potential net energy ($\times 10^{18}$ J)
Traditional	34 324	37.8	1.3
Labor intensive	7 245	37.8	2.7
Green Revolution	7 017	25.2	1.8

[a] Plucknett and Smith (1980).

from crop residues grown in the developing world (Anon., 1981). It is expected that one-third of the crop residue available in the tropics will be used for non-commercial energy purposes. The current rice crop alone could supply up to 200 million tons of the 1500 million ton crop residue target.

If 30% of the rice crop residue is eventually used for cooking and heating (the rice straw can also be used for fibre and other needs), it would represent a non-commercial energy source of about 60 million tons of oil, larger than the current amount of energy supplied from cow dung.

CONCLUSIONS

In the developing world, commercial energy supplies are scarce primarily due to the large rise in fossil fuel prices over the last decade. The improvements in third world agricultural production and the rural economy in general, have been predicted on a continued increase in the supply of energy. The F.A.O. has estimated that a 6—8% annual rate of growth in energy use will be required in the developing world to meet the needs of an expanding population (Anon., 1979). Even a minimal 1% increase in crop production per year would require an increase in energy input of more than 2% (Anon., 1979). A majority of the increased input will come from fossil fuel energy.

Rice crop residues represent a significant non-commercial energy source that has not been fully utilized in the developing world. With the rapid expansion of the use of high-yielding crop varieties, mechanization and improved cropping procedures, rice crop yields have been increasing significantly since the mid 1960s. The use of crop residues could alleviate some of the pressures on energy supply for agriculture especially if small biogas converters are used in rural villages to process the crop residues into methane. Methane can be used as a fuel supplement for small tractors, harvesters, threshers and irrigation pumps. The recycling of organic materials, in the biogasification process, can ultimately increase the overall efficiency of energy use in the rural energy system of the third world. Renewable energy sources such as crop residue can provide the most effective means of sustaining crop yields over time. Each of the components of the rural energy system, the production of dietary energy on the field, the household consumption of commercial and non-commercial energy and the rural village use of renewable and non-renewable energy can function in an integrated manner, affecting both productivity and efficiency (Anon., 1981).

At present, crop residues comprise a very small portion of the overall energy budget of the third world. In 1978, 1195 million tons of oil equivalent were provided by commercial energy sources, and 361 million tons of oil equivalent were supplied by non-commercial energy sources (Anon., 1981). Of the total 1556 million tons of oil equivalent of energy used in the third world, less than 0.5% was derived from crop residues.

The constraints on the use of cereal crop residues must be fully investigated before the initiation of large-scale harvesting programs. The direct environmental risks and the indirect energy costs impose the most significant limitations on the use of rice crop residues. Soil management efforts can minimize the effects of erosion and degradation. Integrated environmental planning practices can alleviate some of the ecological problems associated with pesticide use, sedimentation, and cultural eutrophication (Cox and Atkins, 1979; Freedman, 1982b). Crop residues do represent an energy source that should be more effectively utilized, but soil conservation and environmental management must be given priority in third world development efforts. While it is unrealistic to assume that crop residues will take the place of firewood as a major source of non-commercial energy, it is reasonable to expect an increase in their use in some regions over the next several decades.

The selective harvest of rice crop residues represents an opportunity to harness an expanding renewable resource. The alternatives, such as the increased dependence on non-renewable energy sources such as fossil fuels or the further reliance on non-sustainable renewable resources such as firewood, do not represent viable options at this time (Eckholm, 1976). Crop residues can be relied on as a sustainable energy source that can supplement the supply of traditional energy to the rural inhabitants of the developing world.

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