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Innovative Applications of O.R.

Supply planning for processors of agricultural raw materials

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ABSTRACT

Material use of agricultural raw materials as renewable resources is gaining increasing importance in industrial production. Seasonal availability as well as variations in raw material quantity and quality and of market prices need to be considered in supply planning. This research depicts the planning problem of a processor of agricultural raw materials and illustrates it with data on the industrial use of linseed oil, which is a promising raw material for the production of new polymers. A two-stage stochastic program provides decision support and is applied to the example. The approach can be used for a variety of planning problems concerning the supply of agricultural raw materials.

1. Introduction

The interest of industry in the use of renewable resources as input for production processes is growing, since raw material supply needs to depend less on fossil resources, at least in the long run. Resource efficiency can be achieved by selecting utilization paths that imply options for the use of by-products (Geldermann, 2012). These utilization paths will become more attractive if research improves value chains and reduces costs (Carus, Raschka, & Piotrowski, 2010). Today, knowledge about the limited availability of crude oil motivates the search for alternative raw materials that can be used to produce industrial goods. The European Commission has identified the market for bio-based products as highly innovative, and selected it as a lead market with high development potential. The establishment of this market should be beneficial for economy and society (European Union, 2011).

Renewable resources are defined as "[. . .] all biomass produced from agriculture and forestry that is not used for food or animal feed" (FNR, 2010). Non-food applications of renewable resources for the production of physical goods are referred to as material use (Oertel, 2007, p. 5). Important agricultural raw materials for material use are, for example, sugar cane, corn, and potatoes, which supply sugar and starch. Fibre plants like flax, hemp and jute can be used for the production of cellulose, while soy, rapeseed, and linseed produce oils (Carus et al., 2010; Oertel, 2007).

In many applications, bio-based products compete with conventional products based on petrochemicals. Therefore, the requirements demanded from industry and customers include competitive prices, constant quality, and availability throughout the year. However, supply markets face variations in prices, qualities and quantities of agricultural products (Lowe & Preckel, 2004). They can occur simultaneously both in short term and in long term periods. The respective varying data need to be handled as uncertain since information on the past values is often incomplete. Not all influencing factors are known and the probabilities of the values of some known influencing factors cannot be predicted for the future.

Dealing with uncertain yield and quality of the harvest is one of the biggest challenges connected with using renewable resources in industry. Moreover, agricultural products can only be harvested at certain times of the year. In this paper, an approach and decision support for a processor of agricultural products are presented, where planning of supply requires taking several uncertainties as well as seasonal availability into account. The problem is illustrated by the example of linseed for which real-world data on quality, quantity, and price variation is available from Canada. Information on the industrial use of linseed and linseed oil is provided in Section 2.1. An exemplary supply planning situation of a processor, which requires a risk mitigation strategy, is introduced in Section 2.2. An overview of the present state of research is provided in Section 3. A risk mitigation strategy for the planning problem of the processor is outlined in Section 4.1 and a suitable optimization approach is selected in Section 4.2. Decision support based on stochastic programming is developed in Section 5. The selection of values for the numerical analysis of the example linseed is described in Section 6.1. In Section 6.2, computational results of the model are provided and discussed. A sensitivity analysis in Section 6.3 further illustrates the decision making behaviour of the model. Concluding suggestions for the decision maker are provided in Section 7.

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2. Problem description

2.1. Industrial use of linseed

In 2012, the acreage used worldwide for linseed production was about 2485 Million hectares and about 92,535 tonnes linseed were harvested, with Canada being one of the main growing regions. In terms of resource efficiency, linseed is a very interesting plant because it is possible to utilize all its parts. The seeds contain a high percentage of valuable oil, which can be extracted. The by-product, linseed cake/meal, can be used as a livestock protein supplement with high nutritional value (Prentice & Storey, 1989). The fibres of linseed can be used in the pulp industry to replace wood fibres, which are added in the process of paper recycling and are used for the production of specialty papers. Further potential applications include geotextiles, bio-plastic composites, insulation, and use in the garment industry as new types of cottonized fibres, which can be used for spinning in traditional cotton mills (Flax Council of Canada, 2014; Rowland, 2002; Vromans, 2006). Shives, the non-fibre parts of the stem, compose 70–85 percent of the total weight of linseed straw. They can be used for the production of wood particle boards. Other options are to burn shives and use the energy for heating, use them as mulch or animal bedding, or as fillers in plastics (Rowland, 2002).

Linseed is an interesting raw material due to the properties of its oil. Linseed oil has an extraordinary high content of linolenic acid which enables easy polymerization (Nykter, Kymalainen, Gates, & Sjoberg, 2006; Wool, 2005). Therefore, it is used in well-established applications e.g. as binders in coatings, cross-linked for powder coatings, as a basic resource for the production of linoleum. It does, however, also represent a promising starting point for the development of new plastic materials (Derksen, Kloster, & Cuperus, 1995; Henna, Andjelkovic, Kundu, & Larock, 2007; Meier, Metzger, & Schubert, 2007; Overeem et al., 1999; Rowland, 2002). Petrović (2008) and Zlatanic, Lava, Zhang, and Petrovic (2004) showed that polyurethanes produced from linseed oil had significantly different material properties than polyurethanes produced from other plant oils. In the example of polymer production, high and stable oil quality enables a stable process and reliable product quality. Quality requirements of the industrial customer need to be considered in the planning of all suppliers upstream the value chain.

Uncertainties on the supply side start in the production of the primary raw material. Yield and quality of the harvest of an agricultural crop are influenced by many factors, e.g. seeding time, seeding rate, presence of nutrients within the soil, weather conditions, use of fertilizers and pesticides and harvest time. It is quite difficult to quantify the influence of these factors on the outcome of the harvest (Rowland, 2002).

The Canadian Grain Research Laboratory publishes data on several quality indicators of harvest survey samples from 1990 to 2010 with mean values for the years 2000–2009. The content of linolenic acid varied between approximately 52.1 percent and 61 percent with a mean value of 56.9 percent. For the Canadian State of Manitoba, data on the content of linolenic acid and the linseed yield for the years 1990–2011 are depicted in Fig. 1. In this figure, the yield of agricultural production is indicated by land productivity, which is the output of crop per hectare. If multiplied with the cultivated area, it can be used as a measure for the harvest quantity.

Presently, linseed is only traded over-the-counter. For the years 1990–2011, the prices of linseed in Manitoba are depicted in Fig. 2. Prices for linseed oil are highly correlated to the price of linseed. Data on prices for linseed oil are available from the information provider Oil World, but due to copyright restrictions, they cannot be published here (Oil World, 2011).

Agricultural supply markets can be standardized to different extents. Basically, the processor can order raw materials from a commodity market, where standardized contracts are used, and the quality of goods is labelled in grades. In Canada, three different grades are established for linseed and traded over-the-counter, but the grading system does not consider the fatty acid distribution or the content of linolenic acid in the oil (Canadian Grain Commission, 2014) which is important for the quality of polymers as polyurethane (Zlatanic et al., 2004). Therefore, a processor that delivers oil for quality-sensitive applications like new biomaterials would not use this market and rather specify the iodine value or the content of linolenic acid in the supply contract.

For a rough estimation, the United Nations Conference on Trade and Development publishes Free Market Commodity Prices for

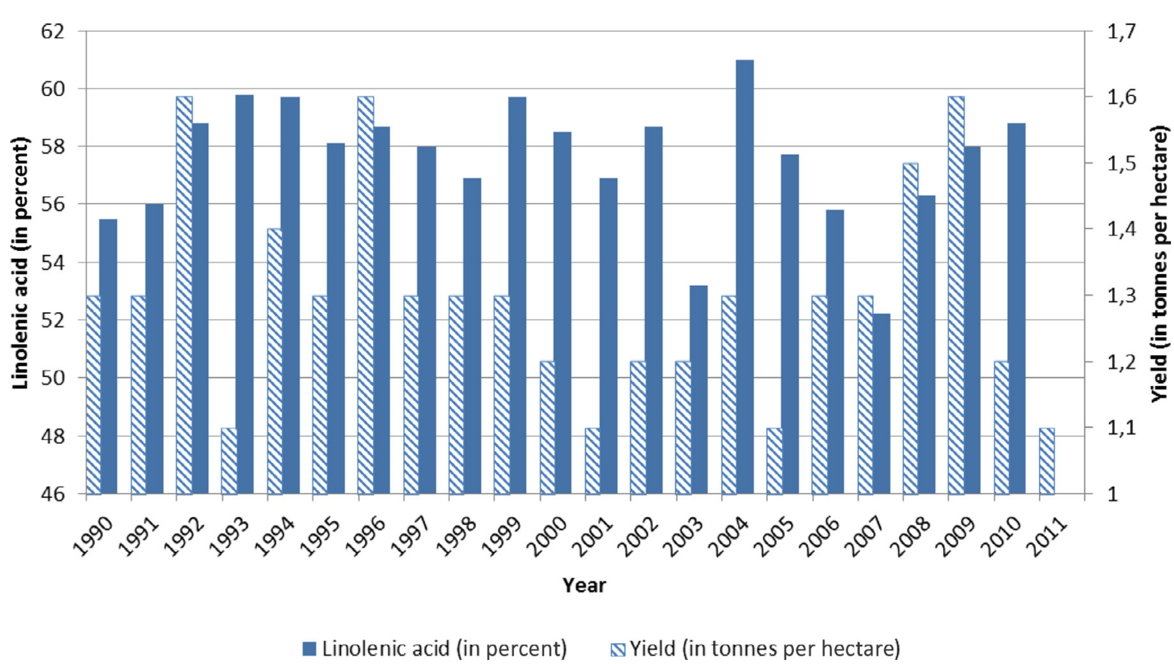

Fig. 1. Content of linolenic acid and linseed yield in Manitoba, Canada (Puvirajah, 2011).