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RESEARCH OPINIONS IN ANIMAL & VETERINARY SCIENCES

The study of biology and morphology processes in rapeseed (*Brassica napus* L.): A review

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Abstract

The aim of this paper is to review the most important biological processes that deal with the yield of winter oilseed rape (*Brassica napus* L.). Normally, biological yield is the product of growth rate and duration of the growing period, both of which are considered as the essential factors for yield improvement. Likewise, a greater harvest index leads to a higher seed yield. There is a lack of information about key physiological processes involved in establishment of the stand, the production of biomass and formation of yield, cessation of growth in winter, flowering and postanthesis growth, therefore, most of these models are considered as poor predictors of biomass and yield. Understanding the structure of the yield and the primary and secondary components are the keys for analyzing yield, which leads to seed yield.

Keywords: *Brassica napus*; Growth; Grain yield; Canola

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Introduction

Winter oilseed rape (*Brassica napus* L.), the most important species of oilseeds, must compete economically with cereal crops and to meet this challenge, the yield of rapeseed crops must increase significantly. Rapeseed hybrids have been recently introduced as a possible means of increasing yield due to heterosis. Becker, (1987) reported that heterosis varies from 4 to 63% over the average parental yield and is relatively large under unfavourable conditions, suggesting that hybrids show better yield stability than their parents (Leon, 1991). Field experiments (Schuster et al., 1999) demonstrated a yield increase of up to 20% compared to the mean yield of the standard cultivars tested. On the farm, hybrids outyielded standard cultivars by 5±12% (Sauermann and Finck, 1998). Grosse et al. (1992b) found that heterosis occurred at all stages of development. Hybrids had 11% more above-ground biomass in autumn, 8% more biomass at flowering and 25% more dry matter after flowering compared to their parents, indicating that major processes involved in the formation of yield are more effective in hybrid varieties. Thus, physiological processes play a key role in variations in yield as well as in selection of highyielding material. A quantitative analysis of processes that determine yield is necessary if greater yields are to be obtained. In recent years considerable effort has been put into the development of models for rapeseed. However, none of these developed so far has performed satisfactorily in predictions concerning biomass and yield. This is because most important processes involved in growth and development have not been studied in depth. Therefore, this review presents information on the yield potential, the most important stages of yield formation, and the yield components of winter oilseed rape including indications of where the existing models would benefit from further work. A more quantitative description with useful data on the various processes which could be incorporated in models is given by Diepenbrock and Grosse, (1995), Leon and Becker, (1995) and Mendham and Salisbury, (1995). Further, the database reflects experience with rapeseed sown in autumn.

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Studies conducted in Australia and Canada (summer rape) reached different conclusions about key features in development of crop yield. This is partly due to the wide range of genetic material used.

Yield potential

Yield potential of a crop is a theoretical assessment of the maximum yield that can be generated when high yielding biological material is grown in an optimum physicochemical environment. Yield is classified as biological yield (total biomass) and economic yield (the economically useful part of the plant). The relationship between the two, the harvest index, is the proportion of seed dry matter to above-ground biomass, i.e. economic yield biological yield   harvest index (Fageria, 1992).

Biological yield

The biological yield of winter oilseed rape is the product of the growth rate and the duration of the vegetative period. Fig. 1 (line 1) (Sibma, 1977) shows the calculated pattern of the highest (i.e. potential) growth rate, based on a closed crop canopy (standard crop) and the incoming radiation. Almost complete interception of light by rapeseed (line 2) is observed from the end of April to the beginning of June. Thus, small interception is probably an important limiting factor of the growth rate in early spring and during maturation. Line 3 presents the product of growth rate (line 1) by percentage of intercepted light (line 2) to describe the potential gross production. For comparison, line 4 depicts the actual growth rate as increase in dry matter, sampled periodically at experimental plots in the hercynian dry region of Germany (Diepenbrock, unpublished). It is clear that the actual growth rate (especially under unfavorable conditions) and the duration of the growing season indicate the significant potential for further increase in the yield of the rapeseed crop. Under approximate optimum conditions in northern Germany, however, Grosse et al. (1992a) measured maximum growth rates up to 283kg DM ha^{-1} per day. In a simulation study conducted by Habekotte, (1997a) proposed several options for increasing the seed yield of winter oilseed rape under optimal growing conditions. An exploration of all the options revealed delayed maturity to be the most important for obtaining higher seed yields, demonstrating the importance of growth duration.

Harvest index

A simple estimation of the potential seed yield of winter oilseed rape accounts for differences in the harvest index between this crop and winter wheat were employed. As reviewed by Austin et al. (1980) and Feil, (1992), genetic increases in cereal grain yield in recent decades were largely due to a higher harvest index. The harvest index of modern cultivars of winter wheat showed a 45±50% increase, while that of winter oil-seed rape increased by about 25±30% (Diepenbrock et al., 1999). This comparison might be misleading; however, because of the energy content in seeds of oilseed rape is greater than that of wheat. A comparison of aboveground dry matter, harvest index, concentration of energy in kernels and straw, and the energy harvest index of winter oilseed rape and winter wheat is presented in Table 1. Above ground biomass of winter wheat at maximum was 194 (dt ha^{-1}) (Ellen, 1993) and that of winter rapeseed 182 (dt ha^{-1}) (Grosse et al., 1992a), so far. Considering ongoing breeding progress (e.g., introduction of hybrids) and for the sake of simplicity, this model assumes that both species produce 200 $dtha^{-1}$ of above ground biomass. The harvest index of wheat remains greater than that of rapeseed, even when the energy content is taken into account. A further analysis of winter rapeseed and winter wheat (Habekotte, 1997b) revealed that, apart from incoming photo synthetically active radiation (PAR), cumulative absorption of PAR and radiation use efficiency (RUE), harvest index is a major parameter that limits yield. It is concluded that further increases in the yield of rapeseed are closely linked to an increase in the harvest index. Genotypic correlations between harvest index and yield are well established (Grosse et al., 1992b).

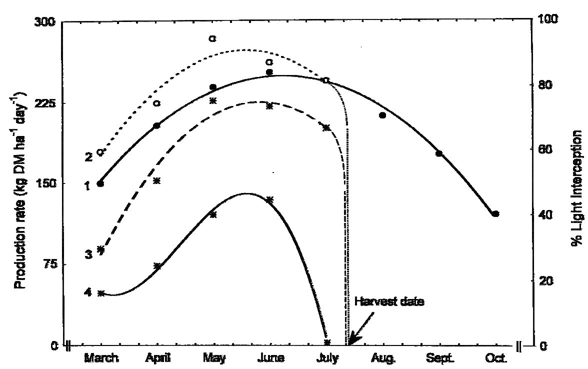

Fig. 1: Potential production rate (line 1), percentage of light intercepted by the crop (line 2), calculated crop growth rate (line 3) and measured crop growth rate (line 4) of winter oilseed rape on experimental plots in the hercynian dry region of central Germany (Sibma, 1977; Diepenbrock, unpublished).

Growth and development

Rapeseed growth models attempt to elucidate breeding goals or to contribute to crop management or systems that support decision making. However, models of rapeseed that can accurately predict biomass or yield have not yet been developed (Gabrielle et al., 1999). Most of the recently published rapeseed models (Table 2) were developed by adapting, with some

Table 1: Yield and harvest index of winter oilseed rape compared with winter wheat

	Biomas(dt.ha^{-1})	Seed yield (dt.ha^{-1})	Harvest Index	*Energy Content (MJ kg^{-1} DM)		Energy harvedt index (MJ seed*100/MJ Biomass)
				Seed	Straw	
Winter wheat	200	100	50	18.4	18.4	50.4
Winter oilseed rape	200	50-(60)	25-(30)	27.6	18.3	33.5-(39.3)

*According to Greef et al. (1993).

Table 2: Recently published rapeseed crop models

Basic model	Symbol	Author
EPIC (Williams et al., 1989)	EPR 95	Kiniry et al. (1995)
DAISY (Hansen et al., 1991)	DAR 95	Petersen et al. (1995)
LINTUL (Spitters, 1990)	LIR 97	Habekottet al (1997a,b)
See Husson et al. (1997)	HUR 97	Husson et al. (1997)
CERES-N maize (Jones and Kiniry, 1986), NCSOIL (Molina et al., 1983), HUR 97 (Husson et al., 1997)	CER 98	Gabrielle et al. (1998a,b)

modifications, complex crop±soil system models, created originally for other crops (Table 2, column 3). Therefore, the principal parameters and algorithms are comparable to corresponding basic models for rapeseed. In all models, potential growth is estimated from the product of absorbed photo synthetically active radiation (PARa) and canopy RUE. In CER 98 and LIR 97, canopy light absorption coefficient and RUE change during plant development. In DAR 95, the RUE term is substituted by a function approximating the saturation type dependence of RUE on leaf area index (LAI) and PARa. Partitioning of biomass to various plant organs and, in particular, to the seeds is generally expressed by a biomass partitioning coefficient (BPC), which varies roughly with developmental stages, to reflect most of the processes that determine yield. Details on the physiology of seed filling are incorporated into LIR 97 (accumulation and redistribution of carbohydrates, maximum potential growth rate per individual seed, seed density) and CER 98 (partitioning of pod photosynthesis among pod walls and seeds, allometric relationships between pod walls and seeds, yield components as a function of radiation intercepted). N uptake from the soil, stress factors and growth constraints are only included in the models EPR 95, DAR 95 and CER 98. The simple model LIR 97 does not include modules for mineral nutrition and water regime, and is, therefore, valid only for optimum growth conditions. Furthermore, LIR 97 does not simulate the autumn and winter development phases and DAR 95 does not account for the loss of leaves by senescence or the partitioning of dry matter between pods and vegetative parts after flowering. CER 98 was tested only for fully irrigated crops. Physiological modules of model HUR 97 are similar to those of CER 98. For these reasons, it is necessary to describe the development of yield and the structure of yield in order to extend the database for model development and to compare and to verify the hypotheses of various models. In general, the fitted curve representing dry matter accumulation is sigmoid in shape. It changes according to genotype and environment and does not represent special events that might occur during development of rapeseed as will be discussed later (Allen and Morgan, 1972). The pattern of dry matter accumulation as affected by three important agronomic determinants: pre-crop, type of N fertilizer and N supply, is illustrated in Fig. 2. Although the curve based on growth data does not describe the special events that occur during the formation of yield, it reveals that N supply followed by the type of N fertilizer and the previous crops all have a strong effect on yield. The important role played by plant-available N in the growth of autumn-sown rapeseed is well established (Rathke, 2000). Plants grown at low N were less dense and their leaves behaved more like sun leaves. Increasing the supply of N had a slight effect on the photosynthetic capacity but a strong, positive effect on productivity as a result of higher LAI and an extended period of photosynthetic activity. To minimize N-loss from the rapeseed crop, plant breeders investigate the genetic variation in N-use efficiency (Sattelmacher et al., 1994). Considerable variation was found among cultivars (Barszczak et al., 1993) and genotypes (Gerath and Balko, 1995) of rapeseed. However, it appears that heritability of N-use efficiency and the utilization and uptake of N is small (Yau and Thurling, 1987).

Germination and seedling emergence

During the early stages of germination and seedling emergence, controlling the distribution of plants per unit area is especially important for yield stability (Sierts et al., 1987). The percentage germination of rapeseed in a standard test correlates poorly with field performance. However, the mean time to germination revealed highly significant correlations with field performance and seed yield (Larsen et al., 1998). The considerable variation in the emergence of seedlings depends on moisture, temperature and the structure of soil.

Yield structure

Yield per area is the product of population density, the number of pods per plant, the number of seeds per pod and the individual seed weight. Fig. 4 shows that secondary yield components can also be defined. Hence, seed yield is a complex trait that includes various components and finally results in a highly plastic yield structure. The situation is complicated by the large variation in patterns of branching. A survey of the literature reveals that the greater the number of compositional characteristics that are considered the more difficult it is to describe the structure of yield. In addition, the reliability of yield analysis depends on how the yield traits have been gathered or selected and whether a single plant or the entire crop is considered.

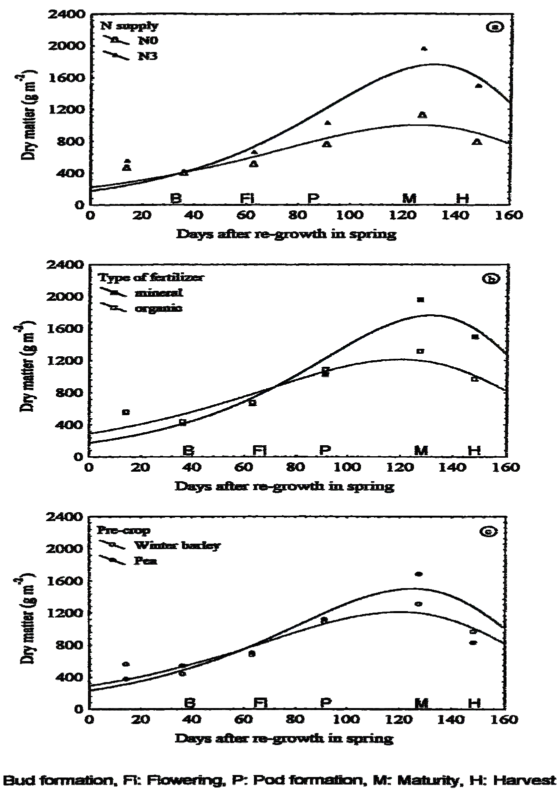

Fig. 2: Dry matter accumulation of winter oilseed rape as affected by N supply (a), type of N fertiliser (b) and pre-crop (c) (Rathke, 2000).

Plant density

Plant density has the greatest effect on seed yield and the yield components of individual plants. Variations in seeding rate and seedling emergence control patterns of distribution of plants per unit area, thus establishing the boundaries of intra-specific competition within the canopy. As reported by Huehn, (1998), inaccurate sowing machines as well as abiotic and biotic effects lead to a non regular distribution of plants in the canopy. Based on three data sets for drilled seeds, different accuracies of the longitudinal distribution within rows were quantitatively measured using the coefficient of variation in the distance between plants within rows. Yield decreased with increased variability in the distance between plants in the row. Competition reduces plant density during crop growth. At the end of the growing season, therefore pod bearing plants are just a proportion of those in the same area at emergence (Boiffin et al., 1981). Results reported Sierts et al. (1987) demonstrate that when plants are evenly distributed there are fewer losses as a result of environmental stress. In consequence, yield is most stable when plants are evenly distributed. Little is known about the genetically based reaction to densely sown crops or the selection of cultivars adapted to high densities (Leon and Becker, 1995). Schott et al. (1994) demonstrated cultivar-specific competition under experimental conditions.

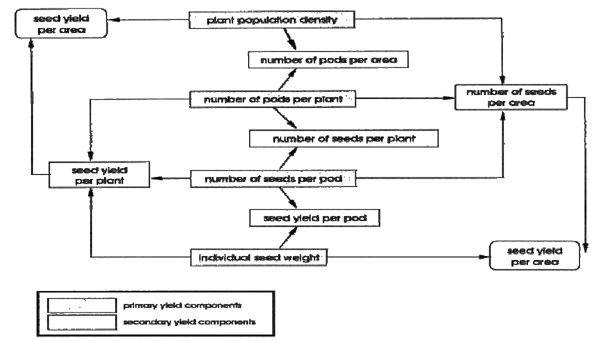

Fig. 4: The yield structure of rapeseed (Diepenbrock and Grosse, 1995).

Number of pods per plant

The seed yield of individual plants is closely related to the number of pods per plant. During the course of development, this trait is ultimately determined by reduction in the number of branches, buds, flowers, and young pods by source capacity, the supply of nutrients and water (Allen and Morgan, 1972; Tayo and Morgan, 1979; Rood and Major, 1984) and hormonal factors (de Bouille et al., 1989; Zanewich and Rood, 1993) rather than by the potential numbers of flowers and pods (Habekotte, 1993). Single plants may have at least 20±25 primary branches, many of which do not set pods due to intra-plant competition. Accordingly, Geisler and Henning, (1981a) reported that at nine plants per m^2 (very weak, or no, competition) only 43% of the potential branches were fertile. External factors such as arrangement of the stand, sowing date and N-fertilization also play a crucial role in control of pod number. It was repeatedly demonstrated that the number of pods per plant is negatively correlated with the number of plants per unit area (Geisler and Stoy, 1987; Sierts et al., 1987). Since the number of branches is directly linked to the geometry of the stand, increasing plant density from 9 to 50 plants (normal) per square meter resulted in a dramatic decrease in the number of fertile branches to

28% of the potential number of fertile branches (Geisler and Henning, 1981a). Furthermore, increased competition not only reduces branching, but also the number of pods on all branches. The terminal raceme is least affected, indicating that its relative contribution to the total number of pods per plant or area increases when the density of the stand is increased.

Conclusions

Studies on yield of winter oilseed rape revealed considerable potential for further improvement. Duration of growth, rate of production and harvest index are crucial for enhancing biomass and seed yield. During the growth cycle, establishment of the stand, use of radiation and availability of assimilates for pod set and seed filling are decisive factors in yield. Improvement and implementation of rapeseed crop models can help to identify factors that limit yield formation by depicting phonological development and dynamics of plant characteristics, utilization of light and primary photosynthesis, N uptake, stress factors and biomass partitioning.

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