# Optimizing bio-energy crop farm profitability with spatial distribution of bio-fuel refinery sites

## Anand Krishnan Plappally (Presenter) and Kevin Duemmel (First Author)

### IIT Jodhpur, Jodhpur, India

www.weentech.co.uk

# Contents

1. The topic and its background

2. The need of the hour

3. Crop Pairs- Selection

4. Maize- Switch Grass Case Study – LP Example

5. Parameters under Study

6. Why an MMR framework?

7. The Denouement

## THE SCENARIO

Simply meeting the current energy demand in some "green" (i.e., "sustainable") manner is not, in the long run, ecologically sustainable.

Why?

Our pattern of consumption is always increasing [Parikh and Ramanathan, 1999].

"Falling Oil Prices"- 2014-15 trends – Asia biofuels market is hit

"Policy uncertainty"- Production is hit, biofuel volume finalization could not be performed under Renewable Fuel Standard

"Broader Global Distribution":
*India looking to expand ethanol bus trial to biodiesel and biogas as well*

"Emissions": Animal fat reduces GHG emissions by 85%

"Increase in Blending"

"Go-High FFA" -Biodiesel are sourced from soybeans, palm or rapeseed, and precisely because they contain less than 0.5% free fatty acid (FFA)

(COURTESY-
http://www.platts.com/latest-news/agriculture/london/asias-biofuels-prices-at-historic-lows-after-27977913

www.

**Over- Arching Goal**
- The goal of a sustainable supply of energy

**Aim and Objective**

Formulating a Problem

Research in Bio-fuels is

1. towards producing bio-fuels or fuel materials

2. Less on feed stock production

3. The thought on meeting present energy requirements will not help future energy management

QUESTION

**What is good for sustaining our own patterns of energy consumption at reduced environmental impact can be nothing but a near-perfect solution**

# Need of the Hour?

- Why the mathematical efficiency of large-scale bio-fuel production does not translate into efficiency and usage at the local level

- What are parameters that influence bio-fuel crop profitability while managing energy cost

- How crop selection in a particular region can effect bio-fuel production

- How transport at any level (i.e, irrigation, labor, machinery, energy feed stock) influence overall bio-fuel efficiency

- What is the say of farmer's choice and private decision on bio-crop profitability

KEEPING IN MIND

To increase the biomass per unit land area is to **grow different crop varieties which are adapted to local climate in the region at a time** [Dhugga, 2007]

Swapping of crops by a farmer -social choices and private decision -role in farm profitability and management practices [Dhugga 2007].

irrigation water, manual labor, machinery utilized to carry activities such as tillage, threshing, cutting which needs to be justified [Abulfotuh, 2007, Plappally and Lienhard 2013].

| Energy Crops | Country | Climate and Geography | References |
|---|---|---|---|
| Sugarcane | Brazil, India, USA, UK | Tropical | Dhugga, 2007 |
| Soyabean | Brazil, USA | Sub tropical | Duke 1983 |
| Micanthus | Canada, UK, USA | Spring and Summer species | Newman 2003 |
| Switch grass | USA | Summer | Newman 2003 |
| Sweet Sorghum | India, USA | Semi-Arid in Tropics | GAIN 2006 |
| Coconut | India, New Zealand, Philipines, Sri Lanka, Vietnam, Thailand, Hawaii, USA | Tropical Sandy Shorelines | Philips 1994 |
| Japtropha | Cameroon, Carribean, China, Florida, USA, **India**, Kenya, Philipines, | Arid to Semi Arid | Gilman and Watson 1993; ICRISAT 2008; Katembo and Gray 2007; Singh 2006; |
| Eucalyptus | Australia, Brazil, India, Taiwan, USA | No Climate or soil barrier | Berkeley ELP 2007 |
| Palm | Cameroon , Saudi Arabia | Tropical | Berkeley ELP 2007 |
| Pongamia | India | Semi Arid-Sub humid | Wani and Sreedevi 2007 |
| Croton Megalocarpus | Kenya | Semi-Arid in Tropics | Keriko 2006 |
| Oleander | Kenya | Semi-Arid in Tropics | Keriko 2006 |
| Rapeseed (Canola) | Argentina, Canada, Denmark, France, Italy, | Winter and Springs | Berkeley ELP 2007 |
| Bamboo | Nigeria, india | Semi humid-Marshes | Berkeley ELP 2007 |
| Peaches | USA | Subtropical climate | Berkeley ELP 2007 |
| Algae | Japan , USA | Lagoon and Sea shores | Berkeley ELP 2007 |
| Cassava | China, India | Humid Conditions | GAIN 2006 |
| Artichokes | Argentina | Springs | Berkeley ELP 2007 |
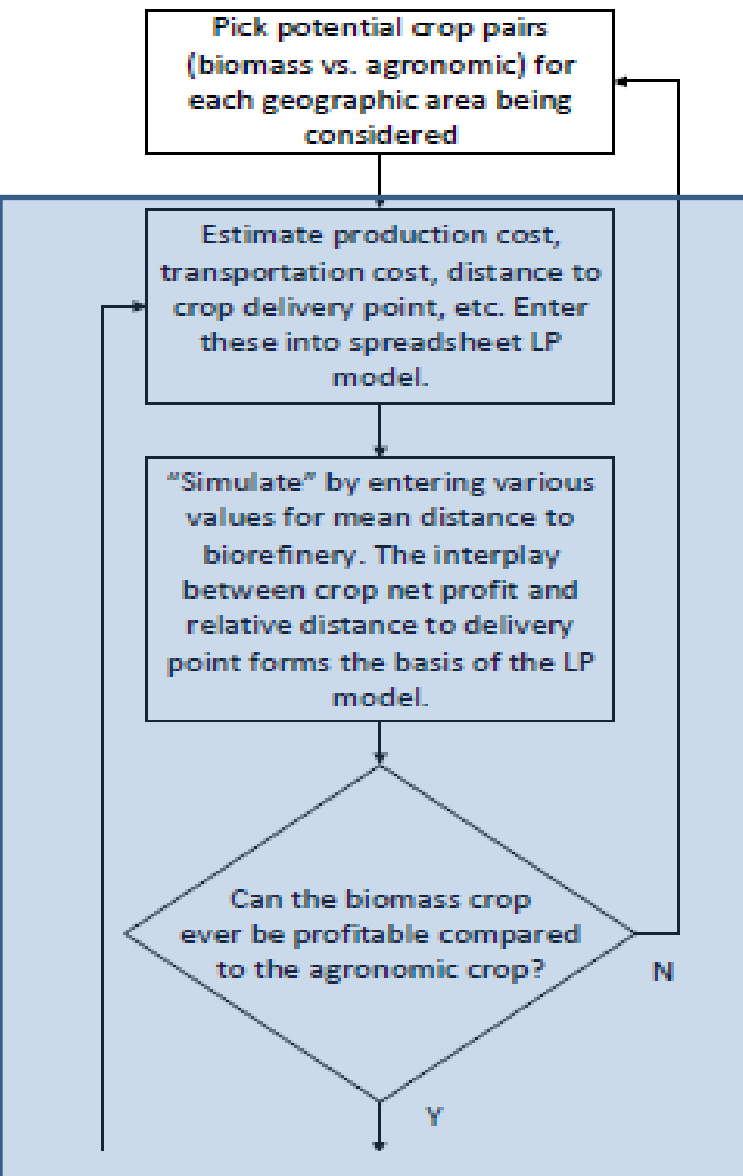
Even though current literatures report that *there is an efficiency of over 50% in production of ethanol from glucose*,

**Costs such as**
1.transport,
2.climatic conditions,
3.demand for transportation fuels and public opinion concerning low productivity concerns
affect the final profitability from the biofuel production system [Christy and Rismani-Yazdi, 2008].

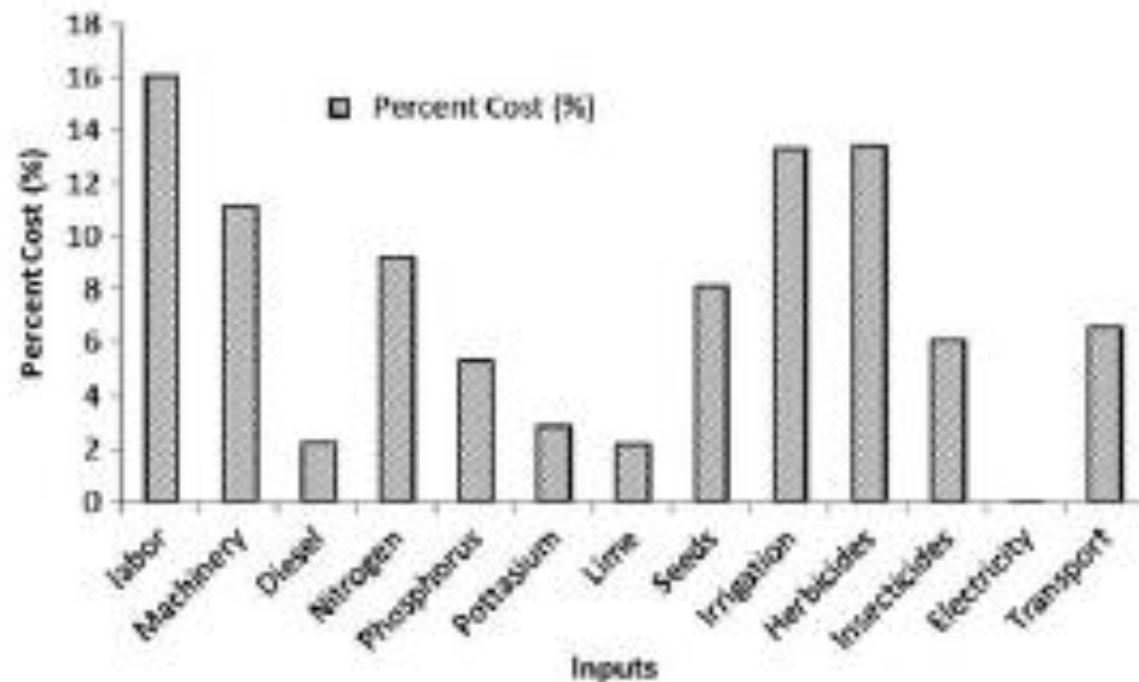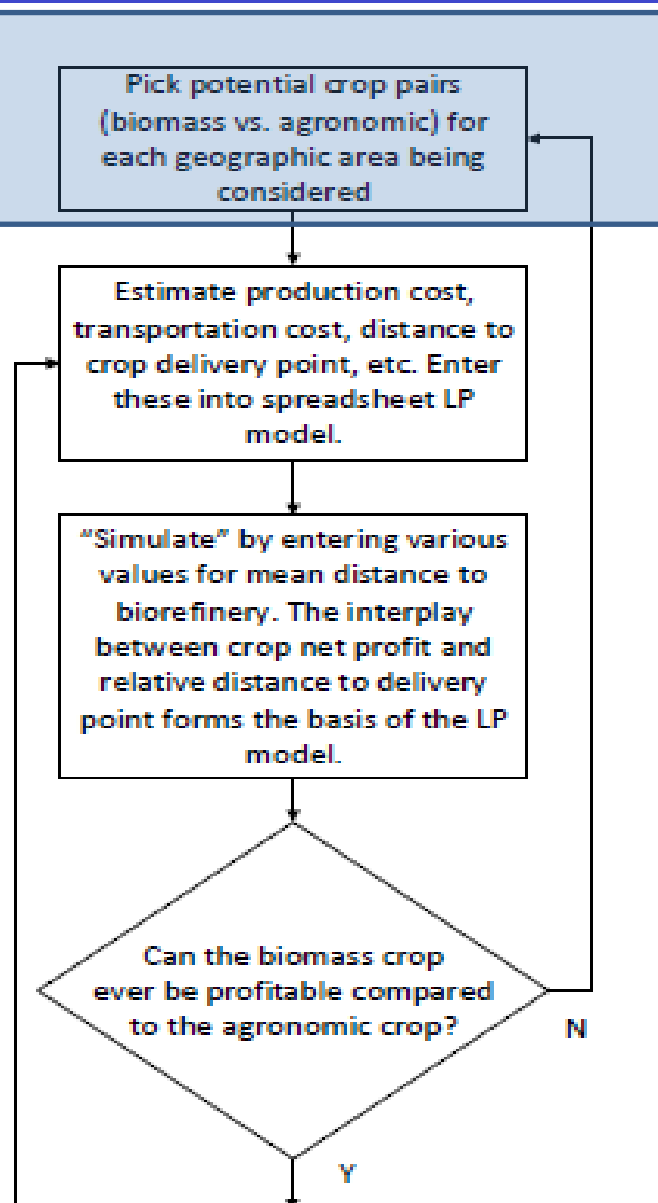# CROP PAIRS- SELECTION

**Eucalyptus-peaches**

**Maize and switch grass**

Source:
https://www.google.co.in/maps/place/United+States/@31.7860603,-132.0853276,3z/data=!3m1!4b1!4m2!3m1!1s0x54eab584e432360b:0x1c3bb99243deb742
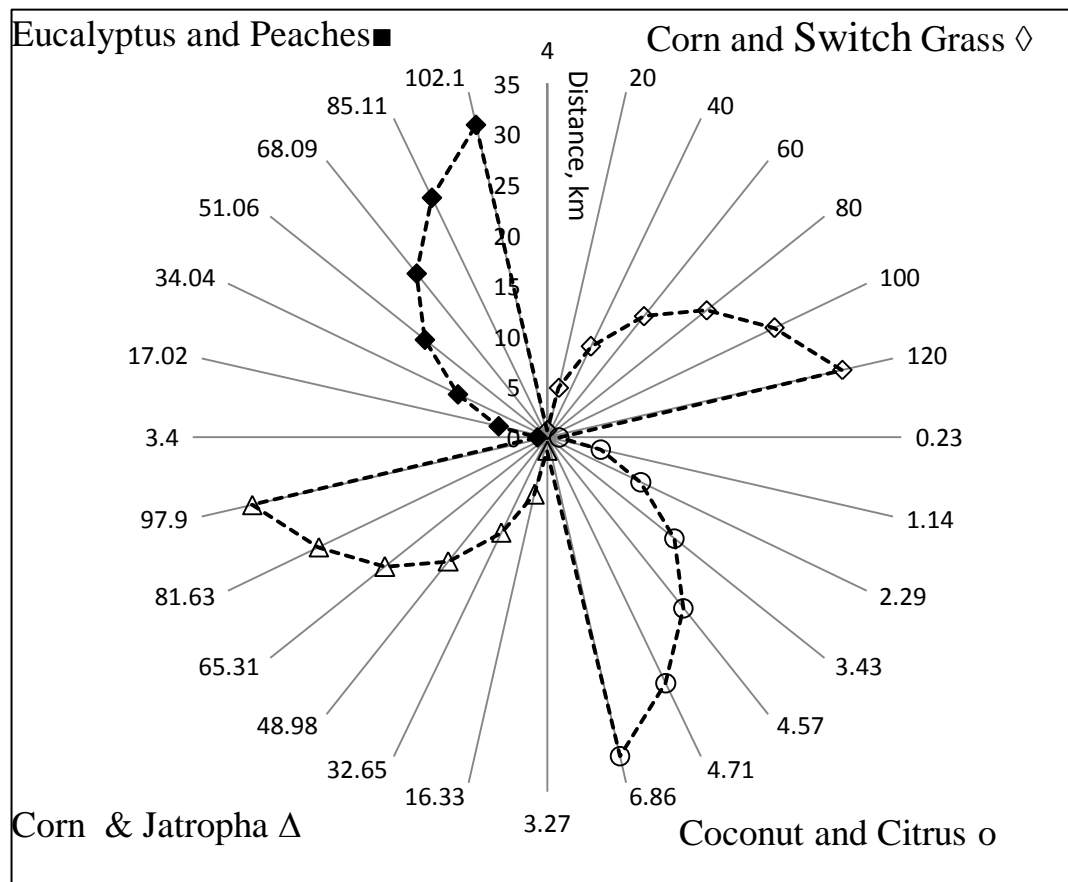
**Coconut citrus**

**Jatropha and Corn**

Cost percentage contributions towards Maize Production in the United States for a hectare field (Source: Plappally and Lienhard 2013)

| Grain Crop | Maize | Exp. Yield (bu/ac) | 140 | Weight/bu (lbs) | 66 | Bushels/ton | 30 | Exp. Yield (tons/ac) | 4.62 |
| Biomass Crop | Switchgrass | Exp. Yield (tons/ac) | 4 | | | | | | |
| Region | Midwest USA | | | | | | | | |

| Grain Crop Production Inputs: | | Prob. | Exp. Cost ($/ac) | | | Biomass Crop Production Inputs: | | Prob. | Exp. Cost ($/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Apply Fertilizer ($/ac) | $250.00 | 0.8 | | | | Apply Fertilizer ($/ac) | $200.00 | 0.8 | |
| No Fertilizer ($/ac) | $0.00 | 0.2 | $200.00 | | | No Fertilizer ($/ac) | $0.00 | 0.2 | $160.00 |
| Apply chemicals ($/ac) | $180.00 | 0.5 | | | | Apply chemicals ($/ac) | $50.00 | 0.5 | |
| No chemicals ($/ac) | $0.00 | 0.5 | $90.00 | | | No chemicals ($/ac) | $0.00 | 0.5 | $25.00 |
| Machinery Used ($/ac) | $50.00 | 0.95 | | | | Machinery Used ($/ac) | $40.00 | 0.95 | |
| No machinery used ($/ac) | $0.00 | 0.05 | $47.50 | | | No machinery used ($/ac) | $0.00 | 0.05 | $38.00 |
| Hire Labor ($/ac) | $12.00 | 0.2 | | | | Hire Labor ($/ac) | $12.00 | 0.4 | |
| No hired labor ($/ac) | $0.00 | 0.8 | $2.40 | | | No hired labor ($/ac) | $0.00 | 0.8 | $4.80 |
| Irrigation Cost ($/ac) | $5.00 | 0 | | | | Irrigation Cost ($/ac) | $5.00 | 0 | |
| No irrigation ($/ac) | $0.00 | 1 | $0.00 | | | No irrigation ($/ac) | $0.00 | 1 | $0.00 |
| Govt. Subsidies used ($/ac) | -$1.00 | 0.1 | | | | Govt. Subsidies used ($/ac) | -$5.00 | 0.7 | |
| No Govt Subsidies ($/ac) | $0.00 | 0.9 | -$0.10 | | | No Govt Subsidies ($/ac) | $0.00 | 0.3 | -$3.50 |
| Buy New Seed ($/ac) | $75.00 | 0.99 | | | | Buy New Seed ($/ac) | $75.00 | 0.05 | |
| Seed from previous crop ($/ac) | $3.00 | 0.01 | $74.28 | | | Seed from previous crop ($/ac) | | 0.95 | $3.75 |

Expected Cost of Grain Crop Production ($/ac) NON-LAND: $414.08

NON-LAND Expected Cost of Biomass Crop Production ($/ac): $228.05

**TRANSPORT:**
| Fuel cost rate ($/km) | $0.50 |
| Maint Cost($/km) | $0.30 |
| Trip (truck) Delivery Size(tons) | 20 |

**DISTANCE:**
| Mean Distance to Biorefinery (km) | **2** 1 |
| Mean Distance to Grain Elevator/Market (km) | 55 |

**PRICES:**
| Price of Grain Crop at elevator($/bu) | $6.00 |
| Price of Grain Crop at elevator($/ton) | $181.82 |
| Price of Biomass Crop ($/ton) | $140.00 |
| Penalty for Delivery to Intermediate (%) | 10 |

**Useful Indices:**

Fertilizer Cost to Crop Value Ratio
| Grain | Biomass, direct del. | Biomass, intermediate del. |
|---|---|---|
| **4** 0.24 | 0.49 | 0.59 |

Distance Ratio (biorefinery to grain elevator): **3** 0.02

Price Ratio (before penalty, biomass/grain): 0.77

| BIOMASS CROP FAILURE RISK | Prob. | | Exp.cost of Prod. ($/ac) | Expected Transportation Cost ($/ac) | Gross Profit ($/ac) | Net Profit, NON-LAND ($/ac) |
|---|---|---|---|---|---|---|
| Successfully produce BIOMASS crop | 0.95 | Deliver to Biorefinery | $228.05 | $4.00 | $560.00 | $327.95 |
| BIOMASS Crop fails (total loss) | 0.05 | | | | | |
| | | Deliver Biomass Crop to Intermediate | $228.05 | $4.00 | $504.00 | $271.95 |

**1** (over Deliver to Biorefinery row)

| GRAIN CROP FAILURE RISK: | Prob. | | | | | |
|---|---|---|---|---|---|---|
| Successfully produce GRAIN crop | 0.95 | Deliver to Grain Elevator/Market | $414.08 | $190.48 | $840.00 | $235.44 |
| GRAIN Crop fails (total loss) | 0.05 | | | | | |

*Break even point*

**KEY:**
| | INPUT CELLS |
| | OUTPUT CELLS |

Expected expenditure (in US dollars) to transport crops as a function of distance to the bio-refinery (in km)

**bio-material transport cost , M$_1$**

Net Energy crop profit vs.
Transportation cost for a 30 km radial distance from the crop field to the bio-refinery.

Bio fuel crop Profit vs Storage Distance

**M₂** is defined

The Storage place of feedstock for animals (feed corn) should be greatly localized to reduce cost. This will help bio-fuel production benefits to soar.

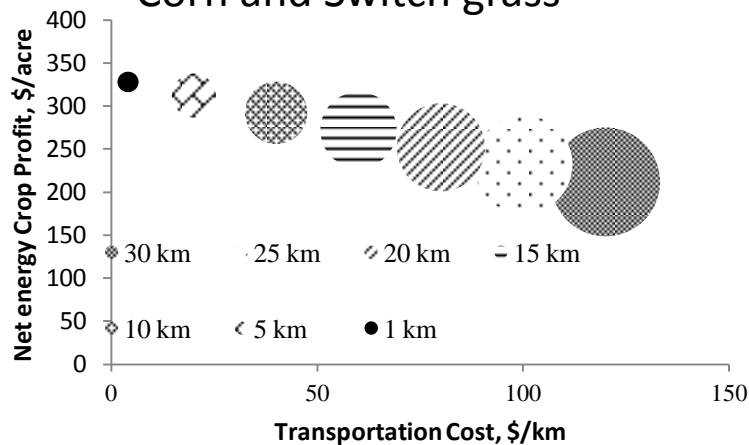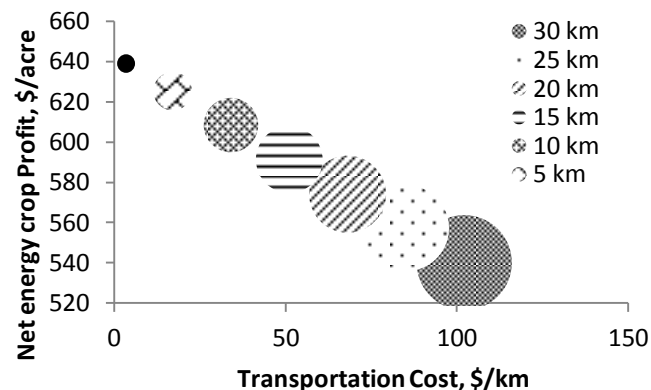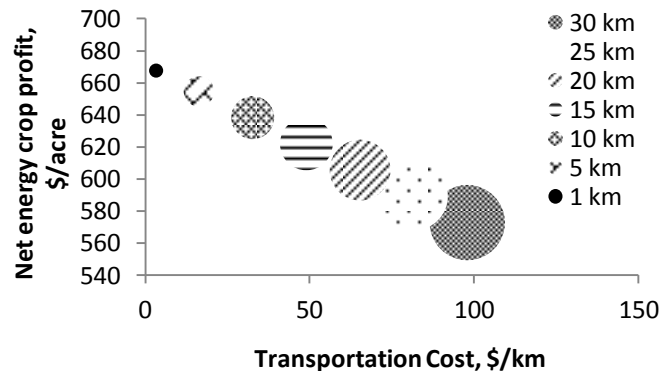| Grain Crop | Maize | Exp. Yield (bu/ac) | 140 | Weight/bu (lbs) | 66 | Bushels/ton | 30 | Exp. Yield (tons/ac) | 4.62 |
| Biomass Crop | Switchgrass | Exp. Yield (tons/ac) | 4 | | | | | | |
| Region | Midwest USA | | | | | | | | |

**Grain Crop Production Inputs:**

| | | Prob. | | Exp. Cost ($/ac) |
|---|---|---|---|---|
| Apply Fertilizer ($/ac) | $250.00 | 0.8 | | |
| No Fertilizer ($/ac) | $0.00 | 0.2 | $200.00 | |
| Apply chemicals ($/ac) | $180.00 | 0.5 | | |
| No chemicals ($/ac) | $0.00 | 0.5 | $90.00 | |
| Machinery Used ($/ac) | $50.00 | 0.95 | | Expected Cost of Grain Crop Production ($/ac) NON-LAND |
| No machinery used ($/ac) | $0.00 | 0.05 | $47.50 | |
| Hire Labor ($/ac) | $12.00 | 0.2 | | $414.08 |
| No hired labor ($/ac) | $0.00 | 0.8 | $2.40 | |
| Irrigation Cost ($/ac) | $5.00 | 0 | | |
| No irrigation ($/ac) | $0.00 | 1 | $0.00 | |
| Govt. Subsidies used ($/ac) | -$1.00 | 0.1 | | |
| No Govt Subsidies ($/ac) | $0.00 | 0.9 | -$0.10 | |
| Buy New Seed ($/ac) | $75.00 | 0.99 | | |
| Seed from previous crop ($/ac) | $3.00 | 0.01 | $74.28 | |

**Biomass Crop Production Inputs:**

| | | Prob. | Exp. Cost ($/ac) |
|---|---|---|---|
| Apply Fertilizer ($/ac) | $200.00 | 0.8 | |
| No Fertilizer ($/ac) | $0.00 | 0.2 | $160.00 |
| Apply chemicals ($/ac) | $50.00 | 0.5 | |
| No chemicals ($/ac) | $0.00 | 0.5 | $25.00 |
| Machinery Used ($/ac) | $40.00 | 0.95 | |
| No machinery used ($/ac) | $0.00 | 0.05 | $38.00 |
| Hire Labor ($/ac) | $12.00 | 0.4 | |
| No hired labor ($/ac) | $0.00 | 0.8 | $4.80 |
| Irrigation Cost ($/ac) | $5.00 | 0 | |
| No irrigation ($/ac) | $0.00 | 1 | $0.00 |
| Govt. Subsidies used ($/ac) | -$5.00 | 0.7 | |
| No Govt Subsidies ($/ac) | $0.00 | 0.3 | -$3.50 |
| Buy New Seed ($/ac) | $75.00 | 0.05 | |
| Seed from previous crop ($/ac) | | 0.95 | $3.75 |

NON-LAND Expected Cost of Biomass Crop Production ($/ac): $228.05

**Fertilizer to Crop Value M$_3$**

**BIOMASS CROP FAILURE RISK** Prob.

| | | | Exp.cost of Prod. ($/ac) | Expected Transportation Cost ($/ac) | Gross Profit ($/ac) | Net Profit, NON-LAND ($/ac) |
|---|---|---|---|---|---|---|
| Successfully produce BIOMASS crop | 0.95 | Deliver to Biorefinery | $228.05 | $4.00 | $560.00 | $327.95 |
| BIOMASS Crop fails (total loss) | 0.05 | Deliver Biomass Crop to Intermediate | $228.05 | $4.00 | $504.00 | $271.95 |

**GRAIN CROP FAILURE RISK:** Prob.

| | | | | | | |
|---|---|---|---|---|---|---|
| Successfully produce GRAIN crop | 0.95 | Deliver to Grain Elevator/Market | $414.08 | $190.48 | $840.00 | $235.44 |
| GRAIN Crop fails (total loss) | 0.05 | | | | | |

*Break even point*

**TRANSPORT:**

| | |
|---|---|
| Fuel cost rate ($/km) | $0.50 |
| Maint Cost($/km) | $0.30 |
| Trip (truck) Delivery Size(tons) | 20 |

**DISTANCE:**

| | |
|---|---|
| Mean Distance to Biorefinery (km) | 1 |
| Mean Distance to Grain Elevator/Market (km) | 55 |

**PRICES:**

| | |
|---|---|
| Price of Grain Crop at elevator($/bu) | $6.00 |
| Price of Grain Crop at elevator($/ton) | $181.82 |
| Price of Biomass Crop ($/ton) | $140.00 |
| Penalty for Delivery to Intermediate (%) | 10 |

**Useful Indices:**

Fertilizer Cost to Crop Value Ratio

| Grain | Biomass, direct del. | Biomass, intermediate del. |
|---|---|---|
| 0.24 | 0.49 | 0.59 |

| Distance Ratio (biorefinery to grain elevator) |
|---|
| 0.02 |

| Price Ratio (before penalty, biomass/grain) |
|---|
| 0.77 |

**KEY:**

| | |
|---|---|
| INPUT CELLS | |
| OUTPUT CELLS | |

## Corn and Switch grass
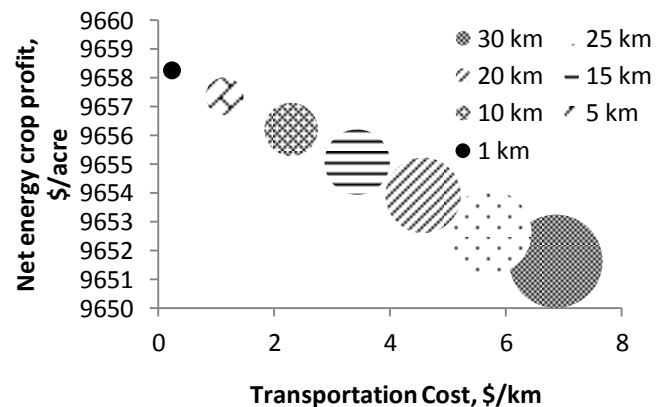


## Peach and Eucalyptus



**Grain crop transport is much low compared to other bio-fuel crops.**

## Corn and Jatropha



## Coconut and Citrus



**This would main that we have to reduce distance of transport
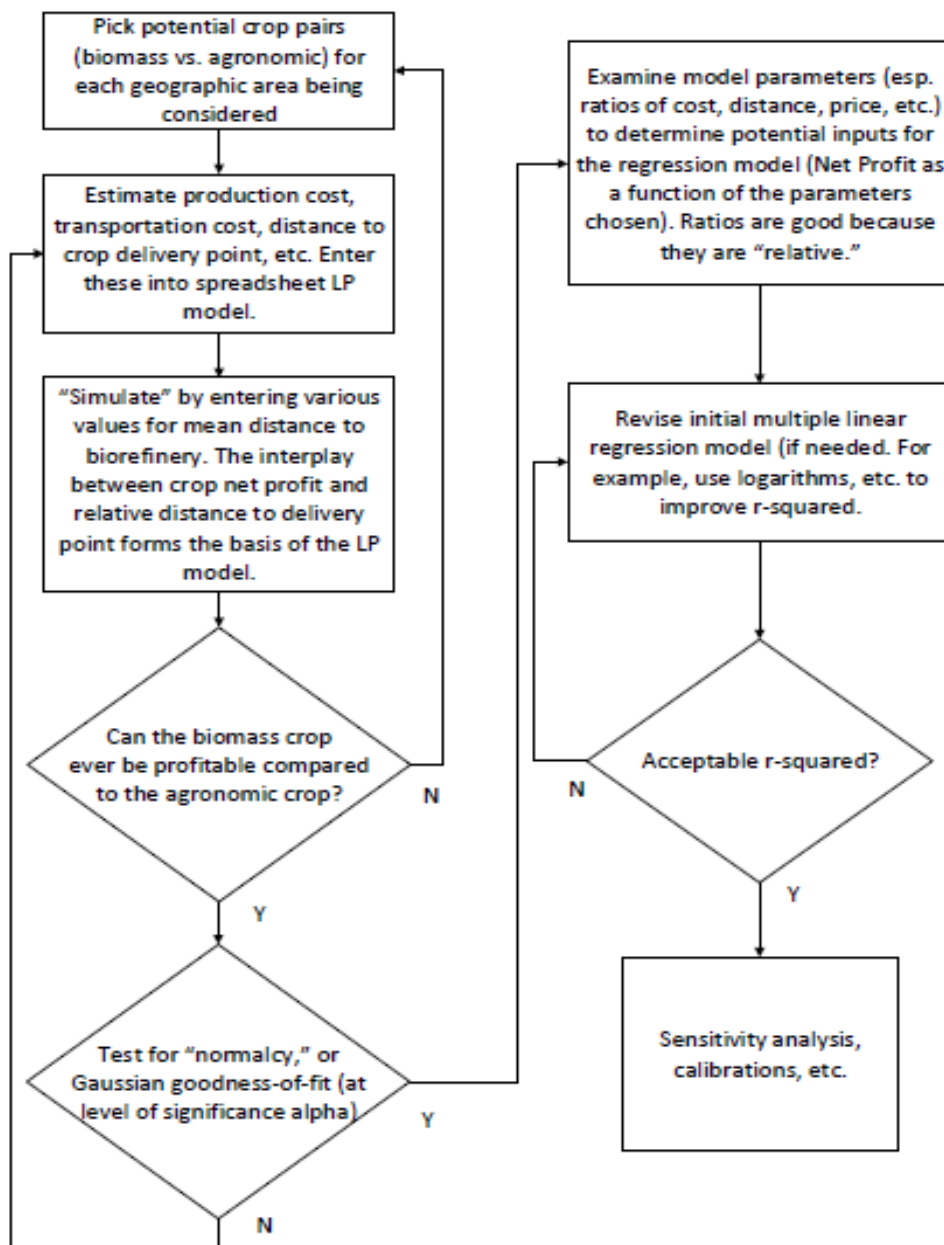of bio-fuel crops tp get profits at par to grains.**

www.weentech.co.uk

16

# Correlation Chart – $M_1$ (T-bio), $M_2$ (Disratio). $M_3$ (Distance) , $M_4$ (F/bio)

|          | T-bio | Distance | Disratio |
|----------|-------|----------|----------|
| Distance | 0.710 |          |          |
|          | 0.000 |          |          |
| Disratio | 0.710 | 1.000    |          |
|          | 0.000 | 0.000    |          |
| F/bio    | 0.376 | 0.084    | 0.084    |
|          | 0.048 | 0.671    | 0.670    |

**Bio-material transport cost (T-Bio) , $M_1$,** $M_2$ is defined the ratio of distance to bio-refinery site to agronomic crop delivery point

These are correlation show that distance M3 is very less correlated to the ratio of fertilizer cost to crop value $M_4$ (ratio F/bio)

$M_1$ and $M_2$ have the capacity to reflect individual grain crop & bio-fuel crop pair property for a specific region

the new net energy crop profit
Biofuels and Bioenergy: International conference and Exhibition (BICE2016), MANIT, Bhopal
23 - 25 February 2016

Pick potential crop pairs (biomass vs. agronomic) for each geographic area being considered

Estimate production cost, transportation cost, distance to crop delivery point, etc. Enter these into spreadsheet LP model.

"Simulate" by entering various values for mean distance to biorefinery. The interplay between crop net profit and relative distance to delivery point forms the basis of the LP model.

Can the biomass crop ever be profitable compared to the agronomic crop? — N

Y

Test for "normalcy," or Gaussian goodness-of-fit (at level of significance alpha) — Y

N

Examine model parameters (esp. ratios of cost, distance, price, etc.) to determine potential inputs for the regression model (Net Profit as a function of the parameters chosen). Ratios are good because they are "relative."

Revise initial multiple linear regression model (if needed. For example, use logarithms, etc. to improve r-squared.

Acceptable r-squared? — N

Y

Sensitivity analysis, calibrations, etc.

$$P_i = r \prod_{i=1}^{2} M_i^{q_i}$$

$$r = P_0 \left\{ \prod_{i=1}^{k} M_{io}^{q_i} \right\}^{-1}$$

For any energy crop-food crop pair irrespective of any specific region in the United States can be expressed as

$$P_i = r' \prod_{i=1}^{3} M_i^{q_i}$$

$M_3$ is the natural logarithm function of r specifically for each specific energy crop-rotation food crop pair (Plappally et al 2011)

Corn and Switch grass

$$P = e^{5.59} V_1^{-0.0994} V_2^{-4.71}$$

Peach and Eucalyptus

$$P = e^{6.38} V_1^{-0.0389} V_2^{-1.71}$$

Corn and Jatropha

$$P = e^{6.43} V_1^{-0.0355} V_2^{-1.57}$$

Coconut and Citrus

$$P = e^{9.18} V_1^{-0.0001} V_2^{0.007}$$

$V_1$ and $V_2$ represent the independent form of $M_1$ and $M_2$.

The Power values of $V_1$ tells that the importance of transportation cost decreases from bottom to top, i.e from a less grain pair to a more grain dominated pair

$$P = e^{6.89} V_1^{-0.701} V_2^{0.896} V_3^{1.29}$$

| Predictor Variables\ Model Coefficients | r' | $q_1$ | $q_2$ | $q_3$ | $R^2$ | S |
|---|---|---|---|---|---|---|
| $M_1$ | 8.72 | -0.629 | - | - | 56.1 | 0.935 |
| $M_2$ | 12.0 | -1.12 | 1.10 | - | 96.4 | 0.274 |
| $M_3$ | 10.7 | -0.855 | 0.824 | 0.0608 | 99.7 | 0.075 |

The above equation basically attests the importance of the ratio of distance to the bio-refinery site to the agronomic crop delivery point ($V_2$ or $M_2$) and
Secondly the importance of the type of crop in a local or nearby region.

Conclusion

1. For bio-fuel profits, bio-refinery should be close than actual grain elevators

2. A new model of energy crop profit as a function of transport cost and ratio of the distance from the bio energy crop farm to bio-refinery and radial distance from food grain farm to grain elevator.

3. Production and Storage of bio-fuel crop should be localized and near to bio-fuel production centers. This means that bio fuel is to be produced from local crops.

**Kevin Duemmel, P.E., Lighting & Signals Engineer**

(614)728-2450

**Ohio Department of Transportation**

Kevin.Duemmel@dot.ohio.gov

**Anand K Plappally, PhD., Assistant Professor**

91 (291) 2449078

**IIT Jodhpur**

anandk@iitj.ac.in

## Corn and Switch grass

| Predictor Variables\ Model Coefficients | r | $q_1$ | $q_2$ | $R^2$ | S |
|---|---|---|---|---|---|
| $M_1$ | 6.03 | -0.118 | - | 77.7 | 0.082 |
| $M_2$ | -9.15 | 2.74 | -2.94 | 96.6 | 0.035 |

## Corn and Jatropha

| Predictor Variables\ Model Coefficients | r | $q_1$ | $q_2$ | $R^2$ | S |
|---|---|---|---|---|---|
| $M_1$ | 6.54 | -0.0461 | - | 80.4 | 0.029 |
| $M_2$ | 1.07 | 0.991 | -1.07 | 97.3 | 0.012 |

## Peach and Eucalyptus

| Predictor Variables\ Model Coefficients | r | $q_1$ | $q_2$ | $R^2$ | S |
|---|---|---|---|---|---|
| $M_1$ | 6.54 | -0.0461 | - | 80.4 | 0.029 |
| $M_2$ | 1.07 | 0.991 | -1.07 | 97.3 | 0.012 |

## Coconut and Citrus

| Predictor Variables\ Model Coefficients | r | $q_1$ | $q_2$ | $R^2$ | S |
|---|---|---|---|---|---|
| $M_1$ | 9.18 | -0.00019 | - | 81.8 | 0.00011 |
| $M_2$ | 9.16 | 0.0043 | -0.0046 | 98.1 | 0.00004 |

The Multivariate Framework (Source: Plappally et al 2011, JEMT, ASME.

$[\rho x_{i,j}]$ is a square matrix, $k \times k$, and if $[\theta_{i,j}]$ is a vector in the null space of $[\rho x_{i,j}]$ and exist in the $n$ dimensional space of the predictor variable $X_{i,j}$ data set, then [4]

$$[\rho x_{i,j}][\theta_{i,j}] = \lambda_{i,j}[I][\theta_{i,j}] \qquad (A1)$$

$$[\lambda_{i,j}[I] - [\rho x_{i,j}]][\theta_{i,j}] = 0 \qquad (A2)$$

Here $[\theta_{i,j}]$ is the null space of the characteristic equation term and left hand also represents two orthogonal vectors in the inner product space. It should be noted that $[\theta_{i,j}]$ contains all vectors perpendicular to the column spaces containing all the predictor variables. There will be one eigen space $[\theta_{i,j}]$ for each distinct eigenvalue $[\lambda_{i,j}]$ for $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, k$ when $n > k$ and so there will be $k$ eigen spaces for . Trace of the eigen value matrix also defines the total variance of the predictor variables [4].

$$[\phi] = \begin{bmatrix} (\theta_1^1)^2 \big/ ((\theta_1^1)^2 + \cdots \ldots + (\theta_k^1)^2) & \ldots & (\theta_1^k)^2 \big/ ((\theta_1^1)^2 + \cdots \ldots + (\theta_k^1)^2) \\ \vdots & \ddots & \vdots \\ (\theta_k^1)^2 \big/ ((\theta_1^1)^2 + \cdots \ldots + (\theta_k^1)^2) & \ldots & (\theta_k^k)^2 \big/ ((\theta_1^1)^2 + \cdots \ldots + (\theta_k^1)^2) \end{bmatrix}^{1/2}$$

$\overline{[T]}$ is an orthogonal square matrix of size, $k \times k$, with normalized eigen vectors $\left[ \theta_{i,j} \right]$ for the three participating predictor variables. The normalized eigen vectors can be represented as [4]

Then $\overline{[T]} = [\phi]^t$, which constitutes the transformation matrix $\overline{[T]}$. The correlated predictor matrix column elements $X_i = \overline{X_{i,j}}$ for $i = 1,2,\ldots,k$ with correlation coefficient are linearly transformed into mathematically uncorrelated variables $V_i = \overline{V_{i,j}}$ and scaled as [4]

$$\frac{\left( \left[ \overline{X_{i,j}} - \mu_{\overline{X_{i,j}}} \right] \right)}{\sigma_{\overline{X_{i,j}}}} = \overline{[T]} \left[ \frac{[v_{i,j}]}{\sqrt{\lambda_{i,j}}} \right] \tag{A3}$$

The Multivariate Framework (Source: Plappally et al 2011, JEMT, ASME.