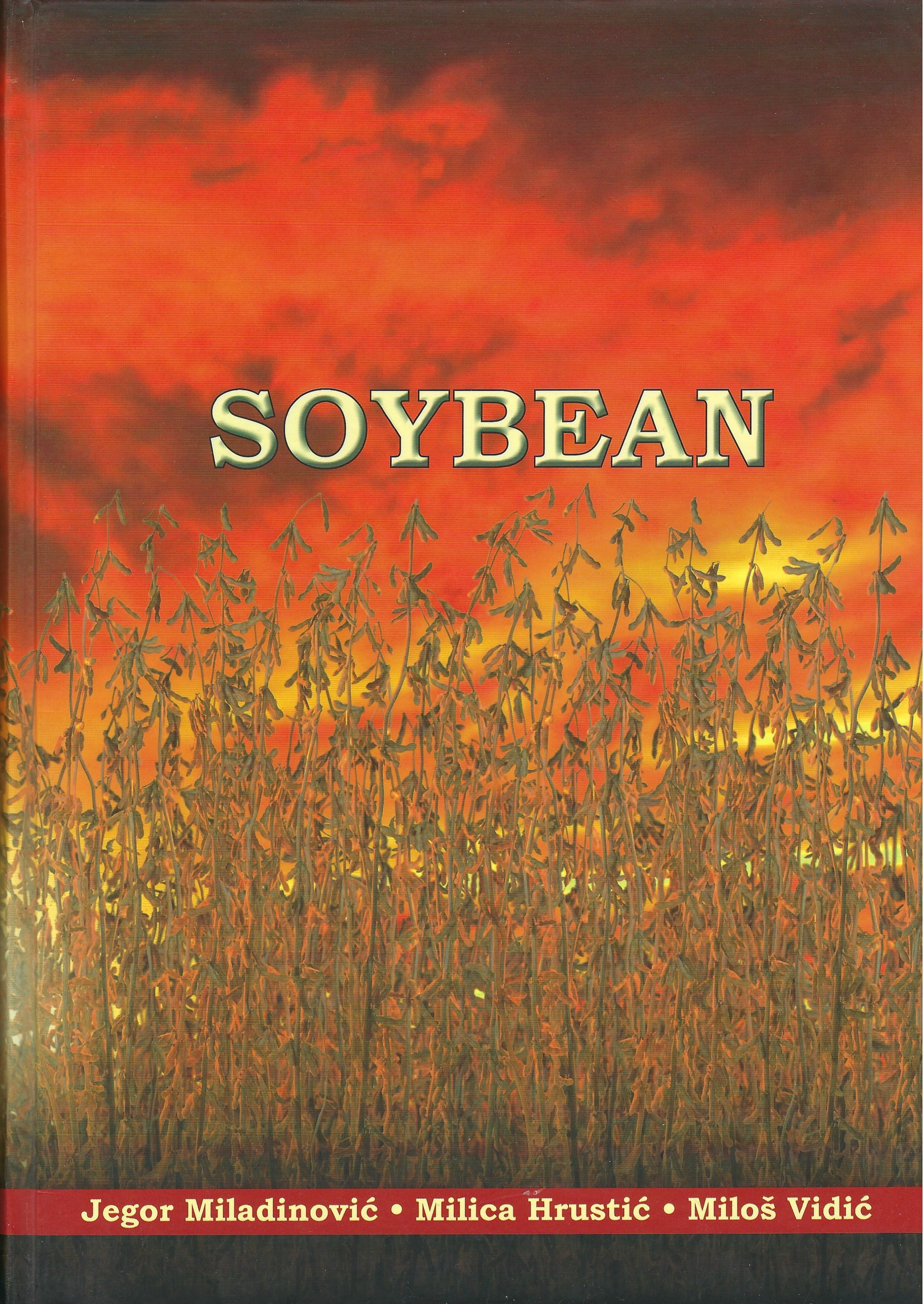

SOYBEAN

Jegor Miladinović • Milica Hrustić • Miloš Vidić

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Dr. Milica Hrustić
Dr. Miloš Vidić

Institute of Field and Vegetable Crops, Novi Sad
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Editors

Jegor Miladinović
Milica Hrustić
Miloš Vidić

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Borislav Đukanović

Translated from Serbian by:

Vladimir Škorić
Tanja Vunjak - Kvaić

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Authors

Dr. Milica Hrustić
Dr. Jegor Miladinović
Dr. Vuk Đorđević
Prof. Dr. Petar Sekulić
Dr. Nastasija Mrkovački
Dr. Vojin Đukić
Dr. Svetlana Balešević - Tubić
Dr. Mladen Tatić
Dr. Miloš Vidić
Prof. Dr. Stevan Jasnić
Prof. Dr. Radosav Sekulić
Institute of Field and Vegetable Crops, Novi Sad, Serbia

Prof. Dr. Reid G. Palmer
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USDA ARS CICGR and the Department of Agronomy, Iowa State University, Ames, Iowa, USA

Prof. Dr. Joseph W. Burton
USDA/ARS, North Carolina State University, Raleigh, North Carolina, USA

Prof. Dr. James H. Orf
Department of Agronomy and PLant Genetics, University of Minnesota, St. Paul, Minnesota, USA

MSc. Igor Kurjački
Prof. Dr. Novica Petrović
Prof. Dr. Ivana Maksimović
Prof. Dr. Jovan Crnobarac
Prof. Dr. Branko Marinković
Prof. Dr. Đuro Bošnjak
Prof. Dr. Tatjana Kereši
Faculty of Agriculture, Novi Sad, Serbia

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FOREWORD

This is a translated edition of the book titled “Soja” published in Serbian language in 2008, which displayed the accumulated knowledge on fundamental and applied soybean research, as well as soybean breeding efforts at Institute of Field and Vegetable Crops in Novi Sad, Serbia.

Global importance of soybean is continually growing, with soybean planted areas reaching almost 99 million ha in 2009 and production of soybean grain exceeding 222 million tons. According to these indicators, soybean is the most important industrial plant worldwide, both as a basic source of protein nutrients for cattle, poultry and fish and as the most important source of plant oil.

Simultaneously with increased interest in growing this plant species, scientific research on soybean has also been enhanced, especially regarding fundamental research. For the most part, this book deals with achievements of Serbian researchers. Chapters dealing with soybean morphology and its requirements during growth and development have been updated and revised. Content of chapters dealing with production technology, seed production and importance, as well as chapters giving an overview of diseases and pests affecting soybean is somewhat characteristic for Serbian climate and soil. Therefore, the authors would particularly recommend to foreign readership the chapters dealing with quantitative and qualitative genetics of soybean prepared for this edition by leading experts and professors from University of North Carolina and University of Iowa. Outline of the most recent achievements in the field of soybean breeding has also been prepared by scientists from the USA, where such research is most developed.

Chapter dealing with soybean importance and origin gives a chronological survey of soybean breeding results at Institute of Field and Vegetable Crops. The previous decade was outstandingly dynamic and successful in this area, witnessed by impressive results. The number of soybean varieties developed at Institute of Field and Vegetable Crops released in Serbia has doubled, while there was a ten-fold increase in the number of varieties released abroad - from four varieties released in 2000 to 49 released so far.

Hence we believe that this edition will be useful to everyone involved in soybean production, especially to students and scientists conducting research on soybean.

Authors would like to thank all who have participated in preparation of this book in any way, and especially to reviewers whose efforts and pieces of advice largely contributed to the form and content of this book.

Special gratitude is extended to the Ministry of Science and Technological Development of the Republic of Serbia for financially aiding the printing of this book.

In Novi Sad, in February 2011.

Authors.

SOYBEAN CULTURAL PRACTICE

Jovan Crnobarac, Vojin Đukić, Branko Marinković

The yields of soybean, just as those of other crops, depend on the growing conditions, variety, and the cultural practice implemented, as well as on the investments and know-how of the grower, whose job is to coordinate and harmonize all the crop growing activities.

The method of soybean growing (cultural practice, growing technology) is a chronological series of agronomic practices whose purpose is to adapt the existing growing conditions to soybean's biological requirements in order to maximize the expression of the crop's genetic potential for yield. However, the effects of cultural practices depend significantly on the year, i.e. the moment at which an unfavorable factor affecting the yield appears, how long it lasts, and how severe it is. Because weather conditions cannot be predicted reliably, a recommended technology of growing will be based on average values, which appear with greatest frequency over a number of years. Even with this approach, mistakes will sometimes be made, but their frequency will be much reduced compared to when the technology is changed every year based on previous year's results. A recommended growing technology that is adapted for a particular area with its average weather conditions is an ideal that should be pursued and an effort should be made to implement such recommended practices to as high a standard of quality and as timely as possible. In actual practice, however, growers often have to depart from the recommended growing technology for objective or subjective reasons. This increases the risk of yield losses, which is something the grower must be aware of before taking such a course of action. Therefore, it is also important to know the biology and growing requirements of soybean as a crop species and of the particular soybean variety being grown, because whether or not these requirements have been met during the growing season will often depend on what cultural practices have been applied. In this connection, it is also significant to know and correctly identify the stages of soybean growth and development, so that cultural practices, especially key ones such as the application of herbicides, fertilizer, insecticides, irrigation, crop tending and harvesting, can be implemented in a timely and efficient manner.

When growing any crop, the goal is to obtain high and stable yields of good quality while making a profit and maintaining soil fertility. Agriculture is part of a country's economy and is therefore subject to certain universal economic laws despite having its own distinctive features. Thanks to the vital strategic importance of food production, the government has an obligation to design and implement such agricultural policies (premiums, subsidies, loans, etc) that will create macroeconomic conditions in which agriculture is capable of generating profit margin levels that are on a par with those typifying the rest of the economy. The reason is that from the microeconomic point of view, i.e. from the standpoint of the grower, profit margin is the only economic incentive for growing a particular crop. Yield level and quality play the key role in this.

Based on light absorption and utilization, the theoretical maximum for soybean yields is 7,300 kg/ha (Sinclair, 2004) to 8,000 kg/ha (Sinclair,1998). In practical terms, the genetic potential for yield of a soybean variety is the yield a variety adapted to a particular set of growing conditions produces when there are no water and nutrient deficiencies and effective control is carried out against pests, diseases, weeds, lodging and other stress conditions. In the past five years, the average yield of soybean in Serbia has been 2,485 kg/ha, which is only a third of the crop's genetic potential. The loss of two thirds of the potential yield has been a result of unfavorable weather conditions and plant requirements not being met by the existing growing conditions. To counteract such conditions is the main goal of cultural practices implemented by the growers.

Successful soybean production requires that only those expenses be incurred that are necessary to obtain an optimum amount and quality of the product and generate a profit. Each cultural practice should be considered from the point of view of its economic justifiability, i.e. it should only be opted for if its implementation brings about an improvement of yield that equals or outweighs the cost price of such measure. Included in this are the basic costs of seed, pesticides, fertilizers, labor, machinery, and fuel as well as the expenses of financing and the costs of soil use and irrigation. Cultural practices can be of the type that requires that a decision be made as to whether or not their implementation would be justified (inter-row cultivation, yes or no), but cultural practice also has segments in which the optimal rate of a particular element (seed, fertilizer) needs to be determined. Cultural practice analysis must take into account the specific growing and market conditions, i.e. the relationship between input costs and yield.

Although the countries of the Far East have a long tradition of soybean growing, this plant has become a globally important field crop only in the last few decades. This means that the growers were faced with a completely unknown crop for which growing methods had yet to be developed and honed. They first had to become familiar with the plant and its biological characteristics, needs, and potentials. After that, particular cultural practices had to be chosen and adapted, so that the existing growing conditions could be suited to soybean plant requirements to as high a degree as possible.

Soybean has been grown in Yugoslavia on a significant acreage only since 1975, so it is not a traditional crop in the region as wheat and maize are. For this reason, there was no science-based production technology for it at the start of this period (Hrustić, 1994). There were quite a few cultural practice issues that had yet to be resolved, since foreign experiences in this area could not be transplanted to the local conditions without modification, because each geographic region has its own unique characteristics and these lead to important differences in production technology (Belić et al., 1983). When soybean began to be grown on a large scale in the country, there were still a lot of unknowns (Hrustić et al., 1996). Primary tillage in soybean is the same as in most other spring field crops, but problems started to occur as soon as seedbed preparation had to be performed, because this cultural practice in soybean is quite characteristic. There were also many open questions when it came to fertilizer use, seed inoculation, planting dates, and plant density. In the time since then, however, domestic soybean growers have managed to develop and master a soybean production technology that has been adapted for the country's growing conditions based on average results obtained in multi-year trials and cumulative practical experience.

CHOICE OF VARIETY

The correct choice of variety is an important part of a growing technology aiming to achieve high and stable yields.

When choosing which soybean variety to grow, the following traits should be considered: yield level and quality, days to harvest, resistance to lodging and pod dehiscence, and resistance to major diseases and pests.

Yield potential is certainly the single most important factor in the choice of variety. However, in cases where it is possible that conditions may arise which might limit the potential yield but could be overcome by the use of a genetically resistant variety, other characteristics must also be taken into consideration. In many situations, a trait other than yield potential will have greater importance in the selection of variety. Generally speaking, varieties that take more time to mature produce higher yields, because they make full use of the growing season. In Serbian conditions, however, it has sometimes been the case in dry years that the early varieties produced higher yields than the late ones. Because of their longer growth period, it is possible that the late varieties go through the critical stages of development (grain formation and grain fill) in conditions of lack of rainfall, high temperatures, and low relative humidity (July, August), which negatively affect pod and grain number and grain size. Varieties with a short growth period (Maturity Group 0) go through all the developmental stages faster, so the critical phases of their development occur earlier in the growing season and they are thus able to avoid the part of the season with the largest water deficits and highest temperatures. In the early varieties, these stress factors affect only grain size, which is why the yields of such genotypes are sometimes higher than those of varieties from MG II (Hrustić et al., 1995; Vidić et al., 1996).

Lodging slows down harvesting and increases yield losses. When lodging occurs prior to the pod formation stage, it reduces the yield by reducing pod number and causing poorer grain fill. Although resistance to lodging is a genetically determined trait, lodging is promoted by factors that stimulate vegetative plant growth such as increased plant density, soil moisture, and soil fertility. For this reason, when growing soybean on an irrigated, fertile soil, varieties with greater genetic resistance to lodging should be used and the seeding rate should be reduced to produce a plant population which is at the lower limit of the optimal stand density range.

In US conditions, the average annual gain in yield attributable to the use of new soybean varieties is about 30 kg/ha (Specht et al., 1999). Every year, therefore, the results of the nearest variety trials should be analyzed and the currently grown varieties should be replaced with the higher-yielding new ones. The best way to pick out the highest yielding variety is look at the average yield across several years and locations. This is because weather conditions cannot be predicted in advance, so a variety that on average produces the best yields in similar locations in dry and wet years is the safest choice. Naturally, the more locations the average is based on, the safer the choice.

Each soybean variety falls into one of 13 maturity groups (000, 00, 0, I, II... X) depending on the geographic area in which it is grown. Since varieties are adapted to a very narrow range of latitudes, the terms early-, medium-, and late-maturing are only relative, that is, they describe the variety's period of maturation in a particular geographic area. Varieties from Maturity Groups II and III can usually be grown with success in any region when planted on standard planting dates. A variety's level of adaptedness in a given area is determined through variety trials. Such trials have shown that the most suitable soybean varieties for the growing conditions in Serbia are those from Maturity Groups 0, I and II. Varieties from MG III take too long to mature, which makes seed maturation problematic in wet years, but such varieties can be recommended when soybeans are grown for silage.

The main goal of crop production is most definitely yield. The choice of the variety, however, also depends on other factors, such as the condition of the plot, planting dates, estimated dates of harvesting, irrigation capabilities, and so on. When deciding which variety to grow, the choice should be made so that it meets as many of the growing requirements as possible. When growing soybean on a larger area, the grower must also take into account all the possible stress conditions that might occur, so in such a case it is advisable that at least two different genotypes be planted. This is because there is no single variety that can withstand the effects of all the limiting environmental factors (Jocković et al., 1994). For this reason, a number of different genotypes should be grown in every growing region (Hrustić et al., 1993).

An even better strategy is to combine varieties from different maturity groups, because in that case, should stress conditions occur, the genotypes will be at different stages of growth and development and the negative effects of stress will thus be reduced or even completely avoided. This approach also make it possible to better organize operations in the field during planting, crop tending, and harvesting, as they become successive rather than concurrent throughout the area (Figure 9.1).

Intensive work on soybean breeding at the Institute of Field and Vegetable Crops has so far produced over 100 varieties. Thanks to the constant advancement of breeding procedures and the simplification of seed production and increase, growers can now choose among several different varieties from each maturity group. Of particular note are the new developed varieties, which are superior to the most widely grown commercial ones.

Among the varieties from MG 0, the highest and most stable yields are produced by the varieties Valjevka and Galina, which have supplanted the long-lived variety Afrodita in commercial production. These varieties produce high yields for their maturity group and are suitable for regular as well as late planting (Table 9.1).

Table 9.1

Recommended soybean varieties, seeding rates, and planting dates for Serbian growing conditions

Maturity Group	II	I	0	00/000
Variety	Venera	Sava	Valjevka	Fortuna
	Rubin	Novosađanka	Galina	Prima
	Trijumf	Victoria		Merkur
	Vojvođanka	Balkan		
No. of viable seeds (000)	350 - 400	400 - 450	around 500	550 - 600
Time of planting	Early April	All of April	All of April	All of spring, or by early July when used in double cropping

The varieties Balkan and Novosađanka were until recently the mainstays of the MG I variety range in the country but are now being replaced with the newly-developed top-quality varieties Sava, and Victoria, which are capable of producing high and stable yields in different growing conditions.

In MG II, the stand-out varieties are Venera, and Rubin. Their best qualities are high yields and resistance to lodging.

Figure 9.1

NS varieties of Soybean *(photo: G. Kuzmanović)*

Soybean can be grown outside the normal planting dates as well, for which purpose varieties with an extremely short growth period (MGs 00/000) are used. In this segment of the Serbian market, the new varieties Fortuna, Julija, and Merkur are gradually replacing the two older varieties of the same type, Jelica and Krajina. All these varieties take about 100 days to mature, which enables them to ripen and produce good yields even when planted late as a second crop in a double cropping system. Trial results and commercial crop production have also shown that early soybean varieties can be successfully grown after harvesting winter barley or winter wheat. When sown in early July and grown under irrigated conditions, such soybean varieties mature in early October and produce yields of 2 to 2.5 t/ha.

SOYBEAN'S PLACE IN CROP ROTATION

Biotic communities are generally characterized by biological balance and self-sustainability due to the coexistence of a large number of species and the uninterrupted circulation of matter. Agrobiological communities, however, are poor in species and often consist of only a single one, and the removal of yield from the plot disrupts their natural biological balance too. It therefore becomes necessary for man to maintain and control this balance using different agronomic, organizational and technical practices. The idea is that a situation where a large number of species live side by side in biotic communities can be partially mimicked in agrobiological communities by the use of crop rotation.

Crop rotation on plowland balances the relationship between field crops production and animal husbandry as well as that among different crops. It makes cultivation and fertilization systems more cost-effective, fulfills cultural practice and biological crop requirements, and addresses the various economic and organizational aspects of crop production. Generally, crop rotation can be defined as an orderly, well thought out plan on how to correctly and cost-effectively utilize the growing environment (most importantly soil and climate) to the maximum. The main goal of crop rotation is to maintain or increase the soil fertility and yield levels of all the crops involved in the rotation. Crop rotation is a planned and predetermined sequence by which crops follow one another in space and time and eventually return to the same field after a while (Molnar. 2004).

In the late 1980s, crop rotation again came to the spotlight globally due to the large impact it has in the field of environmental protection. In conjunction with an appropriate agricultural policy that promotes profitability through the diversification of production, crop rotation makes it possible to reduce the use of chemicals in agriculture and improve soil properties and thus increase the self-sustainability of an agroecosystem. The rotation of crops also increases economic security and cash flow on farms and makes it easier to organize agricultural operations (Heatherly and Elmore, 2004).

Crop rotation reduces the accumulation of crop-specific disease agents and pests as well as weed abundance and adaptability to a particular crop species. Growing a legume crop interrupts the life cycles of diseases in maize and wheat, the two most commonly grown cereals in Serbia. In this sense, crop rotation can be viewed as a preventive, integrated crop management practice that helps protect all the plant species used in the rotation. As a legume, soybean has good quality harvest residues with a low C to N ratio. They increase the soil levels of organic matter rich in organic nitrogen, which is not susceptible to leaching. As an early row crop, soybean fits in very well with the other field crops in rotations. Also, rotating crops with different depths of rooting enables the ascendant biological flow of nutrients and better and more efficient utilization of total nutrients and water from the soil. Ferreira et al. (2000) found that growing soybean in a crop rotation increased nitrogen fixation as compared to when the crop is grown in a monoculture. The alteration of physical soil properties also allows deeper root penetration. All this increases the yields of soybean as well as all those of the other crop species used in a crop rotation without any extra costs.

As the areas in soybean are increasing, this crop is becoming a major constituent of field crops production and an increasing amount of attention is being paid to its place in crop rotations. Soybean is a very good fit for crop rotations, because it is a good previous crop for most of the other field crops grown in Serbia without being very demanding itself when it comes to the crop that precedes it. In Serbian agricultural practice, the most common preceding crops to soybean are wheat, maize, and sugar beet, which are also the most commonly grown crops in the country overall.

Because small grains account for a large proportion of Serbia's crop production, they often precede soybean in the country's fields. Wheat and other small grains are removed from the fields early, which gives the soil plenty of time to rest and regain its properties in a natural way before the next spring crop is planted 8-10 months later. Wheat and winter barley are also becoming increasingly common as a previous crop to soybean when early maturing soybean varieties are used as the second crop in double cropping systems.

Maize is also planted before soybean in Serbia as well as the U.S., the world's top producer of the legume. In the US corn belt (Illinois, Iowa, Minnesota, Indiana, Missouri), over 90% of the agricultural acreage is utilized through a two-crop rotation in which maize and soybean alternate. In Serbian conditions, soybean would be an ideal crop to break up the rotation of maize and wheat (Crnobarac, 2000). Maize is a good preceding crop to soybean, provided the stover is well chopped up and plowed under. One factor that can limit the use of maize before soybean are herbicides based on triazine and sulfonylurea, whose residual effects have a negative impact on soybean.

Opinions vary as to how suitable sugar beet is as the preceding crop to soybean. During the intensification of field crops production, sugar beets were considered a good previous crop for most other field crops. In the last few years, however, sugar beet is increasingly being regarded as an inadequate previous crop. The prolonged dry period in recent years has contributed significantly to this. Without the application of farmyard manure, the biogenicity of the soil will be reduced to the extent that the tillage and fertilizer applied in the course of sugar beet growing will not have the appropriate effect on the crop that follows (Stefanović, 1992). Because of the high fertilizer rates it requires, sugar beet could be a good preceding crop to soybean. The reason that it is not, however, lies in its high water consumption (especially in dry years) and excess moisture during lifting and soil compaction.

Sunflower and rapeseed are high-risk preceding crops to soybean because of many shared diseases. Plots on which sunflowers or soybeans have been infected with white rot should not be used for soybean growing in the next five to six years, because the fungus causing the disease is incorporated into the soil together with harvest residues and remains virulent for a very long time. Soybean should not be grown after other legumes either, not only because of the diseases they have in common but also because the leftover nitrogen is more valuable for other crops.

When it comes to growing soybean as a monoculture, different results can be found in the literature. Johnson (1987) reported a series of results indicating that soybeans give 11- 21% higher yields when rotated with maize or sugarbeet than when grown as a monoculture. According to the same author, maize rotated with soybean also produces higher yields as compared to continuous maize. The prevailing opinion in the literature and the soybean community is that soybeans should not be grown as a monoculture. Growing soybeans repeatedly or, especially, as a monoculture should be avoided due to the accumulation of disease agents and insects, production of allelopathic chemicals during the decomposition of plant residues, and the increasing difficulty of weed control.

The allelochemicals have a negative influence on root growth and the amount of nitrogen fixation in soybean and other legumes. Better use of the soil and better yields are also the reason why soybean's position in a cropping sequence should be carefully chosen. Growing soybean in a crop rotation does not eliminate the problem of diseases, but it does reduce the possibility of infection.

Soybean is a very good fit for crop rotations, because it is an excellent preceding crop to most crop species grown in Serbia. As a legume, soybean also improves soil structure and enriches the soil with nitrogen. Although it produces less harvest residues in terms of mass, soybean has a considerably better C:N ratio than maize and other cereals due to the fact that its nitrogen requirements per unit yield are more than three times higher (Hoeft et al. 2000). Findings on the exact amount of nitrogen that soybean leaves behind on the field vary. Thus, Vanotti and Bundy (1995) reported 45-67 kg/ha, while Mosca et al. (1989) cite 30-60 kg/ha.

FERTILIZATION

Plants need certain amounts of nutrients for their growth and development. The roles individual micro- and macronutrients play in soybean growth and development have been discussed in the chapter Mineral Nutrition of Soybean, so the present chapter will deal only with the plant's needs for the application of particular mineral fertilizers.

The system by which a crop is fertilized will depend on soil and climatic conditions, which means that there can be no universal recommendations in this regard for all crop growing regions without taking into account the specific local growing conditions. Fertilizer application may be the agronomic practice that perhaps benefits the least from experiences from other regions. The results of research on the needs for particular elements are generally similar, but the production conditions vary considerably. Knowledge of the roles individual elements play in the life cycle of a plant and the conditions under which the plant grows will determine the amounts and types of mineral fertilizers that should be applied.

The basic principles of fertilizer application for any crop are applicable to soybean too. Fertilizer use is based on the principle of soil fertility control, i.e. on maintaining the good fertility of fertile soils and improving the poor fertility of less fertile ones while trying to obtain high and stable yields. The basis of the principle is the balance of nutrients at the crop or crop rotation level. The fertilizer rate applied to a crop establishes a balance between the total amount of nutrients the plant needs in order to produce the projected yield and the amount of plant-available nutrients present in the soil. What is also taken into account is that a certain amount of nutrients is removed from the soil by harvesting and that these quantities need to be replenished if soil fertility is to be maintained.

The total nutrient requirements is calculated by multiplying the target yield with the amount of nutrients present in the grains and vegetative plant organs. According to a number of studies, the plant needs 100 kg N, 23-27 kg P_2O_5, and 50-60 kg K_2O in order to produce one ton of grain and the corresponding amount of vegetative biomass. Of these quantities, about 60 kg N, 11-14 kg P_2O_5, and 20-23 kg K_2O are removed with the grain at harvesting, while the remainder of the nutrients that have been taken up by the plants is returned to the soil when harvest residues are plowed under (Franzen and Gerwing, 1997; Johnson, 1992; Cetiom, 1988).

Before determining optimum fertilizer rates that will provide the plant with the right balance of nutrients, one must determine the amount of plant-available nutrient elements present in the soil through soil analysis. Along with information on soil nutrient levels, a soil analysis will usually include a recommendation on the optimum fertilizer rates and time and method of fertilizer application. It has become a common practice to average the results of analysis of several representative soil samples taken from a plot and then apply the recommended fertilizer rate uniformly throughout the entire plot. Fertilizer application provides plants with the minimum amount of nutrients needed to prevent the limitation of yield when optimal growing technologies are used in the average weather conditions of a given area.

It has been a standard practice so far to apply the same fertilizer rate across the whole plot regardless of the variations in fertility observed in different spots within it. This leads to uneven plant development and results in yield losses, as the uniformity of the crop is a key factor in obtaining high yields. Hybrids are as uniform as possible from the genetic point of view, but the phenotypic expression of this potential depends on the uniformity of environments in which individual seeds develop. Because of this, research efforts have been under way to develop and implement an advanced growing technology termed precision agriculture, which makes use of fertilizer rate recommendations pertaining to each individual soil sample. In other words, a precise recommendation is made on how to fertilize each individual part of the plot instead of applying the same, averaged fertilizer rate throughout the plot (Hoeft et al., 2000). In order for this approach to work, soil samples need to be taken at more frequent intervals in order to get a more accurate picture of fertility variation within the plot. Another key part of this system is to pinpoint the exact geographic coordinates of the sampled spot using GPS technology, i.e. to make a map of the plot and a GIS database on a mobile computer. The results of soil tests for each sample with known coordinates are used as the basis for different fertilizer application in different areas of the plot using specially adapted fertilizer spreaders. This is done through the use of a GPS device installed in the tractor that feeds the vehicle's current coordinates into the computer, which then determines optimum fertilizer and pesticide rates based on soil nutrient levels in that particular spot.

The uptake of soil nutrients depends on the stage of plant development. In the early phases of this development, when plants are small, the amounts of nutrients they take up are small as well, but their concentrations in plant tissues are high.

In the latter stages, plant nutrient requirements increase and so do the quantities of micro- and macronutrients taken up by the plant, but nutrient levels in plant tissues become lower due to the dilution effect. The rate of nutrient uptake by a plant is affected not only by the amount of nutrients present in the soil and the form they are found in but by other soil properties as well. If the soil is dry, the uptake of mineral nutrients becomes reduced due to a decrease in soil water availability and uptake. Because the root needs a specific water-air regime in order to perform its activity, nutrient uptake will not be adequate when soil is extremely wet. For this reason, in order to ensure proper plant nutrition, an effort must be made during tillage to provide the future crop with adequate soil water-air and temperature regimes.

Nitrogen deficiency has a similar effect on plant growth and development and yield formation in all cultivated plants. What separates soybean from other field crop when it comes to nitrogen is this plant's ability to meet a considerable proportion of its need for this nutrient through a symbiotic association with nodule bacteria. The proportion of nitrogen originating from nitrogen fixation in the total requirement of soybean for this element ranges between 25 and 70% depending on growing conditions. The remainder of soybean N needs are met by uptake from soil (inorganic N, N produced by mineralization of organic matter, and N left in the soil by the previous crop) (Varco, 1999). Soybeans use soil nitrogen exclusively only in the short period between when they stop using cotyledons for nutrition and the formation of nodules, which, according to most authors, happens within the first two to three weeks of growth and development. This NO_3 form is the predominant source of nitrogen all the way through to the start of pod formation, when its contribution to N nutrition drops sharply (Pedersen, 2004). Later on, as plant N requirements increase, soybeans meet most of their need for N from atmospheric nitrogen. Because the use of fixed nitrogen by the plant predominates from the start of flowering until the grain filling stage (Heoft et al. 2000a), it is important to incorporate root nodule bacteria into soils on which soybeans have not been grown previously. A high amount of nitrate nitrogen prolongs the infection and reduces nodulation, which leads to a decrease in nitrogen fixation. When considering the effects of nitrogen in soybean, therefore, it is always important to indicate whether the plants have been inoculated, and, if so, how successful the nodulation was. Soybeans with well-developed nodules rarely respond to nitrogen fertilizer regardless of the soil type, the time and method of N application, and the amount of N fertilizer applied, so plots with such soybean plants should not be top-dressed (Roth et al., 2003).

In a two-year multi-site trial in Vojvodina, increasing nitrogen rates (with the rates of phosphorus and potassium remaining the same) had a negligible effect on soybean yields, while inoculation had a much greater effect. Other studies found that increasing N rates reduced the number of nodules, so much so that no nodules were found on the roots of soybeans in most locations when the N rate was increased to 90 kg/ha (Belić et al., 1987; Relić, 1988). The same conclusion was reached by Gascho et al. (1989) and Johnson (1992).

Under a certain set of soil conditions (low pH, low organic matter and residual nitrogen contents, a high degree of harvest residue incorporation or soil compaction) soybean plants cannot get enough nitrogen from the soil and N fixation as the sole sources of the element, so the symptoms of nitrogen deficiency appear, in which case the application of nitrogen fertilizer becomes justified, as it leads to a significant increase in yield. Osborn and Riedell (2006) reported that in cooler conditions the incorporation of 16 kg/ha of nitrogen prior to planting resulted in an average seed yield increase of 6% over a three-year period due to faster initial plant growth.

The soybean plant takes up phosphorus and potassium throughout the growing season. The period of peak requirement for phosphorus begins just prior to the start of pod formation and ends when the grains have been fully formed. The uptake of potassium is at its peak during the period of vegetative growth and then slows down at the start of grain formation. The need for the incorporation of these elements into the soil depends on their amounts already present there. According to Ferguson et al. (2006), soybean needs lower soil phosphorus levels than maize and wheat in order to produce maximum yields, which means that this crop, just as the rest of legumes, is well able to utilize the less readily available forms of the element present in the soil. Nevertheless, our research indicates that soil phosphorus and potassium contents that are too high may negatively affect the yields of soybean (Rajičić et al., 1993). High concentrations of readily available phosphorus and potassium in the soil do not harm plants directly. However, due to the possible antagonism between different elements, especially one between phosphorus and other elements, or because of the transformation of other biogenic elements into forms that are not available to plants, a discord may occur in the nutrition of cultivated plants (Bogdanović et al., 1993).

Plants also need micronutrients in order to develop properly. Micronutrient deficiencies are more pronounced in lighter soils, which are prone to leaching, as well as in alkaline and acidic soils. According to Johnson (1992), growers that obtained high yields by providing their crops with sufficient amounts of N, P and K were the first to pay closer attention to the deficiency of micronutrients. The same author also states that an accurate assessment of a micronutrient deficiency requires carefully controlled studies, because the difference between poor, good, and very good micronutrient supply is often minute. If it is determined that a crop is in need of certain micronutrients, they can be supplied by soil or foliar application.

The incorporation of nutrients that are needed by soybeans is mostly done by using mineral fertilizers. The use of organic fertilizers (farmyard manure, green manure, liquid manure, compost) is practically non-existent in soybean production. Soybean is very proficient at making use of the prolonged effects of farmyard manure application and will benefit from it not only when it immediately follows the crop for which the manure was incorporated but also when planted two or three years after the incorporation.

It used to be a common practice in Serbia not to apply mineral fertilizer to soybean, because if this plant was grown on a soil that had good structure and mechanical composition and was naturally fertile, and if the seeds had been properly inoculated, good yields could be expected. In the last couple of years, because of economic difficulties, there has been a drop in the use of fertilizers in all crop species and the soil has been depleted of nutrients as a result. For this reason, when growing soybeans, increased attention should be given to fertilizer application. On a soil well supplied with mineral nutrients, only such nutrient amounts as are removed by harvesting should be returned to the soil in order for its fertility to be maintained. To obtain a grain yield of 3 t/ha on medium fertile soil (10-20 mg P_2O_5 and K_2O per 100 g soil, determined using the Al method), it is recommended to apply 50-60 kg/ha P_2O_5 and 40-50 kg/ha K_2O. If the soil is less fertile naturally, fertilizer rates should be increased. Because soybean yields are less affected by fertilizer application than the yields of other field crops, variety specificity with regard to mineral nutrition has been little studied in this crop. Still, robust, later-maturing soybean varieties require more fertilizer because of their greater need for nutrients. In soybean, fertilization is most commonly done before subsoiling in the autumn using compound fertilizers, while spring preplant application can be used only for incorporating smaller amounts of nitrogen (up to 30 kg/ha). Since any mineral nitrogen incorporated later in the season has a negative effect on nitrogen fixation, no top dressings are applied to soybean crops in the course of the growing season.

It should be borne in mind that no top yields can be expected under conditions of nutrient deficiency. Therefore, decisions concerning fertilizer application in soybean must be made based on knowing the specific conditions in the field in each individual case.

TILLAGE

Tillage is an important factor for the success of soybean production. The tillage systems used differ not only from region to region but also from one field to another, and in some cases the same field will be tilled in a different way depending on the year. Growers should, therefore, make use of the tillage system best suited for the given set of conditions in a particular moment in time (Johnson, 1987). Soybean needs high quality primary tillage and good quality seedbed preparation. Deep tillage activates a larger amount of soil, which promotes the degradation of harvest residues that have been incorporated into the soil and enables the formation of larger moisture reserves, especially those that accumulate during the winter. The purpose of tillage is to provide good soil structure and a favorable water-air and temperature regime and to plow under the harvest residue and destroy weeds.

This promotes uniform emergence, deep rooting, and optimum soybean development throughout the growing season. Tillage should also allow the root system to penetrate into the deeper soil layers and enable better uptake of mineral substances and increased nodule formation and activity. In a compacted soil whose pores are too small, the growth of the root system is limited, which may affect the growth of the above-ground plant biomass and, by virtue of this, yield levels themselves. When growing soybean or any other crop, tillage plays a highly important role in weed control as well. The level of weediness can be reduced by primary tillage and seedbed preparation that are applied in a timely fashion and to a high standard of quality as well as by plowing under weed plants, seedlings, and seeds or by more efficient herbicide application.

Primary tillage

The method and timing of primary tillage in soybean depend largely on soil type and the preceding crop. Soybeans have a great need for good-quality primary tillage applied in a timely manner. Subsoiling must be performed in the autumn, and the best time to implement this agronomic practice in the case of early-maturing preceding crops is late September for heavier soils and no later than the end of October for all other soil types. When a later-maturing preceding crop is used, primary tillage should be performed immediately after harvesting. Applying primary tillage in the spring results in yield losses (Crnobarac, 2002). Spring tillage can be justified only under special circumstances, such as when the terrain is sloping or prone to flooding. Primary tillage in soybean should be at least 25-30 cm deep. Depths shallower than that are acceptable only in the case of light, loose soils. With heavier, compacted soils, however, the plowing depth should not be reduced below the said minimum under any circumstance (Šuput, 1986).

Primary tillage (plowing) is considered to be of good quality when the following requirements have been met: adherence to the recommended plowing depth, making tight tillage passes down the field and tight packing of the overturned furrow slices, good leveling and pulverization of the plowed soil, and burying weed seeds and weed and crop residues down to the full depth of plowing. The quality of plowing during primary tillage determines the quality of subsequent seedbed preparation, planting, inter-row cultivation, and harvesting.

The method of tillage in soybean depends on the preceding crop. If soybean is preceded by a spring or winter small grain (wheat or barley), right after such crop is harvested the remaining stubble is buried into the soil by plowing to a depth of 10-15 cm or the soil is disked using a heavy disc harrow. This results in the incorporation of crop residues into the soil, better moisture retention, and destruction of weeds. It is desirable that the emergence of weeds and volunteer plants be induced during the summer or early autumn, so that these deleterious plants can be destroyed by harrowing or cultivation before they set seed, whereby weed incidence in the next season is reduced. Full-depth plowing (25-30 cm) is performed in late summer/early autumn.

Late harvesting and large amounts of crop residues make tillage after maize somewhat difficult to perform. The first task after the maize harvest is to chop up crop residues, which must be done to a high standard of quality. If this is not done correctly, it will not be possible to properly perform primary tillage either. Crop residue must be chopped and buried in such a way as to enable the seeds to make contact with the soil as opposed to residues of plants. For this reason, full attention should be paid to this agronomic practice. Tillage depth should be up to 30 cm in order to ensure that corn stover is buried in the soil at a depth at which there are favorable conditions for its decomposition.

If sugar beet is the preceding crop, full-depth plowing is carried out right after the sugar beets are lifted, and the field is left unharrowed and exposed to the effects of frost. Plowing depth depends on the condition of the surface on the beet field, soil moisture, and the amount of crop residue. If the conditions for beet lifting have been favorable and the soil has not been compacted to a high degree, plowing can be carried out down to the depths of 20 to 25 cm. Sugar beets are often lifted under very unfavorable conditions, which leaves the soil in a highly compacted state. As a result, the grower cannot take advantage of the deep tillage performed for the previous crop (sugar beet), so the depth of primary tillage for soybean should be 30 cm in such cases.

Before the start of winter, once primary tillage has been carried out, a plow or a disc harrow should be used to smooth out deep dead furrows and tall back furrows in order to make seedbed preparation and planting easier and of better quality. This significantly reduces yield losses, which in soybean can be very high in case this operation is not implemented. A soil that has been plowed in a timely manner and to a high standard of quality should be left to overwinter unharrowed in order that it can freeze better and accumulate more winter precipitation. In Serbian crop production, some growers will harrow the soil lightly in the autumn and close the furrows. This practice is not justified in soybean, because it makes sense only when planting early spring crops that are in need of high-quality seedbed preparation, which is difficult to perform in early spring, because the soil is usually too wet at that time.

Seedbed preparation

Seedbed preparation depends on the soil type and timing and quality of primary tillage and is always performed only when soil moisture is optimal. The goal when preparing the seedbed is to obtain a 5-6 cm layer of fine, warm and wet soil that will facilitate good contact with the seeds and fast and uniform emergence. The rate at which the seed emerges depends on soil moisture and temperature as well as on the closeness of contact between the seed and the soil, because it is through this closeness that soil moisture and temperature are transferred to the seed. Seedbed preparation should also provide uniform planting depth and good seed coverage.

In soybean, as in all other spring crops, the primary goal of seedbed preparation is to level and loosen the soil. Crumbling the soil is not so important, because the soil gets pulverized by frost in the course of the winter. Settling the soil is not a priority either, because the soil settles on its own in the five to six months between the end of primary tillage and the start of spring. With seedbed preparation, the goal is to reduce unnecessary soil water evaporation by increasing soil temperature, because doing so reduces the contact area between the soil and the atmosphere and disturbs the capillary system already established in the soil, thus enabling a more uniform distribution of heat and water in the seedbed (Crnobarac et al., 2003). Loosening the soil introduces air into the surface layer. As air has poor conductivity and a low heat capacity, this allows the seedbed to warm up faster and enables earlier planting and a longer growing season (Figure 9.2).

Figure 9.2

Seedbed preparation *(photo: G. Kuzmanović)*

Seedbed preparation cannot be used to correct errors made during primary tillage, because even though it smoothes out the surface layer of the soil, the deeper layers remain uneven. This results in poorer planting and uneven emergence and makes rooting more difficult, which later affects plant growth and, hence, the yield as well. What is specific about seedbed preparation in soybean is the need to level the soil as well as possible in order to reduce yield losses.

Seedbed preparation is most often implemented in two parts. The first portion is best applied early in the spring, as soon as weather permits, i.e. as soon as the soil dries out, so as to prevent soil from sticking to the implements and to reduce the negative effects of soil compaction and trampling, which worsen soil physical properties, especially where the tire tracks are.Because of this, it is recommended to install double wheels on the tractors and to carry out this operation in as few passes as possible by aggregating several implements or by using combined implements. This operation should not be carried out late either, when the soil dries out too much, because this reduces the uniformity of wetness of the seedbed.

The second part of seedbed preparation is carried out a few days before planting, when the final portion of the preparation is implemented and when the seedlings and emerged weeds are destroyed most easily. This measure can be used to incorporate preplant rates of nitrogen fertilizers and to incorporate herbicides. If done properly, this operation produces finely grained soil structure, which results in more uniform crop emergence as well as better herbicide action. The surface of this layer should be finely lumpy instead of powdery so as to prevent the formation of crust. Below the seedbed, the soil should be loose enough in order to enable easier and deeper rooting and better root aeration. The depth of tilling should be adjusted to the depth of planting, because tillage that is too deep leads to unnecessary water losses and uneven emergence. The disc harrow is used rarely in the spring, except in the case of heavily weed-infested or compacted and heavy soils, because cutting through wet soil creates artificial lumps, which opens up the soil too much and hence increases the evaporation of water from the surface layer.

Preparing the soil for planting a stubble crop

Planting soybean as a stubble crop was not common in Serbia until a few years ago. A reason for this was a lack of appropriate soybean varieties for this kind of cropping, but this obstacle has been overcome in the meantime. Research findings and practical experiences support the increased interest in this form of soybean growing. After wheat or winter barley are harvested, there are enough days without frost left in the season that can be used by very early soybean varieties to reach maturity and produce a certain yield of grain.

The most important thing when preparing the soil for growing soybean as a stubble crop is that the preparation be carried out as soon as possible after harvesting the first crop of the season. Postponing the planting from early July until late July reduces the yield by 53 kg/ha (1.8%) in irrigated conditions and by 19 kg (1.2%) in dry farming with each day of postponement (Van Doren and Reicosky, 1987). The reason for the much greater impact of delayed planting in July than in April is that with each day the planting is delayed in July much more energy (effective temperatures) is lost than when the same happens in April.

As emergence is prolonged, the crop enters grain fill and maturity in late autumn, when the sum of effective temperatures per day is much smaller, which considerably prolongs ripening and hampers harvesting. Since the removal of straw from the field would delay harvesting considerably, it is best that it be chopped with shredders mounted on a combine. In that case, tillage can be performed right after harvesting.

The method of tilling the soil depends on the available machinery. In stubble cropping under irrigated conditions, Vučić (1987) found that minimum tillage - disk harrowing to 10 cm soil depth – very successfully replaces conventional plowing down to 20-25 cm depth. Minimum tillage has the advantage in that it takes less time to perform, and it is also associated with considerably smaller losses of soil moisture, the supply of which is problematic in any case.

In Serbian conditions, stubble cropping can be expected to produce satisfactory yields only in irrigated conditions (this will be discussed in a separate chapter), because in that part of the growing season there is usually not enough moisture in the surface layer for emergence and initial plant development. Plants sown at the start of the season survive thanks to a well developed root system that draws water from the deeper soil layers, whose water content is more stable and originates mostly from winter moisture reserves. The weediness of a stubble crop depends on the previous crop. Part of the weed population can be destroyed by tillage, while herbicides, just as in the case of regular planting, serve to destroy weeds that appear in the course of the season. In conditions where weeds cannot be completely destroyed, the success of growing soybean as a stubble crop is uncertain.

Reduced tillage

Over the last few decades, conventional tillage has been subject to criticism, primarily because it consumes a lot of time and energy. Scientists have begun to develop tillage systems that have been simplified in various ways. This has been done by reducing plowing depth, omitting certain operations, or dispensing with tillage altogether. The main reason for this has been the cost price of tilling, as conventional tillage is the most costly agricultural practice, with plowing accounting for over 50% of the costs. In Serbia, according to Starčević et al. (1995), reduced tillage means tilling the soil without the use of plows and is used primarily when growing winter cereals and, to a lesser extent, row crops. It can be said that reduced tillage reduces the depth of plowing and the number of individual operations (by merging several operations into a single operation or by dispensing with some operations altogether), i.e. certain operations are replaced with simpler and less expensive ones, which decreases production costs and makes work faster and easier to organize. Reasons for reduced tillage can be different: conserving the soil in areas prone to erosion; reducing soil compaction by reducing the number of passes made by heavy machinery; reduction of fuel consumption; or making the production more economical.

Besides having advantages, reduced tillage also has certain disadvantages. These include the necessity of having to purchase specially adapted machines that are relatively expensive, increased weediness, increased difficulty of incorporating mineral fertilizers and crop residues and hence a reduction of soil microbial activity and biochemical processes, increased difficulty of planting, and poorer emergence.

All the other agronomic practices, such as fertilizer application, planting, and crop tending and protection, must be taken into consideration and adjusted, because the reduction of costs must not have a negative effect on the profitability of production. Also, the long-term effects of reduced tillage on soil fertility should also be taken into consideration, in other words, one must monitor and understand the influence this approach has on physical, chemical and biological properties of the soil.

The effects of reduced tillage have been studied in soybean too. According to the findings of Van Doren and Reicosky (1987), reducing tillage depth to 12 cm or less results in yield losses. The losses are especially pronounced if soybeans are grown without tillage (8%), and prolonged growing in this manner reduces the yields by 17.5%. Still, reduced tillage is increasingly used worldwide for growing soybean, especially when this species is used as a stubble crop. In Serbian conditions, Konstatinović and Spasojević (1994) found, soybeans grown in different tillage treatments produced equal yields in the first year of the study, whereas in the second the no-till treatment had 43% lower yield than the other treatments. The authors of the paper concluded that research on this topic should continue. Molnar et al. (1996) studied the effects of tillage method on soybean grain yields and obtained significantly lower yields in the no-till treatment than in the tilled treatments. The reasons for this, according to the authors, lie in the increased weediness of the crop and the inability to attain the desired plant density. No statistically significant differences were observed among the treatments with plowing, chiseling and disking. In Serbian conditions, according to Vučić (1987), no-till farming can only be used to occasionally grow certain crops on good soils, and this approach to tillage should be incorporated into a broader tillage and crop rotation system.

Previous results on the use of reduced tillage are numerous and contradictory and depend on the conditions under which a particular study was carried out, so no general recommendation can be made in this regard. The effects of different kinds of tillage on yield are usually analyzed and compared after a time period of one to two years. In order to properly ascertain the efficacy of reduced tillage, its effects should be monitored in continuity across the entire crop rotation instead of looking at each individual crop separately. In other words, the effects different tillage methods have on yield, weeds, fertilizer use, and soil fertility should be monitored over the long term.

PLANTING

Time of planting

Decision on when to plant spring crops should be governed by the temperature of the seedbed rather than by the calendar. Seedling resistance to late spring frosts should also be taken into account when making the said decision. It is not recommended to plant soybeans before soil temperature stabilizes at 10-12ºC and growing, especially if the seed is not of good quality. Planting soybeans too early at a low temperature slows down germination, and cold and wet soil promotes the occurrence of seed and seedling diseases, resulting in a thinner stand and slower initial seedling growth due to seedling exhaustion and reduced seed vigor.

According to Hoeft et al. (2000b), soybean seedlings are relatively resistant to low temperatures, and their frost resistance is greater than that of maize, although the growing point of maize is below the soil surface until the start of the six leaves stage. Temperatures that will completely destroy the above-ground portion of a maize plant are only capable of causing damage to the apical portion of a young soybean. A young soybean plant can withstand short-lasting frosts of -3 to -4ºC (Gutschy, 1950), so the threat of winterkill is lower in soybean than in maize. For this reason as well as in order to make organizing the planting easier, it is recommended that soybeans be planted before maize in Serbian conditions. In Serbia, soybean planting is often limited by different factors, ranging from weather conditions to the available machinery. Most often, it is carried out during April, when the planting of maize is in progress as well (Hrustić 1996)

Each stage of soybean growth and development requires a certain amount of growing degree days. In soybean, the sum of temperatures above the baseline temperature of 10ºC is constantly at around 100ºC, meaning that soybean will emerge once this temperature sum is reached. With earlier planting at a sufficient moisture level, therefore, the period from planting to emergence and early plant growth will last longer. For this reason, planting a month earlier does not mean that harvesting will be a month early as well. In the same maturity group, on average, every two to three days of delayed planting prolong maturation by a day. The later planting mostly reduces the duration of the vegetative stage of growth and development (from emergence to flowering), while the impact on the period from flowering to maturity is considerably smaller. This is a result of the photoperiodic response of soybean, where a crop that has been sown later begins to flower earlier, because it comes under the influence of short-day conditions earlier. Because of this, planting date has less impact on the yields of earlier-maturing varieties, whereas with the later-maturing ones there is a tendency for yields to be lower with later planting. When planting a number of varieties, the rule is to first plant later-maturing ones. If the planting is well passed the optimum dates, the ripening of the soybeans may come into question. (Figure 9.3).

Figure 9.3

Soybean planting *(photo: G. Kuzmanović)*

When planting soybeans at the start of the season in Serbia, varieties with the longest growth period, those from Maturity Group II, should be sown in early April. Early-maturing varieties can be sown later on in April or even in May. However, to obtain yields that are as good and stable as possible, secure a more reliable water supply at emergence, avoid drought during the critical period, and ensure timely harvesting, it is recommended that these varieties too be sown earlier, in the course of April.

Soybean can also be planted beyond the regular planting time early in the season, either as a double crop or as a re-planted crop of soybean. When this is the case, earlier-maturing varieties should be used. Those from MG 0 will manage to mature if sown in May. If planting is done in June or later (early July), varieties from MG 00 or even 000 must be used.

Planting density and seeding rate

One of the main preconditions for obtaining high yields is to attain an optimal plant population per unit area. In each agroecological region, the optimal plant population must be adjusted depending on the variety, planting dates, rainfall amounts, tillage system, available machinery, mineral nutrition, and pest and weed protection.

Soybeans are highly tolerant of different planting densities. The optimal stand density is determined based on the characteristics of a mature plant, bearing in mind that the quick closing of the rows is the key factor of high crop productivity and that first pod height reduces yield losses while making sure that the threat of lodging and diseases is minimized and taking into account the price of the seed being sown. A study by Rigsby and Board (2003) has shown that soybeans are extremely good at compensating for a thin stand and that they do so through increased branching and by forming more pods per plant. According to Markley-Williams (1950) (as cited by Belić, 1964), the axil of each soybean leaf contains a bud that may develop into either a flower or a branch depending on environmental conditions. If the planting density is higher, most of the buds at the lower nodes will develop into flowers. At lower planting densities, on the other hand, most buds at the lower nodes develop into branches. Because of this, according to Roth et al. (2003), decision on re-planting soybean is a very delicate one. The grower must also bear in mind the cost of re-planting and yield losses caused by the later planting. The yield that has been formed will not decline significantly with a minor reduction of plant density, but yield losses at harvesting will increase significantly. According to Nafziger (2002), insufficient plant density will still limit yield levels due to lower leaf area index and maximum leaf area achieved at the start of pod formation, which has as a result lower sunlight utilization. Also, lower plant densities are associated with greater weed abundance and increased competition from weeds, and they also promote branching and the formation of pods closer to the ground level, which increases yield losses at harvesting. (Figure 9.4).

Figure 9.4

Correct planting density *(photo: G. Kuzmanović)*

Planting density has been the subject of studies both in Serbia and worldwide, but the results have differed greatly due to differences in growing conditions and the varieties used. Different genotypes are grown in different parts of the world, each of which has its early, medium, and late varieties which require different plant densities. In view of all the above, it is therefore not surprising that the optimal stand density per hectare may be 200,000 plants in one region and 600,000 or even 800,000 in another.

The number of plants per hectare and their distribution have been the subject of many studies in Serbia. The conclusion of most of the papers is that early varieties should be planted more densely and that late varieties produced the best yields at lower plant densities (Belić, 1964; Hrustić, 1983; Relić, 1996). The main components of yield are plant number and pod number, i.e. grain number per plant and 1000-grain weight. Pod number per plant decreases significantly with an increasing number of plants per unit area. A small number of plants with a large number of pods produce the same yield as a large number of plants with a small number of pods (Rajičić, 1991). Thus, yields obtained at smaller plant densities are comparable to those obtained in stands that are overly dense. Therefore, it is important to determine for each individual variety at which point an increasing plant number per unit area and a declining grain number per plant will produce the best output, i.e. the largest number of grains per m^2 (Rajičić and Jocković, 1990).

The attainment of high yields depends not only on plant density but on proper plant distribution as well. Several small gaps in a row will result in a loss of yield, but the loss will not be as big as when there is one big gap due to poorer yield compensation in the latter case The gaps cause greater damage because of the occurrence of weeds than because of the yield loss per se (Stivers and Swearingin, 1980). Unlike maize, however, soybean is well able to adapt to a lack of plants in the stand, because at a lower plant density it forms a larger leaf area and branches more (Robinson and Conley, 2008).

As a row crop, soybean is planted in wide rows, and the spacing between rows depends on the organization and technical circumstances and biological characteristics. A series of attempts have been made in commercial soybean production to employ different planting methods in order to obtain yields that are as good as possible. Growers tend to attribute good crop performance in a given year to the influence of a single factor, be it the variety or a particular agronomic practice they used, and are not willing to change their ingrained habits easily. However, numerous studies and many years of experience from commercial production have made it possible to develop a certain technology of growing that, more or less modified, can be recommended for most soybean-growing areas in the country.

First of all, it has been determined that 45-50 cm is the most suitable row-to-row spacing for Serbian conditions, both in terms of available machinery and from the point of view of inter-row cultivation and weed control (Tatić et al., 2002; Vignjević, 2006).

Plant-to-plant spacing is a way of regulating plant number per hectare and is dependent on planting date, variety, and seed quality. Thus, the recommended intra-row spacing for the early varieties (MG 0) sown on optimal dates is 4 cm, while the recommended spacings for the medium and late varieties are 4.5-5 cm and 5-5.5 cm, respectively. These spacings produce about 500,000 plants/ha with MG 0 varieties, 400,000-450,000 plants/ha for MG I ones, and 350,000-400,000 plants/ha for those from MG II. Since soybeans are sown with wide-row pneumatic planters, the planting density is determined via the spacing between the seeds being planted, i.e. via seed number per hectare. With narrow-row planters, therefore, it is incorrect to link planting density with seed quantity per hectare, i.e. the seeding rate, because seed size varies a lot depending on the year and variety (Roth, 2003). It is known that germinability varies according to year, which is why it is necessary to adjust the number of planted seeds taking into account the utility of the seed. In each individual case, therefore, it is necessary to calculate the Spacing Between the Planted Seeds In a Row (SBPSIR) using the following formula in order to obtain the recommended number of emerged plants for a given variety (Crnobarac et al., 2001).

$$\text{SBPSIR}\ (cm) = \frac{1000000 \quad x \quad US\ (\%)}{PNPH \quad x \quad IRS\ (cm)} \Rightarrow \frac{1000000 \quad x \quad 88.20}{450000 \quad x \quad 50} = 3.92\ cm$$

Where:

- *US* – Utility of the seed, which represents the percentage weight of the “seed” in a bag that is capable of germination and emergence, i.e. of developing into plants:

$$US\ (\%) = \frac{PURITY\ (\%)\ x\ GERMINABILTY\ (\%)}{100} \Rightarrow \frac{98\ x\ 90}{100} = 88.20\%$$

- *PNPH* – desired plant number per hectare, e.g. 450,000 plants in the variety Sava

- *IRS* – inter-row spacing, usually 50 cm

In ideal conditions, with such an adjustment and with the existing seed quality and the given inter-row spacing, we will practically plant 510,000 seeds in order to obtain the exact desired number of emerged plants per hectare of 450,000.

The most commonly made mistake in commercial production is to plant a considerably larger number of seeds than what is needed “just in case”. If the planting is late or the seeds are planted on a poorly prepared plot, the number of seeds planted should be increased. In doing so, however, one must bear in mind the fact that seed number is a not a factor that will compensate for inadequate cultural practice and that increasing the seeding rate alone cannot be expected to result in a top yield.

When extremely early varieties are planted later in the season, because of their smaller habit of growth, it is recommended to use a smaller intra-row spacing and by virtue of this a larger number of plants. Such varieties should be planted with a spacing of 3-3.5 cm, which will produce 550,000-600,000 plants/ha.

Plant number per unit area under irrigated conditions is an issue in its own right. It must be borne in mind that adding water by irrigation creates optimal conditions for plant development and that irrigation is not a reason to increase plant number in soybean. Irrigation is intended to improve plant water supply in an optimal stand and does not necessitate increasing the number of plants. Irrigated conditions may lead to somewhat increased lodging and disease severity, so an inadequate number of plants may have the opposite of the intended effect. In France, the recommended plant populations for each individual maturity group are approximately the same as in Serbia. However, the recommended plant number for irrigated conditions in that country is 10% lower for the early varieties and 20% lower for the late ones (Cetiom, 1996).

The amount of seed used for planting depends on seed quality, most notably seed size. The exact quantity of seed needed for planting can be calculated based on the projected plant density, utility of the seed, and 1000-grain weight.

$$Seed\ quantity\ (kg/ha) = \frac{100\ x\ W1000\,(g)}{SBPSIR\ (cm)\ x\ IRS\,(cm)} \Rightarrow \frac{100\ x\ 140}{3.92\ x\ 50} = 71.41\ \text{kg/ha}$$

Because of a large variation in seed size, the required amount of seed per hectare may vary from 60 kg (500,000 seeds x 120 g) to 100 kg (500,000 seeds x 200 g) for the same stand density. Since a package of seed includes information on its basic characteristics (1000-seed weight, germinability), it is possible to estimate the precise seed quantity required for each specific situation.

According to our own data obtained for a seed crop at Rimski Šančevi, the amounts of seed needed for soybean planting were about 80 kg/ha in the early varieties and about 55 kg/ha in the later-maturing ones, which was due to the variable seed size. Therefore, the rule that 100 kg of seed are needed to plant one hectare of soybean is only provisional. It is only a rough estimate, while the exact quantity in a specific situation will depend on the projected stand, seed size, and seed quality.

Planting depth

Planting depth is important for securing reliable emergence and achieving the desired plant density. While emerging, soybeans elongate their hypocotyls and lift their cotyledons above the ground. After emergence, the arching hypocotyl bearing the cotyledons gradually becomes erect, after which the cotyledons separate. Once the cotyledons assume a horizontal position, the plant is regarded as having emerged. If the seed has been planted too deep and the soil is also cold, emergence will take long and the seedling may become damaged. If the seed has been planted too shallow, the surface layer of the soil might dry out, which may slow down germination or cause the seeds that have already germinated to desiccate. For these reasons, planting depth must be given due attention. In Serbian conditions, the optimal planting depth for soybeans is 4-5 cm. On wet, heavy soil, i.e. early in the season, and with better seedbed preparation, the seeds should be planted at a shallower depth, and vice versa. If the soil is dry, however, planting depth should not be increased at all costs in order for the planting to reach the moist layer of the soil. It is more important that the seeds are planted at a uniform depth, so that after the rain they can emerge and go through initial growth as evenly as possible, because plant uniformity in a crop is one of the main prerequisites for obtaining high yields per unit area. Good quality planting requires good contact between the seed and the soil, i.e. slight soil compaction in the area around the seed. In wide-row planters, this is achieved by a well-adjusted furrow wheel. All these requirements are much harder to fulfill if the soybeans are sown with a narrow-row planter for cereals.

SEED INOCULATION

Soybean seeds, unlike those of most other field crops, are usually not treated with fungicides prior to planting; instead, they are inoculated with nitrogen-fixing bacteria. Being a legume, soybean has the ability to satisfy its needs for nitrogen by taking up this element from the soil and the atmosphere through symbiotic association with nodule bacteria. Intensive research on this symbiosis was started in the early 20th century from the point of view of the host plant as well as in terms of the study of bacteria taking part in the association (those from the genera *Rhisobium* and *Bradyrhizobium*). As the importance of soybean increased, so did the volume of research on the genetic basis on which this symbiotic association rested and studies were conducted to find out which strains of the bacteria formed the most effective associations with soybean plants. From the agronomic point of view, this meant determining how to utilize the ability of the soybean plant to use up as much atmospheric nitrogen as possible in the formation of biological yield.

Because plants are capable of utilizing different nitrogen sources, it is important to know the conditions under which the plant will opt for a particular source of this element. In the early stages of development, at germination and emergence, the plant uses nitrogen reserves from the cotyledons. These will last until the 20th day after emergence, at which point symptoms of nitrogen deficiency may appear on the soybean seedling in case there is a poor supply of soil nitrogen or nitrogen coming from N-fixation.

The first nodules appear about a week after emergence and are clearly visible, because they grow intensively. After 10-14 days they are capable of meeting most of the plant's nitrogen needs. The nodules will remain active for the next 6-7 weeks, after which their activity will subside. New nodules form later in the season as well, while the period of their death is during pod formation, when nitrogen fixation is at its peak. The number of nodules formed is inversely proportional to the amount of nitrogen present in the soil. According to Abendroth et al. (2006), N_2 fixation consumes more energy than the uptake of soil or fertilizer mineral nitrogen. Because of this, the plant prefers the latter forms of N, which leads to a reduced level of nitrogen fixation.

Since soils on which soybean has not been grown previously do not usually contain strains of soybean nodule bacteria (Sarić et al., 1988), these need to be introduced into the soil together with the seeds. Soils on which soybean has been grown in the past are characterized by a greater abundance and reduced activity of the natural Rhizobium population, so select strains of bacteria are introduced directly with the seeds in order to promote their growth. Unfavorable conditions for the bacteria that result in decreased nodulation include: a low soil pH; high or low temperature; insufficient soil moisture; unfavorable mechanical composition of the soil; and treatment of seeds with fungicides. When using products through which nodule bacteria are delivered to the grower. One must keep in mind that these are living organisms that may lose their vitality under unfavorable conditions. The biofertilizer Nitragin is mostly delivered together with the seed and care must be taken prior to its use to make sure that it is not exposed to temperatures that are too high or too low during storage. The optimum temperature for storing the product is 4^{o}C.

Nitragin is supplied in quantities sufficient for 50 or 100 kg of seed and there is no use in applying quantities larger than that. Exceptionally, in the case of acid soils in which the activity of nodule bacteria is reduced, an increased amount of the product (twice the usual dose) may be used to promote the formation of nodules. Instructions on how to use Nitragin are printed on each bag and must be followed, because the product will be effective only when used as prescribed. Most importantly, one must use the recommended amount of water - up to 0.5 L for 50 kg of seed. When not enough water is added, the product will not mix fully with the seed. Adding too much water, on the other hand, may cause the seeds to imbibe and to be distributed unevenly during planting. It is important to handle the product in the shade, since the bacteria might lose vitality if exposed to direct sunlight. Inoculation must be carried out before planting. When a large amount of seed is treated but not used the same day, it is recommended to repeat inoculation the following day. It must be stressed that Nitragin remaining from a planting campaign cannot be used the following year.

CROP CARE DURING THE SEASON

Soybean production requires that plant growth and development be constantly monitored and that appropriate crop care measures be promptly taken in the course of the growing season. These measures include mechanical and chemical weed control, crop protection from pests and diseases, and irrigation.

Weed control is especially important when growing soybeans. Weeds cause yield losses by competing with soybeans for water and nutrients and by increasing the extent to which the crop is shaded. This results in a situation where genetic yield potentials of soybean varieties are not fully realized. Weeds also hamper soybean harvesting and reduce the quality of the grain, and there is also the threat of them being spread by seeds, all of which makes weed control a necessary agronomic practice in the production of soybean.

Inter-row cultivation is carried out primarily to suppress weeds, and it also serves the purposes of breaking up the soil crust and loosening the surface layer of the soil. The first cultivation can be performed as soon as the rows of soybeans become clearly distinguishable on the field, i.e. at the stage of the first true leaf. The last is performed just before the closing of the rows. There are usually two inter-row cultivations carried out, while the protective zone is cultivated manually. In cases where herbicides for suppressing Johnson grass from rhizomes are used, the grower should wait at least 10 days before performing inter-row cultivation. If the primary soil herbicides fail to achieve the desired effects, it is recommended that a second inter-row cultivation be applied by all means at the stage before the closing of the rows (Figure 9.5).

It is considered that the loose upper layer of the soil acts as a mulch and reduces water evaporation from the deeper soil layers and the appearance of cracks in the soil when there is a severe drought. This enables better retention of water in the soil at the critical stages of flowering and pod formation and also aerates the soil, which stimulates the activity of microorganisms that decompose the plowed soil organic matter and improve the functioning of nodule bacteria, which ultimately leads to increased yields (Crnobarac et al., 2002). When implementing this or, for that matter, any other agronomic practice, care must be taken that it is performed to a high standard of quality, because only then the positive effects of this operation on soybean yield will be fully manifested.

Good quality weed control is achieved by making sure that the weeds do not become overgrown, because that makes powder application more difficult and leads to the displacement of tine weeders and to soybeans being damaged and cut.

Also, the soil should not be too wet in order that it can remain of finely grained structure, because this prevents water evaporation from the deeper soil layers and increases the capability of absorption of growing season precipitation.

Figure 9.5

Inter-row cultivation *(photo: G. Kuzmanović)*

The depth of operation must be uniform (4-6 cm) in order to prevent root injury. After the application of powder, the soil must be as level as possible in order to reduce the evaporation surface area and the extent of deleterious evaporation directly from the soil (furrows up to 3 cm deep are tolerated). The lower layers of the soil must not be brought up to the surface. If the plants are still too small, care must be taken that they are not buried by soil due to excessive operating speed (about 6 km/h being the optimum).

During the first cultivation, the operating parts can be closer to the rows, whereas in the second, due to the development of the root system, which also reaches the surface soil layer, the recommendation is to go for a smaller operating depth and narrower passes in order to avoid root damage. Between the cultivator and a plant not cultivated by it there should be a buffer zone of about 15-20 cm, and the use of stabilizer levers preventing the free movement of the cultivator is mandatory. For an easier and safer tractor ride, crosshairs aiming towards the plant row should be mounted at the front of the tractor and cultivation should be in the same direction as when planting was being carried out. The grower must use a cultivator with the same or half the passing width as that of the planter used to sow the crop in order for the contact rows between two planter passes to coincide with half the outside cultivator sections. The working area of hoes of a cultivator section should overlap at least 3-4 cm, and the hoes should be sharp enough to make sure that any potentially surviving weeds are cut.

The primary way of combating weeds should involve correct crop rotation and crop hygiene as well as all tillage practices, while chemical weed control should be used only as a final additional measure. Herbicides can be used before planting, between planting and emergence, after the emergence of soybeans and weeds, or, in the case of perennial grassy weeds, later on in the season. There are varying opinions about the need for inter-row cultivation in crops in which weeds have been completely destroyed using chemical control measures. Still, most authors think that yields are positively affected by the destruction of the soil crust that often forms between the rows and by the better moisture retention in the early stages, which increases transpiration relative to evaporation. Therefore, at least one inter-row cultivation at an optimum time is recommended.

It should be noted that besides treating the whole field it is also possible to make use of reduced herbicide application in bands at the time of planting, in which case only the protective zone in the plant row that is about 25 cm wide is treated, with the weeds in between the rows being suppressed mechanically. This reduces herbicide use significantly, by about 50%, and is also more acceptable in environmental terms (Sinđić, 1994).

In the 1970s and 1980s, when soybeans were a rarity in Serbian fields, there were no major problems with pests and diseases. As soybeans began to be grown on an increasing acreage and more frequently, however, pest and disease problems began to appear. These will require greater attention in the upcoming period and will be discussed in detail in separate chapters.

Irrigating soybean is mandatory when the plant is grown as a stubble crop and desirable when it is the main crop, especially when grown for seeds. Details on soybean irrigation in stubble and regular cropping will be the subject of a separate chapter.

PLANT REGENERATION

Crop damage may occur in the field for various reasons during the season. In Serbian conditions, herbicides, game and hail are the most common causes of crop damage in the early stages of growth, with damage from late spring frosts also being possible. A newly emerged soybean plant can withstand short-lasting less severe frosts, but long-lasting more severe frosts will cause damage. If the damage affects only the upper parts of a young plant, the plant will recuperate quickly and continue to grow. Some herbicides may also cause damages slowing down the functioning of leaves developed up to that point, especially if not applied and dosed correctly.

Game and hail cause similar types of damage, as they remove a portion of an already formed planted. Game mostly damage young plants above the cotyledons.

As a result, two lateral branches most often appear at the first undamaged node. The damaged part of the crop may also prolong its season. The impact on yield will depend on the size of the damaged area and the overall crop condition.

Hail damage is potentially the most severe. If hail damage occurs in a very young crop and all plants are injured above the cotyledons, no regeneration of any kind is possible. In that case, re-planting is the only option. When re-planting, attention must be given to the herbicides applied previously and varieties that are somewhat earlier-maturing should be used. If hail affects a crop at the stage where there are several leaves present and the lower nodes remain unaffected, regeneration will occur in most cases. The regenerated crop will take somewhat longer to mature than a crop that has not been affected, but the effects of hail damage will be mitigated considerably. Hail may destroy a portion of the leaf biomass or remove part of the stem. In the early stages of growth, leaf damage by hail will have little effect on yield, even when of greater severity. If hail damage occurs later in the season, the effect on yield will not be proportional to the severity of the damage. When up to 50% of plants are damaged by hail before flowering, the yields will drop by 6-14% depending on the initial plant density (USDA, 2007).

The biggest problems occur when hail damages the crop at the reproductive stages of growth, when the plants already bear flowers and the pods have been formed. According to USDA (2007), hail damage affecting 50% of the plants after full flowering reduces the yield by 28-35%. In addition, damage in the plants will cause retrovegetation, i.e. the appearance of new branches and new flowers, which prolongs the growing season significantly.

The issue of re-planting soybean is a very delicate one, because it depends on a number of interconnected factors, such as the stage of plant growth and development, the calendar date, weather and soil conditions, and the relation between the cost price of re-planting and the price of soybean yield (Roth et al., 2003). First of all, one must consider when the maturation of the re-planted crop can be expected. When making the decision on re-planting, the following procedure should be followed: make an estimate of yield from the regular planting at full plant density; determine plant density and distribution in a thinned-out crop; estimate the potential yield of the thinned-out crop; estimate the potential yield of the re-planted crop in conditions under which the new crop would develop (moisture, weeds, etc.); estimate all additional costs of re-planting; and compare the financial gains of the thinned-out and re-planted crops. The decision on whether re-planting would be justified or not should be made only after all this has been taken into consideration.

If the decision is not to go with re-planting, an effort should be made to help the damaged plants regenerate as much as possible. This is done through inter-row cultivation, which breaks up the crust that usually forms under such conditions. At the same time, it also destroys the weeds that have appeared in the meantime.

HARVESTING

Soybean harvesting is carried out at technological or technical maturity, which, according to Roth (2003), usually occurs 7-14 days after physiological maturity (R7). In commercial crops, physiological maturity starts at the point after which no further increases in yield occur. Between physiological and technical maturity, the grain dries out naturally in the field. This drying is a passive process, because the plant is already dead. The rate of drying depends primarily on weather conditions, i.e. temperature and precipitation. According to Hoeftu et al. (2000c), the water content may drop daily by up to 6%, with 3-4% being the usual rate. During drying, as the connection between the plant and its seeds weakens, seed losses occur in the field. These losses increase at harvesting, especially if the harvest is delayed.

Therefore, the yield may become significantly reduced in the field due to harvest losses, which is why harvesting is an important measure in soybean production. Shay et al. (1993) report results of many experiments according to which soybean yield losses at harvesting were up to 12%. According to the same authors, when the right adjustments are made, the losses may be reduced to 5%, which is considered acceptable.

Herbek and Bitzer note that the average yield losses at harvesting are 10%, ranging from 20% to 1-2%. The acceptable level of these losses is 5% or less and can be achieved by the correct adjustment of the combine and other measures. At a yield level of 3 t/ha, a reduction of the loss from 15 to 5% will result in 300 kg more of payable soybean being harvested. The authors have made a rough estimate according to which 16 seeds being found on an area of ¼ m^2 (0.5*0.5 m) translates into a yield loss of about 100 kg/ha. According to a three-year study by Philbrook and Oplinger (1989), delayed harvesting makes carrying out this operation more difficult and increases the loss of yield by 11 kg/ha, or 0.2%, with each day of delay. The average losses were 10%, ranging from 5.5 to 12.7% depending on the year. With timely harvesting, the loss was 6.1%, whereas harvesting delayed by 42 days increased the loss of yield to 13.7%. The percentage loss decreases with increasing yield level. It should be noted that precision adjustment and combining comes at no extra cost, so reducing harvest losses results in a direct increase of profits (Figure 9.6).

Harvesting losses must be borne in mind as early as when the soil is being prepared and the choices of variety and stand density are being made.

Losses at harvesting can be reduced if the dead furrows are closed in the autumn and if the plot is well smoothed out during seedbed preparation, which makes it possible to perform the cutting evenly and close to the ground, leaving as few pods as possible below the cutting height. If several pods, each containing two or three grains, are left unharvested on most plants, it is clear that the harvest losses resulting from this action alone will exceed the amount of seed used for planting several times.

Figure 9.6

Soybean harvesting *(photo: S. Stevanov)*

The correct choice of variety can also help reduce losses at harvesting. Knowing the capacity of the available equipment and the dynamics of the autumn farming operations, such varieties must be chosen that will reach maturity at a time when it will be possible to perform a timely harvest. Planting varieties from different maturity groups extends the duration of harvesting, so that each variety can be harvested at an optimum moisture level, which reduces harvesting losses (Herbek and Bitzer). If a mature crop is left on the field for a long time, pod dehiscence may occur and part of the yield can be lost even before the harvest. According to Hoeft et al. (2000c), it is precisely because of pod dehiscence that the largest losses of yield occur in the field, especially if there are sudden alternations between wet and foggy weather and weather that is warm or characterized by low relative humidity.

Resistance to pod dehiscence is variety-specific and is more common in earlier varieties because of their faster maturation. In varieties that take longer to mature and that become ripe in late autumn, when harvesting conditions are more difficult, it may become necessary to employ desiccation or dry out the moist grains. This nullifies the potential of the late varieties to produce higher yields. Stand density can also affect the quality of harvesting. In a thin stand, there is branching and pod formation at the lower nodes, which most often remain unharvested. In a stand that is too dense, increased lodging may occur, which also hinders harvesting. If provided with sufficient growing space, a soybean plant will form pods at the lowest nodes, which means that the height of the lowest pod will depend on the amount of space in which the plant grew. Among other things, optimum growing space is that space which enables the formation of the lowest pod at a height that will not cause harvesting losses, provided, of course, that the first pod is not formed too high, which would reduce total pod number and result in yield losses. A study has been carried out with 23 Novi Sad varieties and lines of soybean in order to determine the effect of first pod height on total harvest losses in commercial production conditions (Miladinović et al., 1996). The harvesting losses were very small, as low as 3.75%, while losses due unharvested pods were no more than 0.69% of the total yield. Based on this, the authors have concluded that harvesting losses can be reduced to acceptable levels by agricultural practices and that the genotypes involved in the study develop the lowest pods at heights that do not result in major yield losses..

Harvesting should start when the seed water content is at 13-14%. The harvest can also begin earlier, but in that case additional drying is required. Later harvesting increases yield losses and reduces soybean seed quality. According to Hoeft et al. (2000c), harvesting losses and seed damage are minimal at a moisture of 12-15%. Harvesting at moisture levels of over 18% is not recommended because of increased losses in the thresher, seed indentation, and seed coat damage as well as because of the high additional costs of drying (Herbak and Bitzer, 1997). According to Hurburgh (1995), the optimum seed moisture for soybean harvesting is 13-15%. Soybean can be harvested after the grains mature and the leaves fall off. At 18% moisture or more, however, the threshing is more difficult and many grains become dented. If moisture is below 13%, field losses due to lodging or pod dehiscence will increase, as will the losses at harvesting, which may be 10% or more. With each percentage point of decrease of moisture below 11%, the weight of payable soybean decreases by 1.15%. Under favorable weather conditions, grain moisture drops to 13% three to five days after the leaves fall off. This is the optimum grain moisture level for soybean harvesting and storage (Hrustić, 1998).

However, it often happens that, because of stress conditions during the growing season (drought and high temperature), the plant progresses through some stages of growth and development faster and reaches maturity earlier. Thus, it may happen that the leaves will remain on the plant hindering harvesting, although the pods may be mature and the grain of appropriate moisture. It may also happen that an already mature crop cannot be harvested because of rain or excess soil moisture.

Soybean grain is sensitive to impact, since the embryo sits just beneath a thin layer of pericarp and can be easily damaged by mechanical means. This sensitivity is affected by grain moisture content, so a grain with 8-10% moisture is much more sensitive to impact than grains having a moisture content of 11-15%. Damage occurring in the grain may sometimes not be visible, especially with moisture of over 15%, but such damage can significantly reduce germinability nevertheless. Hoeft et al. (2000c) argue that seed soybean should be harvested before seed moisture drops below 12% because of pod dehiscence and pericarp damage. According to Hurburgh (1995), seeds with a moisture content of less than 10% becomes very brittle and splits in half easily during harvesting and handling, so processing such seed soybean reduce germinability too. The new combine harvesters with axial mass flow damage the seeds only half as much as the combines with the classical method of threshing (Herbak and Bitzer; Taylor, 1997).

The reduction of soybean harvesting losses is significantly affected by how well adapted and adjusted the combine is to the plant, i.e. by the specific variety and field conditions. Thus, according to Roth (2003), harvesting losses will be reduced by lower combine speed, appropriate clearance and number of drum revolutions, appropriate adjustment of the sieve and air current, harmonization between peripheral winch speed and combine speed, and cutting that is as low as possible.

The largest harvest losses occur at the header and can reach up to 80% of the total losses, which is why these have to be given due attention. Soybean is easily threshed out of the pod. Its seed size and shape and the fact that the leaves fall off on the plot before harvesting enable easy separation from impurities, but poor adjustment of the combine to the crop and field conditions may significantly increase the losses (Bennett et al., 1999). For this reason, attention should be paid to the following adjustments during combine operation.

Combine speed should not exceed 5 km/ha, because at speeds above that the hoe does not manage to cut the stem; instead, it partially pushes it before cutting, thus increasing harvest losses. Combine speed should be reduced if the cut made by the hoe is too high and uneven and if the losses occurring at the hoe are large. If the crop is weedy, the speed can be less than 3 km/in order to avoid overburdening the combine and enable better threshout and clean up of the seeds.

The floating flexible header with automatic cutting height control makes possible copying the terrain in the direction of and transversely from the direction in which the combine is moving, resulting in lower cutting height, i.e. the collection of even the lowest pods on the stem. Compared with the classical header, the losses with this implement are smaller by 25-30%. According to Hoeft et al. (2000c), the total losses occurring when a well adjusted combine with this kind of header is used do not exceed 4%, as compared to 8-10% for the classical header. The cutting height is usually 5-8 cm, while cutting heights of 10 cm or more will already significantly increase the losses (the lower pods that are unharvested or cut).

A hoe that is sharp enough and well adjusted and narrower hoe points will result in greater cutting width and hence better operation at greater combine speeds.

The peripheral speed of the winch can be higher than the speed of the combine by about 25%, while the winch axis should be about 15-30 cm in front of the hoe.

The drum speed should be reduced to a minimum in order to enable threshing with as little seed damage as possible. Decreasing seed moisture decreases the number of drum revolutions and increases drum and concave clearances as well as the wind (Herbak and Bitzer, 1997). Mature soybean grains absorb and release moisture easily, so grain moisture will vary by up to several percentage points in the course of the day, which is something that must be kept in mind when adjusting the combine. Because of this, Heatherly and Elmore (2004) state that the combine should be adjusted at least twice a day (in the morning/evening and at noon) in line with the fluctuating seed moisture content. According to data provided by Hoeft et al. (2000c), the seed moisture content dropped from 15.3% in the morning to 9.9% at noon, as relative humidity decreased from 82 to 42%.

Harvesting should be completed as quickly as possible, starting at 15% seed moisture. If the seed water content is below 13%, harvesting should be done in conditions in which the pods are more elastic (fog, light rain, high relative humidity).

SUMMARY

High soybean yields require the harmony of all production factors. In practical terms, this means the right choices in selecting the plot and the most suitable crop rotation, then timely apply tillage measures, fertilizer, and, if necessary, weed control, and finally, promptly and efficiently harvest the crop. In addition, one has to know the variety and its needs in terms of plant density, nutrient requirements, and the depth and timing of sowing, so that edaphic, climatic, and genetic factors can all be broughy into harmony with the help of cultural practices. Carefully selected, and through the years proven cultural practices should be used to attain high yields, making sure that the fertility of the soil is maintained as well. Neglecting basic requirements in terms of cultural practices or reducing certain measures will inevitably lead to yield losses.

The failure to do something at a certain point during the prroduction cannot be compensated for later in the process without the loss of yields. If the soil has been badly prepared, one cannot achieve a good stand even if more seeds are sown. The late removal of weeds may make harvesting easier, but the damage has already been done, since the weeds have already destroyed part of the crop. The ommission of NITRAGIN will reduce yields or increase the costs by requiring the application of nitrogen. In order to attain high yields, therefore, due care has to be paid to each and every step in the production process.

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