# SIMULATION OF INDUSTRIAL PRODUCTION FROM AGRICULTURAL FEEDSTOCKS: THE CASE OF NYLON 13/13 AND INDUSTRIAL RAPESEED IN MISSOURI, U.S.A.

LEE DONG-PHIL *
MELVIN G. BLASE **
DONALD L.VAN DYNE **

## I. Introduction

Industrial rapeseed is a new crop contains about 40 percent of high erucic acid (HEA) oil and 60 percent of high protein meal. The HEA oil can be utilized as lubricants for steel casting and molding, and raw material to produce brassylic acid (BA) which is currently obtained from petroleum. Although the BA has been used in the production of perfumes, synthetic lubricants, paints, coatings, and plasticizers, the most promising usage is the making of nylon 13/13. Nylon 13/13 is a high quality industrial nylon which would compete with nylons 11 and 12. Although the uses of these nylons are many, the primary growth market appears to be in the transportation area due to efforts to reduce the weight of vehicles in order to improve gas mileage.

Producing industrial rapeseed and substituting nylon market by the nylon 13/13 probably would provide incomes for farmers via diversification of typical agriculture. In doing so, it could strengthen the rural economy through; (1) linkages of farm and non-farm activities, and (2) its spill-over effects into the community. In addition, this new industrial crop would help the national economy via; (1) reducing surplus production of program crops, supporting the national

* Fellow, Korea Rural Economic Institute, Seoul, Korea
** Professor and Research Associated Professor of Agricultural Economics, University of Missouri-Columbia, U.S.A

industrial base, (3) providing import substitution, and (4) reducing the use of depletable resources.

In spite of these attractions, it is difficult to decide investment for the commercialization of this industry because of the uncertainties involved in introducing the new crop which does not have any supply or demand schedules.

This study is designed to identify the range of economic conditions in which industrial rapeseed would be produced as a commercial crop whose oil would be used to produce a high quality plastic for applications such as in automobile parts.

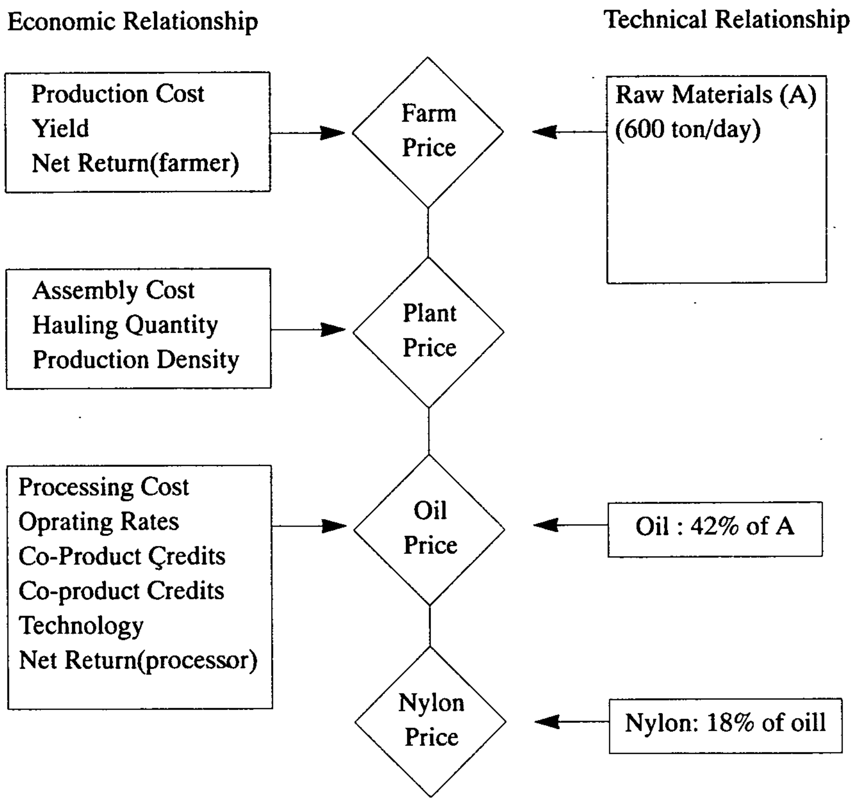
Although this study deals whole system of rapeseed industry in the United States, the simulation methodology to evaluate ecomomic feasibility of producing new materials has applicable implications for the analysis of vertically integrated agri-business which does not have enough data to apply typical methods.

## II. Analytical Methods and Data

One basic determinant of the commercial potential of a new crop is the profitability of its final product(s), as well as all intermediate products. Thus, costs and acceptable net returns at all phases of the marketing chain must be evaluated. Not only does the final product(s) have to be profitable but also desired demand in the backward linkages must be sufficiently robust to make the whole system profitable.

Assuming nylon 13/13 is the primary final product of industrial rapeseed, costs involved in the production, assembly, and crushing of oilseed, as well as those in the manufacturing and marketing of the nylon combine to form the final product cost that must be covered by gross income of the final products. Adding net margins at each market stage to the sum of these costs will give a total cost that should be equal to or less than the price of substitutable products, in order for a new product to enter the existing nylon market. Economic and technical relationships for the production of nylon 13/13 with industrial rapeseed are provided in Figure 1.

**FIGURE 1** Structure of Manufacturing Nylon13/13 with Industrial Rapeseed




A 64 mile radius supply plane, centered on Mexico, Missouri, U.S.A., was chosen as the region to be simulated. In building the model the following assumptions were made; (1) farmers would haul industrial rapeseed from their farms to the plant location in the center of the supply plane, (2) the quantity to be hauled would be enough to keep a 600 ton day oilseed crushing plant operating 300 days (24 hrs/day) per year with pre-press solvent extraction process, (3) a 46 ton day chemical plant operated on the same schedule as the crushing plant could be built aside of the crushing plant to convert all the HEA oil into brassylic acid, and (4) a plastics plant could be constructed aside of the chemical plant to make nylon 13/13 from brassylic acid.

Since industrial rapeseed does not have established price, yield, and production cost data in commercial base, net return is not available to evaluate feasibility of introducing this new crop as usual techniques. To overcome this problem, an affordable price concept which includes production cost and normal net return is introduced and simulated with alternative production cost and yield per acre. Data for yield and production costs for industrial rapeseed were obtained from existing studies[1] and adjusted for the study region.

Plant price is sum of the affordable farm price and assembly cost for the raw material. Per unit assembly cost function was estimated by the budgeting methods[2] as shown in the Equation 1.

$$AAC_{im} = 1.00+0.089\ D_{im} \qquad (1)$$

where $AAC_{im}$ is average assembly costs per ton of rapeseed, and $D_{im}$ is the round trip distance from farm-gate to plant. The intercept includes loading and unloading costs per load, the slope includes fixed and variable operation costs, and transit labor costs per mile.

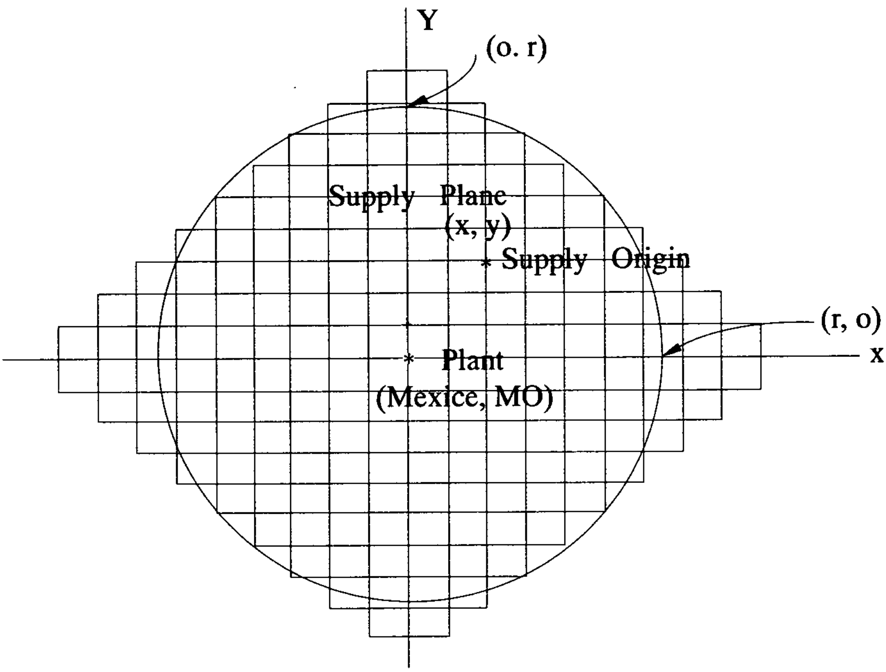
Since quantity to be assembled depends on the operating rates of the crushing plant which was assumed 600 ton/day, relationships between assembly costs and hauling volume should be identified.

---

1 See Reddick's *The Economic Potential of Winter Rapeseed in Missouri* (1990), and Blase and Van Dyne's production cost projections for rapeseed (1990).

2 For the estimation of assembly cost function, the followingg assumptions were made: (1) farmers use 2-ton trucks for hauling the rapeseed with an average speed of 30 miles per hour, and (2) the trucks are used for 20,000 miles of hauling per year and one-tenth of their fixed costs can be allocatid to rapeseed hauling.

**FIGURE 2** Supply Area with a Square Grid Road System for a Centralized Oilseed Crushing Plant




Based on the assumptions that the supply plane is circular which has a square grid road system and uniform production density as shown in Figure 2, the average distance ($D_a$) from a certain supply origin (x,y) to the plant location can be expressed by the ratio of the areas as follows:

$$D_a = \left(\frac{4}{\pi r^2}\right) \int_0^r \int_0^{\sqrt{r^2 - x^2}} (x+y)\, d_y d_x \qquad (2)$$

$$= 8r / 3\pi$$

Since total supply volume (S) of the circular production area is production density (P) times ares, the radius (r) of the supply plane is:

$$r = \sqrt{\left(\frac{S}{\pi P}\right)} \tag{3}$$

Substituting <Equation 3> into <Equation 2> gives the relationship between hauling quantity and hauling distance

$$D_a = 0.4789\sqrt{\frac{S}{P}} \tag{4}$$

where S is volume to be assembled, P is average production density, and $D_a$ is average hauling distance.

Plug <Equation 4> into the <Equation 1> and multiply by quantity to be hauled gives total assembly costs. That is, higher operating rates which means increasing quantity to be assembled with given production density will increase distance to be hauled and results higher assembly costs.

Processing procedures are separated as: (1) crushing oilseed and extraction oil, and (2) chemical conversion and manufacturing nylon 13/13. Choosing a crushing volume determines not only quantity to be hauled, but also quantity to be processed into nylon 13/13 with assumption that all the extracted oil are used for manufacturing nylon. In addition, quantity of final product and co-product are predetermined by the technical input-output relationships.

Processing costs are estimated for both crushing oilseed and manufacturing nylon 13/13 through the cost engineering methods based on the previous studies[3]. Since existing oilseed crushing plant can be used for extracting industrial rapeseed oil with simple modification, processing costs for both modified and new crushing plants are separated.

---

[3] See Helgeson and Cobia, et al's *The Economic Feasibility of Establishing Oil Sunflower Processing Plants in North Dakota* (1977) and Scheithauer and Dripchak's *Economics of Vegetable Oil Processing* (1988) for the estimation of oil seed crushing costs and Sohns' "Cost Analysis for New Products and Processes Developed in USDA Laboratories" (1971) for the estimation costs of manufacturing nylon from industrial rapeseed oil.

All the prices of inputs and outputs, yields, and operating rates were not fixed. Therefore, various prices, yields, and operating rates were simulated to measure the sensitivity of these changes on the costs of producing nylon 13/13. After discussing initial results to make nylon 13/13 at 600 ton/day size crushing plant[4] in the base solution, various scenarios will be reported under several alternative sets of assumptions.

## III. Base Solution

The cost per ton of oilseed depends on yields, production costs, and normal net returns per acre. Under current production techniques and agro-climatic conditions in the study area, industrial rapeseed yields of 39.74 bushel per acre (Reddick, 1990) can be expected for farmers accustomed to raising the crop in the study region. Production costs of $174.10 per acre are estimated under these circumstances. An additional 40 percent incentive to normal net returns, i.e., $21.65 per acre, are assumed to be needed as an incentive for farmers to start growing the crop (Van Dyne and Blase, 1991). These values are assumed constant over the supply plane, with 8.5 percent of the cropland producing rapeseed.

A 600 ton/day crushing plant requires 180,000 tons of industrial rapeseed per year. It can produce 75,600 tons of industrial rapeseed oil and 104,400 tons of meal. The price of meal is evaluated at $120 per ton. An industrial rapeseed price of $214.21 is assumed which consists of $205.75 per ton of oilseed plus $8.46 assembly cost.

The oil produced by the crushing plant yields 13,633 tons of nylon 13/13. In addition, 5,999 tons of glycerine, 13,497 tons of pelargonic acid, and 21,131 tons of mixed fatty acid are produced as co-products[5]. Normal net returns for both plants are assumed as 7.5 percent of the initial investment capital. Since new and modified plants are different in the size of investment, processing costs also dif-

---

[4] Choosing a crushing plant size determines quantity of raw material to be assembled and processed to nylon 13/13 by assumption that all the extracted oil are used for manufacturing nylon 13/13.

[5] These physical input-output relationships are taken from Sohns (1971).

fer. Average operating costs per ton of oil in a new crushing plant are estimated at $28.00 while that for the modified plant is estimated as $19.40 for a 600 ton/day crushing plant (Lee, 1991).

The annual operating costs for chemical conversion and manufacturing per ton of nylon 13/13 is estimated at $1,824.90 ($0.91/lb) for a 46 ton/day nylon plant. Using these annual operating costs, the cost per ton of nylon 13/13 is projected as $1,136.80 for the new plant and $964.20 for the modified plant (see Table 1).

**TABLE 1** Estimated Costs to Produce a Ton of Nylon 13/13: Base Solution

| | New Plant | Modified Plant |
|---|---|---|
| | -------- dollars | ---------- |
| a. Oil Price | 2,353.30 | 2,181.30 |
| b. Operating Costs | 1,824.90 | 1,824.30 |
| c. Processing Costs(=a+b) | 4,178.20 | 4,005.60 |
| d. Co-Product Credits | 3,223.60 | 3,223.60 |
| e. Net Costs(=c-d) | 954.60 | 782.00 |
| f. Net Return for Processor | 182.20 | 182.20 |
| g. Nylon Price(=e+f) | 1,136.80 | 964.20 |

Note: Difference in oil price due to the different use of crushing plants; new and modified plant

Although total processing costs, including industrial rapeseed costs, are estimated at $4,178.20 per ton for a new plant and $4,005.6 per ton for a modified plant, co-product credits cover more than 75 percent of these costs. Since the current market price of substitutable products, nylon 11 and nylon 12, is $ 2.05-3.50 per pound (Van Dyne and blase, 1990), the estimated cost of producing nylon 13/13, $0.50-0.60 per pound, suggests it would be highly competitive in the market place.

## IV. Alternative Solutions

As there is no existing commercial base industry except for a crushing plant, certain ranges of values must be applied for the sensitivity analysis for major cost factors such as various yields, production costs per acre, range of operating rates, and co-product credits. The results are reported as estimated oilseed prices, assembly costs, oil and nylon prices. In the next section alternative levels of net returns for both the farmer and processor, as well as a new alternative chemical process for producing brassylic acid in place of the traditional method assumed above, are discussed.

### 1. Changes in Yield per Acre

A change in yields varies not only the oilseed price, but also the assembly costs. Thus, it changes the raw material cost of producing oil and, subsequently, that of nylon 13/13. Since industrial rapeseed is relatively new crop, a range of yields was incorporated to determine the entire system's sensitivity to this factor. Analyzed results are reported in Table 2.

**TABLE 2** Estimated Prices with Alternative Industrial Rapeseed Yields in Missouri, 1990

| | New Plant | | | Modified Plant | | |
|---|---|---|---|---|---|---|
| | ------- Yields (bu/ac) -------- | | | | | |
| | 35 | 40 | 45 | 35 | 40 | 45 |
| | ------- $/ton ------- | | | | | |
| Oilseed Price | 199 | 174 | 155 | 199 | 174 | 155 |
| Assembly Costs | 9 | 8 | 8 | 9 | 8 | 8 |
| Oil Pice | 494 | 421 | 364 | 463 | 390 | 333 |
| Nylon Price | 1,527 | 1,118 | 800 | 1,354 | 945 | 627 |

Oilseed production costs per ton are estimated at $199.00 when yields per acre are assumed to be 35 bushels. However, that cost is reduced to $154.76 per ton when the yield per acre is 45 bushels.

Within these yield ranges, the nylon price is estimated to drop from $1,527 to $885 per ton for the new plant and from $1,354 to $627 per ton for the modified plant. Although net returns for the processor on a per ton basis are the same[6] ($13.40 for the new plant, $2.80 for the modified plant, and $182.20 for the nylon manufacturing plant), farmer's net returns are increased from $26.90 to $34.60 per ton of oilseed production.

Even with the worst case yield — 35 bushels per acre of industrial rapeseed — there is strong market potential because nylon can still be produced significantly below the existing market price of substitutable products, which range from 2.50 to $3.50 per pound.

## 2. Changes in Production Costs

Variations in production costs are another possibility. Although this study used a cost of production of $174.10 per acre for the study area, $181.15 per acre has been estimated as the average production cost in Missouri. Based on the state average production cost, plus and minus 5 percent changes are applied as alternative production costs per acre in the sensitivity analysis.

The estimated price of producing nylon 13/13 with these changes in the production costs range from $1,109 to $1,360 per ton in the new plant and $936 to $1,187 per ton in the modified plant.

In the simulation with the most expensive components, nylon 13/13 can be produced at $0.68 per pound. In these scenario the farmers' cost per acre is $190.20 and the new plant is used to crush the rapeseed. This is the highest cost of production because more than 75 percent of total processing costs for manufacturing nylon 13/13 (which consists of 57.3 percent raw material costs and 42.7 percent operating costs) are recovered by co-products credits regardless of the cost of producing the rapeseed.

---

[6] The difference in the net return of the new and modified plant are caused by the method of estimation which is calculated as 7.5 percent of initial investment to estimate final product price. However, the net return for modified plant and higher yield case should be larger than that of new plant and lower yield if prices are fixed.

## 3. Changes in Net Returns for the Farmers

Introducing a new crop involves many risks, not only in production but also due to price variation. To cover these risk, three different levels; zero percent (i.e., no additional incentive), 120 percent, and 130 percent of the projected net margin were used in the sensitivity analysis. Because industrial rapeseed prices are influenced in the long run by production costs and net returns to the farmer, changes in the level of net returns will also be reflected eventually in the price of oilseed, oil, and nylon 13/13.

Price per ton of nylon 13/13 is estimated at $1,016.90 without any incentive for the crop, but it goes to $1,076.80 and $1,106.80 in the new plant when 20 percent and 30 percent additional incentives are provided to farmers. These changes in levels of net returns affect the cost of nylon through changes in oilseed and oil prices as well as annual operating costs. The latter costs change because inventory values change. The price of nylon 13/13 is estimated to go to $844 and, subsequently, to $934 in the modified plant with zero percent and 30 percent incentives, respectively.

## 4. Changes in Operating Rates

Operating rates for the processing plant vary from time to time, and are crucial to its profitability. A 100 percent operating rate assumes 300 days per year and 24 hours per day of operation in the base solu-

**TABLE 3** Estimated Prices with Alternative Operating Rates in Missouri, 1990

| | New Plant | | | Modified Plant | | |
|---|---|---|---|---|---|---|
| | ----- Operating Rates(%) ----- | | | | | |
| | 100 | 75 | 50 | 100 | 75 | 50 |
| | dollars per ton | | | | | |
| Oilseed Price | 206 | 206 | 206 | 206 | 206 | 206 |
| Assembly Costs | 8 | 7 | 6 | 8 | 7 | 6 |
| Oil Price | 424 | 428 | 444 | 393 | 388 | 385 |
| Nylon Price | 1,137 | 3,018 | 6,910 | 964 | 2,858 | 6,586 |

tion. The simulated results for 3 different operating rates; 100 percent, 75 percent, and 50 percent are presented at Table 3.

The per ton nylon price for a 75 percent operating rate is $3,081 per ton from the new plant and $2,858 from the modified plant. This is 2.7 and 3 times higher than that for a 100 percent operating rate for the new plant and modified plant, respectively. Even so, a 75 percent plant operating rate was in the competitive price range for the end product, assuming no change in the prices of competitive products. However, a 50 percent operating rate for both the new and modified plant resulted in a price of production of $3.30 to $3.50 per pound of nylon 13/13, which would make penetration of the current nylon market difficult, if not impossible.

Although a constant net return of $30.50 per ton farm production is estimated, total assembly costs are decreased from $8.46 to $7.46 and $6.28 for 75 percent and 50 percent operation, respectively. This is because the assembly costs depend on the quantity to be hauled which is impacted by a different hauling distance.

## 5. Changes in Co-product Credits

Co-product credits offset about 30 percent of total crushing costs and 75 percent of nylon manufacturing costs. From a 600 ton/day crushing plant, 104,400 tons of high protein meal can be obtained per year. In addition, co-products of producing a ton of pelargonic acid ($0.97/lb), and 1.55 tons of mixed fatty acid ($0.25/lb) (Sohns, 1971, and Van Dyne and blase, 1990).

The price per ton of nylon 13/13 is estimated at $1,967.70 and $1,795.10 for new and modified plants, respectively, when total co-product values are reduced 20 percent from the base level. The estimated price of nylon is only $305.90 and $133.30 per ton for the new and modified plants, respectively, when co-products are evaluated 20 percent higher than that of the base scenario. No changes are assumed in the net returns per ton of $30.50 to the farm, of $13.49 to the crushing plant, and $182.20 to the nylon plant.

## 6. Changes in the Level of Net Returns for Processor

The base solution incorporates 7.5 percent of initial investment as net returns for processors; both the oilseed crusher and the nylon manufacturer. However, this level of net returns will change the cost of the oil and nylon if it is changed. Three different levels of net returns; 5 percent, 10 percent, and 12.5 percent are incorporated as alternatives.

The price per ton of nylon 13/13 is estimated at $1,051 for a new plant and $898 for a modified plant when a 5 percent net return is assumed for both crushing and nylon plants. Simulated prices are $1, 223 and $1,308 for new plants and $1,030 and $,1097 for modified plants when levels of net returns are 10 percent and 12.5 percent of initial investment costs.

## 7. Improved Technology for Converting HEA to Brassylic Acid

Recently, scientists at North Dakota State University developed a new, simpler technology to split HEA into brassylic and pelargonic acid through chemical oxidation with a catalyst. According to their findings, this new technology is safe and simple. Knowledgeable analysts believe this technology will require about one third the investment of an ozone plant. Moreover, this new technology is expected to lower operating costs significantly, and be more environmentally friendly than the ozonolysis process.

Although detailed information is unavailable concerning the processing costs for nylon 13/13 with this new technology, there is a high probability it will reduce nylon production costs. To evaluate the potential economic impact of the new technology, 20 percent, 30 percent and 40 percent reductions in the total processing costs (from the base solution which assumes use of the ozonolysis thchnology) are incorporated into the analysis. In this scenario nylon 13/13 can be produced for $3,813.20 to $3,448.20 per ton. However, prices are reduced to a range from $406.80 to $771.80 per ton of nylon 13/13 after accounting for co-product credits. Obviously, at this cost of production most of the processing costs are covered by co-product credits.

## 8. Changes in Oilseeds and Oil Prices

Previous discussions concerning changes in yields, production costs per acre, and levels of net returns for farmers resulted in oilseed price changes. Thus, this change in the oilseed price can be used as a comprehensive indicator of these variables. Three different price levels, $200, $220, and $240 per ton of industrial rapeseed, are incorporated as alternatives.

The price per ton of nylon 13/13 is estimated at $941.30 when the $200 per ton of oilseed price is applied. At that price, the cost of the oilseeds constituted 54.2 percent of the total processing costs. The price per ton of nylon 13/13 is estimated at $1,491.60 per ton when $240 per ton price is used. Oilseed costs amount to 59.6 percent of total processing costs, $4,533, in this case. Applying the highest expected industrial rapeseed price, $240 per ton, nylon 13/13 can be produced for $1,216.50 per ton. This price includes a net return for farmers, covers assembly costs, and provides a net return for processors. Thus, there is a strong possibility of being able to penetrate the existing nylon market even at that higher price for the feedstock.

The industrial rapeseed oil price can also work as a comprehensive indicator which represents changing factors not only in oilseed price, but also in operating rates of processing plants, levels of net returns for processors, value of co-products, and technology applied for processing. Three different industrial rapeseed oil prices; $400 per ton, $600 per ton, and $800 per ton were incorporated as alternatives.

The price per ton of nylon 13/13 is estimated at $1,000 when the oil price is $400 per ton and $2,123 when the oil price goes to $600 per ton. The oil price represents 54.9 percent of total costs when the oil price is $400 and 64.4 percent when the oil price is $600 per ton. In the case of the current industrial rapeseed oil price, $800 per ton, the price per ton of nylon 13/13 is estimated at $3,246, which is $1.60 per pound. This is in the competitive range to penetrate the existing market. Moreover, it shows that oilseed prices are vary important to the commercialization of this crop.

## IV. Conclusions

The results of the simulation analysis of the production of nylon 13/13 in Mexico, Missouri, U.S.A., vary depending upon the incorporated alternative scenarios. However, most scenarios suggest the product can penetrate existing markets.

Nylon 13/13 can be produced for $1.50 per pound which is lower than the competitive nylon market price of $2.50 to $3.50 per pound even with current industrial rapeseed oil priced at $800 per ton.

According to the base solution, industrial rapeseed oil can be produced for $424.38 from a new crushing plant and for $393.35 from a modified crushing plant. Applying these oil prices, nylon 13/13 can be produced at $0.48 to $0.57 per pound with appropriate net returns at each step in production, processing, and marketing.

Especially yields per acre, operating rates of crushing plants, and co-product credits are the most important variables determining the production costs of nylon 13/13. Thus, research on (1) production technology, (2) modification of existing crushing plants, and (3) improvements in the value of co-products should be emphasize to enhance the feasibility of introducing industrial rapeseed as a commercial crop.

## REFERENCES

Collier, Courtland A. and William B. Ledbetter. 1982. *Engineering cost analysis Happer* & Row Publish, New York.

Council for Agricultural Science and Technology. 1984.*Effects of a development of new crops; needs, procedures, strategies, and options* Report No. 102. Ames, Iowa: Council for Agricultural Science and Technology (October)

Dicks, Michael R. and Katharine C. Buckley. 1989. *The potential for import substitution through the development of alternative opportunities* Economic Research Series, *USDA* (December)

French, Ben C. 1960. Some considerations in estimating assembly cost functions for agricultural processing operations", *Journal of Farm Economics.* 42, No. 4: 767-778

Helgeson, Delmer L., David W. Cobia, et al. 1977. *The economic feasibility of establishing oil sunflower processing plant in North Dakota* Fargo, North Dakota, North Dakota University

Humphery, Kenneth k. and paul Wellman. 1986. *Basic cost engineering* Marcel Dekker Inc. New York

JAOCES. 1988. Developing new commercial crops", *Journal of American oil chemists's society..* 65. No. 1: 12-20

Lee, Dong Phil. 1991. *A feasibility analysis of the introduction of industrial rapeseed in Missouri* Ph. D. dissertation, UMC

Miller, Julian C. 1971. *Plant introduction and development of new crops in the South* Southern Cooperatives Series, Bul. 161

Reddick, Cedric L. 1990. *The economic potential of Winter Rapeseed in Missouri* M.S. Thesis, University of Missouri

Roetheli, Jóseph C. 1989. *Commercializing products using crop oilseeds high in erucis acid* AAIC Conference, Peoria, IL

Scheithauer, R. and K. Dripchak. 1988. *Economics of vegetable oil processing* Oak Ridge National Laboratory: ORNL/Sub/SAI85/1

Sohns, V.E. 1971. Cost analysis for new products and processes developed in USDA laboratorres, *Journal of American oil chemists' society*, 48: 362A-384A

United Nations. 1977. *Guidelines for the establishment and operation of vegetable oil factories.* New York

USDA. 1986. "New crop economics-commercialization" *Growing industrial materials* (July)

Van Dyne, Donald L. and Melvin G. Blase. 1990. Process design and market potential for nylon 13/13 produced from erucic acid, *American chemical society and American institute of chemical engineers.* Biotechnol. Prog., 6, No. 4: 273-276

——, and K.C. Carlson. 1990. *Industrial feedstocks and products from high erucic acid oil: crambe and industrial rapeseed University* of Missouri in cooperation with Corruptive State Research Service, USDA (March)