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NON-WOODY LAND PLANTS

AS A RENEWABLE ENERGY SOURCE

BIOMASS AS A NONFOSSIL FUEL SOURCE

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& % CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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NON-HOODY LAND PLANTS AS A RENEWABLE ENERGY SOURCE

Presented To The ACS Symposium

BIOMASS AS A NONFOSSIL FUEL SOURCE

Honolulu, Hawaii, 1979

Contributed By.

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PRODUCTION OF NON-NOODY LAND PLANTS AS A RENEWABLE ENERGY SOURCE

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PRODUCTION OF NON-WOODY LAND PLANTS AS A?RENEWABLE ENERGY SOURCE

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[INTRODUCTION

Non-Woody Land Plants in Perspective:

Literally thousands of terrestrial plant species can be regarded as

potential energy sources. A majority of these are herbaceous seed plants

which complete their grouth and reproductive processes within a single

growing season of a few months duration, They are widely distributed from

arctic regions to the tropics (1,2,3). They are equally diverse with respect

to their growth and anatonical characteristics, their cultural requirement:

and thetr physiological and biochenical proce:

1s (2-9). Yet all have the

capacity to convert sunlight to chemical energy and to store this energy in the form of biomass, An oven-dry ton of herbaceous biomass represents about. 15 x 10° Btu's of stored energy. The direct firing of one such ton, in a ?stoker furnace with fiigh-pressure boiler having a 70% conversion efficiency, would displace about two barrels of fuel ofl.

Im addition to their fibrous tissues, some species also produce sugar

and starch in sufficient quantities to warrant extraction and conversion to

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ethanol. The latter can displace petroleum ii the production of motor fuel or chemical feedstocks (10-19). Other species store additional energy in the form of natural hydrocarbons (20,21,22).

Waite ir is not correct to say that herbaceous land plants have been over

Looked as a domestic energy resource, only a enall number have been examined

closely for this purpose. Anong the latter are tropical grass species of Ze.

Sorghum, Saccharum, and Pennisetum vhich were recognized for their high yields

of fiber and fermentable solids long before the of1 enbargo of 1973. Through-

out their history as cultivated crops, plants such as corm, sweet sorghua, sugarcane, and napier grass have evolved extensive technologies for their cultivation, harvest, post-harvest transport and storage and for their processing

ust be made in their

.24).

and

and marketing. Yet,even for these plants major chan;

managenent if they are to serve most effectively as energy crops (6,5,23,

Other tropical plants having very fine botanical or agronomic attributs

enjoying

ignored as energy resource

year-round climate suited to biomass production have been generally

Pineapple, cassava, and a range of underutilized

?@

tropical species are appropriate exanpl 13)

A majority of herbaceous land plants have never been cultivated for food

or fiber. In warm climates vild grasses such as Sorghum halepense (Johnson

er

where occasional use has

)» Aeundo donax (Japanese cane), and Banbusa species are borderline cases

mn made of their high productivity of dry matter.

In cooler climates self-seeding plants such as reed canary grass, cattail,

wild oats, and orchard grass nay be vieved with mixed feeling by landowners

unable to cultivate more, valuable food or forage crops. Plants such as rag~

weed, redroot pigveed, and lanbsquarters are recognized for their persistent

Srouth habits while otherwise regarded as common pests. Hovever, the value

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Of such species could rise dramatically as biomass assumes its future role

a8 a non-fo

il domestic energy resource,

2, Prior Studies on Herb

us Plant

as Energy Source

Aside from sugarcane and ?allied? tropical grasses (6,7,13,23,24,25), relatively Little attention has been given to herbaceous land plants specif-

ically as sources of fuels and chenical feedstocks. Studies were initiated

recently at Battelle-Colunbus Laboratories on common grasses and weeds as

Potential substitutes for fossil energy (26), Plants showing promise as

boiler fuels include perennial ryegrass, reed canarygr:

sudangrass, orchard-

of

rass, bromegrass, kentucky 31 fescue, lanbsquarters, and others. A ran speci

hhave indicated sone potential as sources of oil, fats, protein, dyes,

alkaloids, and rubber. Such plants include giant ragweed, alfalfa, jimsonveed,

eranbe, redroot pigweed, doghan, millweed, and pokeweed.

Im 1978 the US Department of Energy issued an RFP for herbaceous plant screening as means to close the information gap in this area of biomass energy

development (27). The DOE objective has two phat

First, to identity

pronising species for whole-plant bionass production in at least six different regions of the U.S., and second, to perform field evaluations on at least 20 species per region, with a view tovard identifying those nost suitable for crop~ ping on terrestrial energy plantations. Arthur D. Little, Inc., vas selected to conduct Phase I (2).

Six regions were designated on the basis of climatic characteristics,

Jand availebility, and land resource data provided by the U.S. Soil Conserva~

tion Service (2). A list of 280 potential species vas prepared on the

of published literature and personal interviews, These were screened in

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accordance with botanical snd economic characteristics, with emphasis on

previously uncultivated species. Certain

yricultural plants were also

considered.

Factors such as yield potential, cultural requiresents, tolerances to

Physiological stress, production cost

+ and Land availability were considered

in ranking the candidate species of each region (2). Plants with yields less

than 2.2 tons/acre (5 metric tons/hectare) vere eliminated. For the potential

energy crop species comparisons vere dram with six categories of econonie

plants, including tall and short broadleaves, tall and short grasses, legues,

?and tubers. Some 70 species were reconmended for consideration in the progran's

Second phase (field screening). Sone of these plants (redroot pigveed, lanbs~

?quarters, Colorado river henp, ragueed) have no prior history as cultivated

?erops and their cultural needs renain obscure. Other

ecies (Bermida grass,

Kenaf, reed canary grass, sudan grass) have beon improved and cultivated for decades (2).

?BOTANICAL AND AGRONOMIC CONSIDERATIONS

?The initial steps taken by DOE to.evaluate herbaceous land plants will help to clarify their value as a renewable energy source. However, an extensive research effort is needed to complete this task even as it applies to existing plant forms already managed as agricultural crops. A continuing effort will be needed over a period of several decades in the areas of new species evaluation, genetic improvenent, herbaceous plant cropping on marginal lands, and crop tailoring to changing energy needs. The renainder of this Paper offers some general guidelines and considerations for dealing with the vast pool of existing herbaceous land plant

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1, Botanical Considerations:

(a) Photosynthesis: Photosynthesis is the process by which the radiant

?energy of sunlight is converted to chenical energy by plante. Ite eumary

reaction can be stated simply ast

Sunlight

00, + #,0 ???cu,0) + 0,

Green Plante

?The amount of energy retained in the photosynthate (CH,0) is about 468 kj/aole.

Although not an efficient process

conversion on earth that has operated at any appreciable sagnitude and with any

» tt ds the only systen of solar energy

appreciable econony for any appreciable period of time. An estinated 1350 Joules/a? arrives at the earth's upper atnosphere in the form of solar radiation but only about half penetrates to the earth's eurface (28). A thedretical 8 Percent of this radiation could be converted photosynthetically; however, a ?saximum conversion, efficiency of only 4 percent has been attained and this under

?conditions of low light intensity (29). Agricultural plants average perhaps 0.5

to 1.0 percent efficiency. Land plants on a world-wide basis probably average

less than 0.3 percent efficiency. Nonetheless, the earth's plants store annually

shot 10 enna mre cut tha a hind tl soe 0 vane tse thn so
cool snay te tnd G2),

Picoenia cnet of to past (a) Brey cpa, ying eben
sncey ot voulng pean), tn sedacien or seeder? af samt
ony, Th earn ceduecin pte 8 sama ty then atvince pete
(ey tk. ach pcany A fun mg th ws herbenon te
Hames bt th uty ts tha tnt dey attracts et glee sch

assimilate carbon at night, are relatively less dnportant eventhough their utiliza-

ton of water 4s generally more efficient than for C, epectes. The C, pathway

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was at first thought to reside only in sugarcane and related tropical grasses

(Gi, 32,33). It was soon found in temperate plants such as Zea, Sorghus, and

Amaranthus (34-38). The C, species constitute a kind of apex in photosynthetic

Proficiency, afded to sone extent by attributes euch as a lov 0, compensation

point, a

?and higher Light intensities than do C, and CAM species (549,39).

fack" of photorespiration, and a capability to utilize both lover

4n important aspect of photosynthetic energy conversion often overlooked in higher plants is their "spectral proficiency", that is, their ability to

convert different regions of the sun's spectral energy distribution. When Photosynthesis by a given leaf is measured at different wavelengths of equal

quantum flux, say from 400 mm in the blue-violet to 720 nm in the far-red, a

Photosynthetic action spectrum is attained which tells us much about the leat

ability to "nary

" the entire package of visible light energy received from the sun. With suffietent replications an action spectrum characteristic of the species is derived, a kind of spectral finger print complete with peaks and Sepressions typifying that species. Trontcally, more than 60 percent of Ancoming solar energy is received at wavelengths shorter than 550 nm, while (apparently) most plants are photosynthetically active at wavelengths longer than 600 nm.. There is some evidence that Saccharum and a few other species have major photosynthésis activity in the blue-violet to blue-green region

(40,41). Photosynthetic action spectra have been determined for approximately

30 agricultural plants (40-45). The vast majority of herbaceous land plants

have not been examined in this context.

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?A plant physiologist

() Photosynthesis in an Energy Crop Perspectiv

or biochenist measuring photosynthesis in the laboratory usually determines

the quantity of CO, assinilated per unit of leaf area in an hour oF sone other

convenient time interval (mg C0,/en"/nx"1). 1 does not necessarily follow

conditions vill translate

that superior assimilation rates noted under th

to high photosynthate yields in the field. A more convenient measure of photo~

synthetic potential in biomass-candidate species is the quantity of dry matter

Produced per square meter of leaf surface per day (g/DM/a*/day). A majority of herbaceous 1and plants would produce in the order of 2-8 grams of oven-dry

?srouth or tissue

zpmsion phase. A yield of 15 g/n"/day would be quite good and vould typify

material per square meter per day, during the peak of th

sone C, pathvay species. Potential maximum yield estinates have been placed at 34 to 39 g/a"/day for Cy plants and 50-54 g/n*/day for Cy plants (46).

To an energy planter the most meaningful measure of solar energy conversion to biomass is the number of kilograms of dry matter produced per hectare per

year (or tons per acre per year). While photosynthetic processes per

Fennin an important factor, equally important are all other processes and constraints of plant growth and development which come into play as photosynthate is elaborated to harvestable bionass. Each of these factors finds expression in the energy planter's gross yield of biomass. Annual éry satter yields in the order of 22,500kg/ba (10 tons/acte) are common for a few species but the

majority of herbaceous land plants probably yield less than 4500 kg/ha (2 tons/

acre).

?The reckoning of dry matter yields on aii annual basis rather than an

hourly or @ daily basis might seem inappropriate to non-woody species whose

Browth period lasts only a few weeks or months. However, it is correct to do

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80 since many of the energy planter's expenses (including land rentals, taxes,

?equipment depreciation, and land maintenance) are incurred on an annual basis

(9,47,48). Moreover, some herbaceous plant species do produce dry matter

continually throughout the year and others could do 60 if managed as energy crops.

?A plant such as sugarcane propagated as a 12-onth sugar crop can yield dry

matter at the rate of 10-12 g/m*/day, or about 10 tons/acre/year. The highest

dry matter yields attained to date by the author were with first-ratoon sugar-

cane managed for total biomass rather than sugar. These asounted to 36.6 tons/

acre year, or 26.6 g/a/éay over a tine-cour of 365 days (49).

It

safe to say that for most plants there is no direct relationship
between photosynthetic potential, as determined in the laboratory, and the total.

ry biouass to be harvested in the field, The principal reasons for this are a

series of botanical and agronomic factors which prevent the elaboration of
Photosynthate to biomass at rates commensurate with the plant's, carbon reduction
Potential. Some of these factors are fundanental constraints against grovth
and development essentially beyond the control of the energy planter (though

sometines controllable by the plant breeder). Other constraints are a reflec-

tion of plant management and can be eliminated through research and developsent of the species

fan energy crop.

It is also safe to say that sone non-woody land plants will be found to have good bionass potentials but Little prospect of ever being managed as ageicultural energy comodities. For such plants a decisive attribute willbe their ability to survive and produce sone biomass vith the barest minimm of Production inputs (8,2), Yet even in these instances one must not over~ enphasize photosynthesis rate as an energy yield indicator; there is simply

too much variability in the measured rates of photosynthesis and too little

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correlation vith measured biomass yield (5,33,50). An exanple of this vas found

ina photosynthesis rates

ries of "wild" sugarcanes (Saccharum species) vho varied by factor of 10 while their bioass yields varied by a factor less than 2 (40). Variation is similarly high anong the hybrid sugarcanes of commerce (G3,51). In a given field of sugarcane, completely uniform as to soil series, variety, planting date, and cultural management, one can expect to find photo-synthesis and grovth rates that vary by a factor of 3 to 5 among randomly-selected sampling sites (5).

(©) Reduction State of the Primary Photosynthate: To this point we have considered biomass as "elaborated photosynthate", consisting mainly of cellulose, and lignin derived from glucose or polyglucosides having the basic formula (giiy20,). This is quantitatively the most important fore of biomass for both woody and herbaceous plant species, However, as a for of atored energy it has the Limitation of being only partially reduced. The presence of oxygen in the structure of plant tissues, starch, and extractable sugars limits the energy content of such materials to approximately 14-16 x 10° BrUs per dry ton. Alter~ nately, some plant species store energy in more highly reduced compounds having

progressively less oxygen in their structure, Plant materials auch

isoprene
polymers, sterols, oils and waxes consist mainly of carbon and hydrogen and contain in the order of 40-50 x 10° stUs per dry ton. Calvin and others have advocated the study of ?hydrocarbon plants" as euperior bionass energy sources (22,21,52). Many of these species have the added advantage of good adaptability to lands that are semi-arid, roughly-contoured, and othervise marginal for the Production of more conventional food and energy crops (8 453,54)+
Wydrocarbon-bearing plants include both woody and herbaceous species.

Some of the better-known examples, such as the rubber tree (Hevea brasiliensis)

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and guayule (P: woody perennials, while others, such

?as Euphorbia and Calotropis species, are borderline cases that could be managed either as forest or agronomic energy crops. Milkweed species (Asclepidacea) are predominantly herbaceous, but one menber found in the tropics, Calotropis procera (the "giant miliveed"), is a woody perennial reaching heights of 9 to 12 feet over a period of several years. In Puerto Rico it is regarded as a forest specimen (55), but as an energy crop vould most Likely be managed as a

frequently-recut for:

(55), Hydrocarbon-bearing land plants as a group have

been generally underexplored by the ERDA and DOE bionass energy program

(4) Mater Utilization Efficiency: Water will quite definitely be a deci~

sive limiting factor in the vorldvide expansion of agriculture (54, 9,37),

It is therefore important that water utilization efficiency be considered in the future screening and development of herba:

jous land plants as energy

resources. Three factors must be assé

ed from the onset: (a) Ue{lfzation

efficiency in photosynthetic processes; (b) water extracting capability from

the candidate species! natural terrain; and (c), the species capacity for water

conservation by anatoaical means.

?Among candidate herbaceous species the efficiency of water utilization will

bbe influenced markedly by the plant's pathvay of carbon reduction. C, species

should tend to reduce more carbon per unit of water transpixed than C, species

bbut Jess chan plants using the CAM pathway. C, plants such as sugarcane (5944)

have a lower mesophyll resistance (rq) than Cy plants, favoring in turn a steeper

00, gradient between the atmosphere and photosynthetic reaction sites in the leaf. CAN plants have 1a tq comparable to C, plants, but ? ey assimilate carbon at right vhen transpir ional water loss is at a minimum, The CAM pathway in

effect is 1 plant wate conserving mechanism.

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-u-

Intensively-cultivated herbaceous plants, such as sugarcane, require shout 150 ma of vater per month (6 inches) to sustain mextmun growth (60,61,54). Most herbaceous plants having some potential as bionass resource Will not receive that quantity of water as rainfall nor are they Likely to be siven this quantity as érrigated crops. An ?portant feature of any herbaceous

plant screening program for arid or semi-arid regions would be the selection

of deep-rooted (or tap-rooted) and thick-leafed candidates having the capability t0 draw upon subsoil water and to conserve vater used in tissue expansion. Irrigation for such species would be confined to the planting period to aid germination or plant establishnent. Considering that virtually all regions of the U.S. receive adequate rainfall on a seasonal basis, sone effort should be nade to identity herbaceous species that will survive arid conditions and Produce a "flush" of biomass when rainfall is adequate to do eo. Examples of herbaceous plants that do this include willoveed, tansy (Tanacetun), ragvort

(Genesio), alfaifa, and most Euphorbia species.

2. Agronomic Considerations:

The production of bioaass involves the collaboration of physiological, biochemical, botanical, and agronomic factors under any set of conditions. However, for the intensive managenent of biomass production, particular atten tion must be given to? field-seale behavior of plant masses in vhich an individual Plant oF crow complex loses the importance ve attach to it as a botanical or horticultural entity. Several agronomic considerations critical to successful

biomass production are herein discussed.

(a) Grovth Characteristica: To attain maximum biomass on a per annum

basis one would ideally select a year-round growing season and plant speci

capable of growing on a year-round basis. Certain tropical grasses (sugarcane,

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-nrapier grass, Johnson grass, banboo) do thie very nicely if planted in the tropics, Some of their menbers produce well also in sub-tropical or even tem-erate regions, but given equal managenent they vill realize only part of their full yield potential when grovth is constrained for several months by cool temperatures,

Te is important to recognize also that grovth is a 2i-hour process as well 2 12-month process. The photosynthetic and tissue-expansion systens that operate each day are fully dependent on the nocturnal transport and mobilization of grovth-supporting compounds. For this reason the tropics are again favored by their ware nights for biomass production. In a similar vein the cool nights of the southwestern arid Lar are probably as restrictive for biomass as are

the Limited moisture supplié

Posaibly the most desirable grovth characteristic of all for herbaceous species is the ability to produce new shoots continually throughout the year, year after year, fron an established cro, This is a predominant characteristic of sugarcane and certain other tropical grasses both related and unrelated to Saccharim species. Such plants do not require the periodic dormancy and rest intervals so important to most temperate species. Nor is this compensated by

ofa

the intensive flush of May-June growth by temperate plants?over the cour: year the slover-growing tropical forms vill out-produce then by a factor of three oF four.

A less obvious but utterly critical feature of the perennial crom is its continual underground contribution of decaying organic matter to the soil. This Process proceeds concurrently with the continuous renewal of underground crown

?and root tissues, For this reason the long-term harvest and renoval of above

round stems, together with the burning off of "trash", does not have an adverse

effect on sugarcane lands. There are sofle in Puerto Rico that have produced

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ane

sugarcane nore or less continually for four centuries without destruction of

their physical properties or nutrient-supplying capability. On the other hand,

seasonal crops such as field corn and grain sorghum do not develop a perennial

?crown. For these plants a good case can be made against the renoval of above~

Ground residues from thie cropping site.

(b) Tissue Expansion vs Maturation: A common misconception holds that bionass grovth involves mainly a visible increase of size, and that per acre tounages of green matter are a reasonably accurate indicator of a plant's yield potential, It is also frequently assumed that the moisture content of plant tissues is essentially constant at around 75 percent, and that dry matter yields can be calculated rather closely from green weight data, These assumptions are not correct in any case but are particularly erroneous with respect to herbaceous species. In virtually all such plants "growth" consists of discrete, diphasic processes of tissue expansion folloved by maturation. The tissue expansion phase produces visible but succulent grovth consisting mainly of water (in the order of 88-92 percent moisture). The maturation phase corresponds to physiological aging and senescence, that is, to flovering and seed production, slackening of visible grovth, yelloving and loss of foliage, and hardening of the formerly succulent tissues. During this period the dry matter content will increase by

@ factor of two to four in a time ?interval that may be shorter than that of the

yue-expansion phase. For exampl

the hybrid forage gras Sordan 70A nore

than doubles its dry matter yield in a time-span of only two weeks (23), ie,

during weeks @ to 10 in a 10-veek grouth and ?reproduction cycle. For this

reason the optimal period of harvest must be deterained with care for each

candidate species. Again, as a rule of thunb, the allowing of additional tine

before harvest will work in favor of increased bionass yields from herbaceous

plants.

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~ ue

For most herbaceous plants the production? of dry matter can be plot:

?an S-shaped curve (Pigure 1), Dry matter content will not ordinarily exceed

20 to 12 percent during the period of rapid tissue expansion but will begin to

rine dramatically at sone point in tine that is characteristic of the individual species. Dry matter will rarely increase beyond 40 percent in herbaceous plants. Attempts to hasten this rise (by withholding water) or to delay it (by use of

?srovth stimulants) have met vith limited success in tropical grasses (63). Sose increase in the magnitude of dry matter accumulation has been attained over short

Periods of tine with the plant grovth regulator Polaris (63).

(©) Harvest Frequency: Once the diphasic nature of biona:

growth and
?maturation is recognized the importance of harvest frequency is also underscored,
?The optimal period for harvest in the maturation curve of one species will differ enormously from the optinal harvest period of another?even anong varieties with im the same genus and species. For this reason it is convenient to group candidate species into distinct categories based on the tine interval that must elapse after planting to maximize dry matter yield (63). The managenent and

hharvest requirenents of each group vill also vary. On this basis it has been

convenient to organize tropical ¢: short ,~intermediat

+ and Long-

rotation" categories (Table 1).

As illustrated in?Figure 2, the tissue maturation curves for typical nesbers

of each category vary greatly over @ time-course of 12 months. Hence, to

harvest sugarcane at the 10-veek intervals favorable to Sordan 70A vould yield

Little dry matter. Similarly, any delay of the Sordan harvest beyond 12 weeks

4 waste of time and production resources, ?Napier grass, an "intermediate

rotation" species, is more than a match for sugarcane at two-and four-nonths of

age, and will nearly equal sugarcane yields at #ix months, but thereafter sugar

cane vill easily out-produce napier grass. In this context @ short-rotation

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species should be harvested four or five times per year, an intermediate-rota~ tion species two oF three tines per year, and a long-rotation species no more than once per year. This need for careful attention to the maturation profiles of candidate species is underscored by yield data for sugarcane and napier grass harvested at variable intervals over a time-course of 12 months (Table 2).

Ie is also evident that, while Sordan and napier grass attain rather level

Plateaus for dry matter, sugarcane continues to increase dry matter beyond 12 monthe (Figure 2). Sucrose accumulation profiles are very similar for suger cane. For many years sugar planters have taken advantage of this feature by extending the cane harvest interval beyond 12 months. lence, the Puerto Rico sugar industry harvests two erops?the "gran cultura? (14 to 16 months between harvests) a8 opposed to the prinavera crop (10 to 12 months between harvests).

In Havaii sugarcane is comonly harvested at two-year intervals.

@) Energy Crop Rotations: Fron Figure 2 one would surmise that the energy

plantation manager should plant a herbaceous species auch as sugarcane and leave it there?up to 18 months if possible?before harvest. In aifdition to maximus fiber he would also harvest fermentable solids as a salable by-product. This reasoning vould probably be correct in a tropical ecosystem suited to Saccharum species and vhere a regional tradition exists for sugar planting. However, these circumstances do not exist in many countries having an? otherwise good Potential for growing biomass. For example, there is no region of the U.S. mainland suited for 12-to 18month cro

16 Of sugarcane, although there are

vast regionsthere suited,to some form of tropical grasses. Hence, a future energy planter in Florida, Louisiana, southern California, or southern Texas might seriously consider vhether he should harvest a 6 to 8 month crop of sugar cane per annun or two crops of napier grasa in the sane time-frame,

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Equally important is the fact that sone countries will not be able to

afford a land occupation of 18 months by 2

ingle energy crop. This is especially
true of densely populated, developing tropical nations having an urgent need for

donestic food production (64). In such cases a short-rotation species such

Sordan may be the popular choice for energy planting since it can be sown as a

stop-gap between the harvest of one food crop and the planting of another. In

this capacity it would also prevent soil erosion and weed growth while acting

avenger for residual nutrients left over from the prior food crop.
Seasonal climate changes vill also be a factor in the rotation of biomass

energy species with conventional food and fiber crops. Short-rotation tropical grasses such as Sordan are ideally suited to the tropics?but they can be grom on a seasonal basis during the heat of sumer in most temperate regione. Such

plants could be propagated to maturity in a mid-June to mid-August tine frame.

In a given year the same site could produce a cool season food crop (a Brassica species, spinach) or a cool season forage (ryegrass, fall barley) both preceding

and folloving the biomass energy crop.

BARVEST AND TRANSPORTATION

Perhaps the weakest point in current production research for biomass is the lack of proven harvest equipment and methodologies for the maxinized stands

of bionass that each contractor strives to attain, This is sost evident in

woody bionass scenarios where conventional forest harvesting technology is either not applicable or simply doesn't exist in the context of silviculture energy plantations. The outlook for harvesting herbaceous land plants is

considerably better but a good deal of research renains on harvest and post-harvest technology, together with equipment redesign and nodification.

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1. Moving ve Conditioning As Harvest Options?

?he vast majority of herbaceous land plants can be harvested nicely with the sickle-bar mover (assuming that Land slopes and contours are otherwise suited for mechanized operations). This implenent was designed nore than a century ago as a replacenent for the hand sickle and manual grass scythe. As 44 horse-drava implenent it revolutionized the harvest of grain and forage crops.

?Today it is usually operated from the power take-off of Class I and II tractors.

?The original wooden parts have been replaced, bearings and lubrication systens hhave been improved, and it is no longer geared to the slow forvard pace of draft animals. But it operates on basically the sane principle as its horse-dram predecessors.

There are two principal Linitations of the sickle-bar mover as a harvest inplenent for herbaceous biomass crops: (a) It is designed to operate in

Felatively low-density stands of plants, and (b), its cutting process is confined

to a single slice near the base of upright stems. In other words it is a mechanized sickle for severing stens rather than a stem conditioner., This over has a preference for dry and upright stens whose total mass does not exceed about 12 green tons per acre. It experiences real difficulty with wet and lodged materials and with plant stands in any condition vhose mass exceeds 15 green tons per acre. Since its operation is based on a cutting principle the sickle must be kept continually sharp for effective performance. Its efficiency is imediately lovered by contact with mole hills, rocks, wires, scrap metal, and durable objects of aay kind encountered in the field.

In the author's experience the modern sickle-bar mover operating ina

typically dense tropical gr:

Sordan 70A (about 20-25 green tons/ acre), will experience a frequent tripping of its "fail-safe" mechaniem. This is a built-in feature of the implement designed to prevent ite destruction when

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striking unseen stumps or other fixed objects at operational speed. Nonethe-?less, the sickle-bar mover is probably very adequate for harvesting most herbaceous land plants, that is, those plants whose standing green mass willl not exceed about 12 tons per acre at any given harvest interval.

For harvesting sonevhat higher densities of herbaceous material a series of ?flai1" and "conditioner" designs have proven to be superior to the sickle-bar mover, Such implenents do not perfors on a cutting principle but rather break off the plant stem by striking it vith extrene force. Sharpness of the contact blades is not a decisive feature, ia fact they will perform fairly adequately even when duli fron long use. These machines, do require high horse-Power (90 to 120 hp) and high P10 speed (1000 rps).

The most effective inplenent of this type tested to date in Puerto Rico is the MAC ?rotary scythe-conditioner". The plant stens are broken off by four Lines of whirling blades and are repeatedly shattered as the blades reatrike the stens at 3-to S-inch intervals. The resulting "conditioned! biomass is evenly distributed in a broad sath behind the rotary scythe, In this state the subsequent drying and baling operations are nore easily performed than with conventionally-noved biouass, that ia, with plant materials received in clumps and matts and vith only one cut surface to facilitate water resoval.

4a additional advantage of the rotary scythe-conditioner is its capacity to harvest plant densities roughly double those handled by the sickle-bar mover.

A second added advantage is its ability to harvest lodged and wet materials. Such plants are harvested about as readily as those in a dry and upright condi- ton. A third advantage is its relatively trouble-free operation. The number of parts subject to malfunction are purposely reduced to # minisun,

At this writing the rotary seythe-conditioner has given excellent perform ance in plant densities anounting to about 22 green tons per acre 2). It is believed that its upper density limit will be in the order of 40 green tons

per acre (65).

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Plant yields considerably higher than 40 green tons per acre are anti

cipated for a few herbaceous species. Sugarcane yields in excess of 90 green

tons per acre year were recently denonstrated in Puerto Rico (49). Most sugar- cane harvesters marketed today begin to have difficulty with cane densities in the range of 50 to 60 standing green tons per acre (65). The most effective

sugarcane harvester in Puerto Rico at present is the Class Model 1400. Originally developed in East Germany, the Class is a single-rov, whole cane harvester which eaploys @ powerful air blast to renove organic trash and soil from the ?cane at the point of harvest in the field. It has accosnodated over 60 tous

of green cane per acre. With modifications it might por

ly harvest 80 to 90

tons per acre (65).

2. Solar Drying:

A characteristic difficulty with bionass is its low density relative to fossil energy and its high ater content which is costly to transport to

sing centers. Wherever possible it is desirable to renove most of this water at the harvest site by solar drying. One exception to this is the use of ?green? bionass for anaerobic digestion. Another exception is found in

sugarcane. Tn this case the vhole green stalk is transported to a centralized

Bill for devatering. The plant's soluble fermentable solids are recovered there

from the expr

fed juice and sold as refined sugar or nolassés.

Very adequate equipment for the solar drying of non-voody land plants can

be found in the cattle forage industry. The rotary acythe-conditioner described

above does much to prepare herbaceous plants for rapid drying in the sun (66,67).

Ordinarily these materials would be turned over once or twice in bringing the

poisture content dovn to about 15 percent. Three windrovs would then be combined

into one shortly before baling. Each of these operations can be perforned with

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~~

standard side-delivery forage rakes operating from the power take-off of «

Class I or II tractor. When higher donsity biomass is to be raked (Sordan or

napier grass) a heavy-duty "wheel" rake may be more suitable. These implements

fare also becoming standard equipment for forage-making operations.

3. Compaction And Baling:

Solar-dried bionass is rarely transported to its processing site today in

4 loose state, although once this vas standard practic:

For econoay of space

im transport and storage, as well as ease of handling, such waterials are first

compacted and then bound with a suitable twine or wire. The standard hay

alex" today is actually a compactor. Tt produces convéniently-sized cubes

having @ controlled density range of roughly 8 to 20 pounds per cubic foot.

A typical hay "bale" would weigh 60 or 70 pounds and is easily handled by one

man in transport and storage procedures or in cattle-feeding operations.

A different concept in biomass baling has appeared in recent years. This

is the "bulk" or "round" baler which operates as a windrow wrapper rather than

4 compactor, This implenent produces large cylindrical bales weighing up £0

1500 pounds each (68,69). Since no appreciable compaction is involved the bale

density is relatively lov?in the order of 10 to 12 pounds per cubic foot. More

Fecent modifications enable this machine to produce cube-shaped bales which are

- Both, front~and rear-end

more econonical of space during transport and stora,

loaders suitable for handling these bales are marketed as conventional tractor

attachments (65).

There are two types of balers for sugarcane bi The baling press

?and the briquetting press (JO). ?The first type is

hydraulic press euploying

the same compaction principle used for hay, The bagasse is baled in a a

Breen stat

and the formed cubes are tied with twine or wires to prevent thea

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-n-

from reexpanding. Their density will range from 25 to 40 pounds per cubic foot.

Bales of this type must be stacked carefully to prevent spontaneous cosbustion,

that is, with sufficient space between then to allov air circulation. The

briquetting press operates with dry bagasse having a moisture content of 8 to 15

a

percent. This press provides high pressures in the order of 5,000 to 15,000

Under these conditions extrenely compact cubes are produced which retain their form without the use of twine or wir

?Transport And Storage:

Herbaceous bionass that has been solar-dried and baled can be transported

to processing or storage sites without appreciable difficulty with existing

equipment. However, this can entail @ significant cost. Ordinarily euch

aterials would be loaded directly in the field on a low-bed truck. Standard

bales (60-80 pounds) can be loaded manually or vith mechanical loaders requiring

only one laborer on the truck for final positioning of the bales. Bulk bales

would be stacked two layers deep on the truck bed with tractor-mounted loaders.

?The sane truck would transport the biouass to a final processing or storage facility without intermediate transshipuent operations. In the case of sugar~

cane, the harvested whole stalks, or sten billets, vhatever the case may be,

are hauled in carts to the adjacent mill. The ease materials could be carted

to an intermediate reloading point for truck delivery to more distant suger

mill

Delivery costs will vary considerably with the individual biomass produc

tion operation. As a general feature a 40-ton low-bed truck with driver can be

hhired for about $180 per 24-hour day. Loading equipaent with operators must be

stations

each end of the delivery run. In an ideal biomass production

operation, ie, one managed by a private farmer for profit, the land omer would

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probably om and help operate the truck and accessory equipment. An estimated

delivery cost for solar-éried biomass on a 20-mile run would be $6.00 to 8.00

per ton.

PRODUCTION cosTS

Published production costs for both herbaceous and woody biomass show broad variations that are both understandable and inevitable (48,58, 6,7,3).

A given contractor will want to present his speciality crop in the best possible Light relative to the dollar inputs needed to obtain a m{llion BTUs in biouass form, This topic was revieved in detail recently in a USDA report by Kathrya

A, Zeimets (48). The author concluded that most biomass researchers greatly underestinate the cost of biomass production, excluding from their calculations significant indirect costs, long-term repercussions on ecosystem resources, fucure competition for land and vater, and both the cost and efficiency of

biomass conversion systems.

1. Obeaining Correct cost

A seriously misleading trend is to base the production costs of a biomass

candidate on its published yield performance

4 conventional food or fiber

crop. Sugarcane is an, appropriate example. In Puerto Rico, sugarcane managed

for sucrose yields 25 to 30 green tons per acre year; as an energy crop it can

yield 60 to 90 tons per acre year with only moderate increases in production

8 G9). Napier grass data are similarly misleading. There is a wealth of

Printed matter on the yields of napier gr:

?wanaged as a tropical forage crop,

that is, vhen harvested re}

tedly at five-or six-veck intervals at moisture

pProaching 90 percent. As an energy crop napier gra:

Produces

Toughly tvo to three tines more dry matter per annum at less cost than the cattle

forage (49).

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2. Production Goses For Tropical

Since June of 1977 considerable inforuation has been gathered on production

costs for sugarcane and other tropical grasses. whose agriculture has been managed

for maximum dry matter yield in a tropical ecosysten (62,63). A breakdown of

Production input charges for ?energy cane" is presented in Table 3. These data

pertain to a privately-owned, 200-acre operation yielding 33 oven-dry tons of biomass per acre year, Total cost, including delivery to the milling site,

amount to $25.46 per ton or 1.70 per million BTUs. Under Puerto Rico condi~

?tions about 70 percent of this dry matter would be burned as a boiler fuel.

?The remainder would be extracted as fermentable soli

during the cane de-

watering process and later sold as constituents of high-test molasses. This is

a solid credit to the insular energy cane planter oving to Puerto Rico's pre-

carious reliance on foreign molasses as feedstock for her rum industry (11).

?Assuming a market price of $0.75 p

gallon for high-test molasses the fermentable

soli

?from one such ton of energy cane would be valued at more than $45.00,

?OF about $1500.00 per acre. Cane milling costs today in Puerto Rico are about $4.50 per ton (72).

Production costs for Soréan 70A are presented in Table 4. Although Sordan's biomass yield is lover then that of energy cane, production input costs are also lover. The final cost of an ovendry ton of Sordan 70A is about $24.00, of $1.50 less than a ton of energy cane. In this instance there is no sale of fermentable solids. Production costs for napier grass vould be nod-arately lover than Sordan 70A oving to a much higher yield per acre year for

napicr grass (49,62). This crop similarly hag no sales of fermentable solids.

3. Managenent As A Production Cost Factor:

Production costs for energy cane Listed in Table 3 include ?nanagenent"

as 10 percent of the cost subtotal, This is an indefinite term covering the

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me

adainistrative skills expended by vay of good agricultural technique to maxinize biomass yield. It also reflects the morale (or profit incentive level) of the Individual grover or institution in charge of production.

The managesent factor contribution to future biomass production scenarios

?can range from very good to very bad, but it will have the potential to be ang

scisive in all production operations. Again, using sugarcane as a convenient example, it 1s comon knowledge that litte profit {s to be made anywhere in the

world today by planting sug:

+ but Lt is the vell-nanaged operations that will Minimize losses and offer the best prospect of survival until sugar values are

again equitable, At one extreme superior managenent will be found in privately~ omed plantations which in some countries are still basically fantly operations, Were the land owner has an inherent interest in his property and capital invest

ments and possess

the skills and incentive to make @ good Living from agriculture.

Such individuals can still be found today, for example, in the Queensland suger

sodustry. At the other extrene is the government-owned production operation.

Uistorically, governments have not made good farmers. A farm manager who has

ttle incentive to make profit and who cannot be held accountable when making

a lo

will ultimately have the inferior production record.

Governnent take-over of an agricultural comodfty is sometines viewed

necessary intervention in a free market vhere important soctal or political

considerations could not otherwise be served (73). This was the case with ou

cane in Puerto Rico whe;

@ large and othervise unemployable labor force could no

longer be sustained by privat

Anterprise (64,79). As a consequence it now costs

about 28 cents to produce « pound of sucrose in Puerto Rico, at a tine when ite

value on the world su

we market 1s only about 14 cents per pound, It is fatr to

?say that management is not the only factor contributing to high production costs?

environmental quality standards have also had a negative impact on the PK sugat

industry (29)?but poor management 1s clearly the main contributing factor.

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In a well-managed production scenario for herbaceous terrestrial bionas:

some straight-forvard steps will need to be taken to assure maximum returns from production input expenditures. These will include the following: (a) Correct and preparation, including land Leveling and planning vhere needed; (b) correct design and installation of the irrigation systea; (c) correct seedbed preparations (d) careful selection and trestnent of seeds (¢) correct seeding (relative to depth, density or row spacing, and season); (f) reseeding of vacant space when necessary; (g) correct pest control prograns (including adninistration of control on weekends and holidays when required); (h) maintenance of correct irrigation, fertilization, and cultivation programa; (i) correct timing and synchronization of harvest operations; (j) correct selection and use of harvest equipment; (h) post-harvest maintenance of land and machinery.

For most bionass crops the costs of these measures will accrue whether they

are performed correctly or not. The decisive factor will be the skill and

motivation of the operation's field managers. Good management can best be assurred ?when production is retained in the context of privately owed plantations that

are operated for personal profit.

SUMMARY

?The nature of herbaceous Land plants and thefr potential usefulness as a

fuvure energy resource is presented in broad outline, The large nusber of herbaceous species found in both cool and warm climates and in both the wild and cultivated state suggests that at least « small percentage of these could become valuable sources of fuel. Extensive screening will be needed in a range of

ecosystens to bring the number of candidate species to a manageable level. Both

botanical and agronomic features to be evaluated during the screening process are

briefly discussed, Some of the production and harvest operations required of

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herbaceous plants as agricultural comodities are also reviewed, together vith Partial cost analyses for the production operations. Management of the energy crop is seen to be the decisive cost input. This factor vill be optimized in

privately-owned operations motivated by a strong profit incentive.

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TABLE 1, Categories of Tropical Grasses and Leading Candidate Clones Under

Investigation as Renewable Energy Sources in Puerto Rico 1/

Harvest Interval

Category (ont) Candidate clones

I. Short Rotation 2 Sordan 70A %

foun 7

ite 2

Bermuda Grass

XK Hybrids

Roma (Sorghum)

TL, Intermediate Rotation 4-6 Merker)

Napter Hybrid PI 30086 2/

Napier Hybrid PI 7350

NK Hybrid

Saccharum spontaneust

US 67-22-2

us 77-70

SES 231

S. spont. Hybrid (Wild)

Tntergeneric Hybrids

IIT, Long Rotation 12-18 Saccharum Hybrids

NCo 310

PR 980 2/

PR 6G-1791

B 70-701

us 2

USDA Imports

re

AY DOB Contract No, DE-ASOS~78ET20071.

2/ Underlined clones are leading candidates for their category.

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TABLE 2. Dry Matter Yields of Sugarcane and Napier Gra:

Variable Frequencies Over a Time-Course of One Year 1/.

Inte fo. of Tons DM/Acre/Year For ?

(@onths) __Harvests Species Plant Crop Ist Ratoon Crop

2 6 Cane 6.5 33

Napier 2/ 12:7 3

4 3 cane wat 1.9

Napier 22.6 25.1

6 2 cane 16.6 20.6

Napier 25.6 33.0

2 2 Cane 25.5 33.6

Mapier 9:3 25.8

4 nos contract No. DE-ASOS~788120071.,

2

conputed mean of three varieties and two row spacings.

computed wean of one variety and two row spacings.

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TABLE 3, Dry Matter Production Costs for Firat~Ratoon Sugarcane Managed

?as an Energy Crop

aa

Land Area: 200 Acres

Production Interval! 12 Months

TM Yield: 33 (Oven-Dry) Short Tons/Acres Total 6600 Tons

Preliminary Cost Analysis

ten Gost ($/Year

1, Land Rental, at 50,00/Acre 20,000

2, Seedbed Preparation, at 15.00/Acre 3,000

3, Water (600 Acre Feet at 15.00/f¢) 12,000

4, Water Application, at 48.00/Acre Year 9,600

5. Seed (For Plant Crop Plus Tvo Ratoon Crops),

1 Ton/Aere Year at? 15.00/Ton 3,000

6. Fertilizer, at 180,00/Aere 36,000

Pesticides, at 26.50/Acre 5,300

Harvest, Including Equipment Charges,

Equipment Depreciation, And Labor 20,000

9. Day Labor, 1 Man Year (2016 hrs at 3.00/ne) 2/ 6,048

10, Cultivation, at 5.00/Acre 1,000

11, Land Preparation & Maintenance (Pre-& Post-Harvest) 600

12, Delivery, at 7.00/Ton/20 miles of Haul 46,200

13, Subtotal: 152,748

14, Managenent: 10% of Subtotal 15,275

15, Total Cost: 168,023

e023

¥Y vot contract no, DE-AS0S-78ET20071.

2! Labor which {2 not included in other costs

Total Cost/Ton: (168,023 + 6600): 25.46

Total Cost/MilLion BTUs: (25.46 +15)! 1.70

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TABLE 4, Dry Matter Production Costs for Sordan 70a 2/

Land Area: 200 Acres

Production Interval: 6 Months

Sordan 70A Yield: 15 (Oven Dry) Short Tons/Acre, Total 3,000 Tons

Preliminary Cost Analysis

Item

1, Land Rental, at $50/Acre Year

2, Water (Overhead Irrigation), 360 Acre £¢ 2,160

3. Seed, at 60 Ubs/Aere 4,800

4, Feretitzer 10,000

5. Pestieldes 4,000

6. Bqutpaent Depreciation (6 mo.) 2,650

7, Equipment Maintenance (73% of Depreciation) 1,988

8. Equipment Operation (75% of Deprectatton) 1,988

9. Diesel Fuel 2,200

10. Day Labor (90.00/Day for 140 Days) 12,600

U delivery, at 6,00/Ton 18,000

13, Managenent (10% of Subtotal) 6,538

SSeS

1k, Total Cos 71,924

Y dor contract no, DE-AS05-78E720071.

Total Cost/Ton: (71,924 + 3,000): 23.97

Total Cost/Million BTUs (23,97 = 15): "1.59

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50

Sugarcane

10}

Napier Grass

DRY MATTER (2)

8

2 16 20 30 ~ 30

AGE OF SPECIES (WEEKS)

Figure 2, Relative maturation profiles for Sordan 70A, napter grass,

and sugarcane over a time-course of one year. The:

plants are

Fepresentative of the short-,intemmediate-, and long-rotation

cropping categories, respectively.

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Period of

?Tiscue Maturation

DRY MATTER (x)

Period Of

?Tissue Expansion

° 10 30 30 70 30

AGE OF SPECIES

Figure 1, 4 generalized representation of the maturation profile of herbaceous land plants. While no specific time-frane or plant

form is depicted, the diphasic process of tissue expansion followed

by maturation is typical of non-woody plant species. With the visible growth phase essentially completed, the energy planter will nin much additional dry matter by allowing a brief additional

?time interval to elapse before harvest.

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