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Five Decades of Soybean Research at Pantnagar (1967-2016)

G.B. Pant University of Agriculture and Technology
Pantnagar, Uttarakhand

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Directorate of Experiment Station
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Foreword

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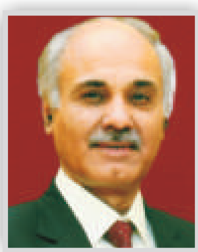
Dr. J. Kumar
Vice Chancellor



Soybean (*Glycine max* L. Merrill), otherwise known as a 'miracle crop' with over 40% protein and 20% oil, originated in China. However, centuries ago it was introduced to India through the Himalayan routes, and also brought in via Burma (now Myanmar) by traders from Indonesia. It has been traditionally grown on a small scale in Himachal Pradesh, the Kumaon and Garhwal Hills of Uttarakhand, eastern Bengal, the Khasi Hills, Manipur, and the Naga Hills. Locally it is referred as *bhat, bhatman, bhatmas, ramkulthi, garakalay*, and *kalitur.* It is a high value crop with multiple food, feed and industrial uses and plays a vital role in agricultural economy of India.

During 1960s several projects received synergistic support from agriculture industries and the Government, which not only ensured seed production, farm credit, irrigation water, fertilizer and pesticides, but also provided food storage and processing capacity to provide a market for the produce. The green revolution helped the country to become self sufficient in food grains with the introduction of dwarf wheat and rice varieties. At the same time the growing protein shortage became apparent due to stagnant pulse production. Thus during 1960s efforts were put forth to exploit the possibilities of cultivation of soybean on commercial scale in India. With the collaboration of University of Illinois, USA, in 1965-66, pioneering work on testing soybean varieties was initiated at GBPUA&T, Pantnagar along with JNKVV, Jabalpur. The encouraging results of some varieties, for example, Bragg and Hardee yielded 3-4 t ha^{-1} within 110-130 days. This prompted ICAR to initiate All India Coordinated Research Project on Soybean on April 1, 1967 with main centres at Pantnagar, Jabalpur and Delhi and several sub-centres across the country. With the help of germplasm received from USDA, Pantnagar soybean breeders developed high yielding varieties resistant to yellow mosaic virus and rust, the diseases which had caused a setback to soybean cultivation in early years in India. Till date, Pantnagar centre has developed 23 varieties of soybean having resistance to different diseases and/or insect pests. Besides varietal improvement, significant contribution has also been made over the past 50 years by agronomists, microbiologists, plant pathologists, entomologists of the university to build soybean research program at the national level.

Presently India ranks 4th in terms of global soybean area sown and 5th in terms of soybean production after USA, Brazil, Argentina and China. During 2016-17 the expected production of soybean in India is 14.125 million tonnes from 11.4 million hectare area with average productivity of 1.2 t ha^{-1}. The crop has potential of mitigating rampant protein energy malnutrition as well as becoming ideal food of the state as well as India on account of a number of nutraceutical and functional compounds.

I am happy that on the occasion of 47th Annual Group Meet of All India Coordinated Research Project on Soybean being held at GBPUA&T, Pantnagar on May 2-4, 2017, the soybean group of the University has compiled the work of 50 years on soybean carried out by dedicated researchers at Pantnagar in the form of Research Bulletin "Five Decades of Soybean Research at Pantnagar". I congratulate the authors of the research bulletin for this stupendous task and wish the dedicated team led by Dr. Pushpendra further success in their endeavour for increasing the productivity of soybean for substantiating food security, nutrition security and income security.

(J. Kumar)
Vice-Chancellor

Message

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Dr. J.P. Singh
Director

Soybean is a wonderful crop having high protein and oil content considered as functional food. It is being grown traditionally in various parts of the north India, particularly in hilly terrains of Uttarakhand, Khasi hills, Manipur and Naga Hills. The attention of the scientists and policy makers was invited to this crop in the light of the stagnated production of various pulses leading to protein deficits. The collaborative work of GBPUA&T, Pantnagar and JNKVV, Jabalpur in 1960s and subsequently with the scientists of the University of Illinois showed the potential of soybean cultivation in India. To strengthen the work in the arena in 1967 Indian council of Agricultural Research implemented an All India Coordinated Research Project on Soybean with three main centres and several sub-centres across the country.

Since 1965-66 the team of scientists of Pantnagar University has contributed significantly to the soybean research through developing improved varieties having resistance against various diseases and insect pests along with the contribution in the field of cultivation practices, plant protection and microbiology. It is a happy and proud moment that on the eve of completion of 50 years of research in soybean at Pantnagar we got an opportunity to hold the 47th Annual Group Meet of AICRP on Soybean. On this occasion the soybean team of Pantnagar has compiled the 50 years of soybean research in the form of Research Bulletin "Five Decades of Soybean Research at Pantnagar". I congratulate all the authors of this research bulletin for this achievement. I am confident that this publication will be of great help to researchers, agricultural officers, extension workers and others.

(J.P. Singh)

ACKNOWLEDGEMENT

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At the outset I take this opportunity to put on records the able guidance of the Hon'ble Vice-Chancellor, Dr. J. Kumar, for encouraging us to bring out the bulletin entitled “Five decades of Soybean research at Pantnagar (1967-2016)”, that highlights the major research accomplishments on Soybean crop of the University.

The information on research achievements, scientific findings, recommendations and technologies develop for soybean improvement compiled in this document are the outcomes of dedicated research efforts of the authors, technical staff and students in the field of Genetics and Plant Breeding, Agronomy, Soil Science, Plant Pathology and Entomology. I wish to thank past Breeders Dr. B. B. Singh, Dr. Hari Har Ram, Dr. B. V. Singh, Pathologist Dr. P. N. Tahapliyal, Agronomist Dr. A. S. Chandel, Microbiologist Dr. L. M. Pant and many others under whose leadership the earlier research work embodied in this publication most sincerely acknowledged.

I am grateful to the Director Experiment Station, Dr. J. P. Singh for extending help in publication of the bulletin on the occasion of Annual Group Meet of All India Coordinated Research Project on Soybean at the G. B. Pant University of Agriculture & Technology during May 2-4, 2017. His valuable suggestions and generous financial support in getting this document published through Directorate of Experiment Station are gratefully acknowledged. I am also thankful to Dr. D. S. Pandey, Dean, College of Agriculture for providing the assistance and facilities that has been very useful for preparation of this document.

My sincere thanks and appreciations are due to the members of present team of soybean scientists, technical staff and students who have not only contributed immensely to the research achievement compiled in the bulletin, but also in compiling the information for this research bulletin in their area of specialization.

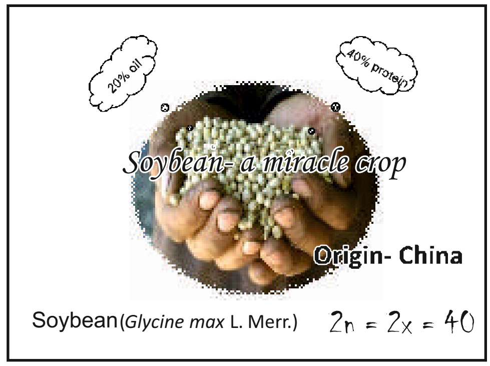
The financial support received from Indian Council of Agricultural Research in the form of AICRP on Soybean, ongoing bio-efficacy projects, sponsorship provided by Syngenta India Ltd., The Soybean Procedures Association of India, Indore, DuPont, S.P. SOLVENT P. LTD, Rudrapur, Bayer Crop Science Ltd. , Dhanuka Agritech Ltd., Ruchi Soya, Indore and Uttarakhand biotech council and other agencies, for organizing 47 AGM on Soybean is gratefully acknowledged. My thanks are due to Mr. Dharmesh Kushwaha, DPA for providing excellent assistance in typing the manuscript.

(Pushpendra)

Contents

Introduction 1

Soybean (*Glycine max* L. Merrill), popularly known as "Miracle bean" is the single largest oil seed producer crop in the world. It contains well balanced 40% protein (Lysin rich) and 20 % oil enriched with essential fatty acids. Also, it contains isoflavones which protect human body against the cancer, diabetes, osteoporosis, blood pressure, coronary heart disease etc. Globally soybean is used as main source of oil and De Oil Cake (DOC) being used for animal feed as well as food processing unit for food product development. The cultivated soybean originated from its wild ancestor *Glycine ussuriensis*, which is presently known as *Glycine soja*. Soybean is native of China from where it migrated to neighboring countries with the development of sea and land trades during early seventies.



History of Soybean

The oldest description of soybean can be traced back 3000 years ago in the Zhou Dynasty of China. Ancient Chinese literature, however, reveals that it was extensively cultivated and high value as a food for centuries before finding place in literature. It has considered as one of the grains planted by Hou Tsi, a good of agriculture. This crop is known to have been cultivated in China for more than 4000 years (Hymowitz, 1970). The first written record of the plant is contained in Materia (Pen Ts'ao Kong Mu) written 5000 years back, describing the plants of China written by Emperor Sheng Nung in 2838 BC. This document also briefs on the utility of soybean as a staple dietary item in China for more than past 7000 years (Morse and Cartter, 1937; Lal, 1968). The crop had a status of the most important cultivated legume and one of the five sacred grains or 'We Ku' (rice, soybean, wheat, barley and millet) essential to the existence of Chinese civilization. The Emperors of China sowed seed of the plant yearly with great ceremonly, and poets extolled its virtues (Lal, 1968; Gibson and Benson, 2002). The records of methods of culture, varieties for different purposes, and numerous uses indicate that the soybean was perhaps one of the oldest crops grown by man (Morse and Cartter, 1937). In Chinese writings, soybean has been referred as 'soja' or 'soya' might have been derived from these. Long before the dawn of civilization, primitive man is believed to have made free use of wild soybean seeds.

Origin and domestication

According to Goldblatt (1981), based on a basic chromosome number of x =10 is proposed for cultivated soybean. It is hypothesized that a putative ancestor of genus *Glycine* with 2n=2x=20 arose in Southeast Asia (Singh *et al*., 2001); however, such a progenitor has either become extinct or yet to be collected. Tetraploidization (2n=4x=40) through auto or allopolyploidy occurred in the progenitor species either prior to or after dissemination from the ancestral region. The progenitor of wild perennial species spread southward to Australian continent and northward to China adapting to ecological niches. The wild perennial species, which evolved on Australian continent, were not domesticated. The path of the migration northwards towards China from a common progenitor is assumed by Singh *et al*. (2001) as; wild perennial (2n=4x=40; uncommon or extinct) – wild annual (2n=4x=40; *Glycine soja*) - soybean (2n=4x=40; *Glycine max* cultigens).

The place of origin of the cultivated form of soybean is still argued though Piper and Morse (1923) reported it to be a native of eastern Asia. According to them, *G. soja* the progenitor of *G. max* was known to occur in China, Manchuria, and Korea. Fukuda (1933) argued that Manchuria is the center of origin as (i) *G. gracilis*, a closely related species is distributed widely in Manchuria; (ii) numerous soybean varieties are grown in Manchuria; and (iii) many of the varieties have primitive characteristics. Vavilov (1949/50) considered Central Western China as the center of origin for soybean. Nagata (1959, 1960) indicates that the center of origin was most probably China proper, especially in North and Central China. According to him the cultivated soybean (*G. max*) has originated from its ancestor *G. soja*, which is found wild in China, Korea, Manchuria, Taiwan, and Japan throughout the Yangtze River valley, the Northeastern Provinces of China and the adjacent areas of USSR (Fig. 1). The Yellow River region in China is generally considered as origin center of soybean based on the existence of a great number of wild soybeans and the earliest record of soybean in China (Hymowitz and Kaizuma, 1981; Wang and Wang, 1992). More recently the real picture of origin of genus *Glycine* is depicted by Hymowitz (2004).

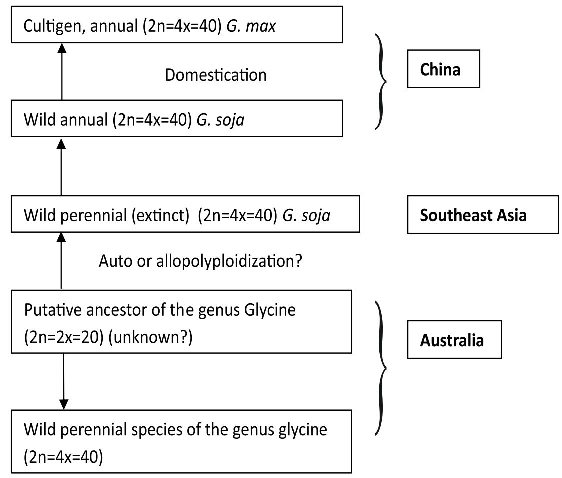


Figure 1: Origin of genus *Glycine* (Source: Hymowitz, 2004)

The best evidence available on the antiquity of the soybean has been found from analysis of the picot graph 'shu' for the soybean found in the Book of odes and Bronze inscriptions. These evidences provide a clue that the process of domestication could have undergone by the soybean during the Shang Dynasty which preceded the Chan Dynasty, or even earlier. Hu (1963) reported that the cultigens soybean (*Glycine max*) appears to be domesticated by the farmers in the eastern half of northern China during the dynasty (1550-1027 BC) or perhaps earlier. Experimental studies on the time taken for a crop to respond to selection pressures under domestication to the level of refinement when it is readily accepted by others outside its area of natural occurrence gained importance only a few decades ago (Oka and Morishima, 1971).

Linguistic, geographical, and historical evidences suggest that the soybean emerged as domesticated around the 11^{th} century BC in the eastern half of north China. Domestication is a process of trial and error and not an event. In the case of the soybean the process of domestication probably took place during the Shang dynasty (c. 1700-100 BC) or perhaps earlier. By the first century AD the soybean probably reached central and south China, as well as peninsular Korea. The movement of the soybean within the primary gene center is associated with the development consolidation of territories, and degeneration of Chinese dynasties (Hymowitz, 1997).

Soybean Migration

Soybeans were introduced into several nearby countries from about the first century AD to the age of discovery (Singh, 2006) with the development of sea and land trades, probably in the 7^{th} century and land races were developed in Japan, Indonesia, Philippines, Vietanam, Thailand, Malaysia, Burma (Myanmar), Nepal and North India. These regions comprise the secondary gene center. Soybean was introduced into neighboring countries (Japan, India, Nepal and Russia) around the first century (Wang and Wang, 1992; Gai, 1996). It appears that missionaries may have been the first to bring the soybean to Europe early in the 18^{th} century (Hymowitz and Newell, 1981). The movement of the soybean throughout this period was due to the establishment of sea and land trade routes, for example the silk route the migrations of certain tribes from China, for example the Thais; and the rapid acceptance of the plant as a staple food by other cultures, for example the Indonesians. Although many different foods were developed from the soybean the four most important are miso, soy sauce, tempeh and tofu in Japan. These traditional foods have little physical or flavor identity with the original bean. Thus it is not too surprising that the first Europeans who visited China or Japan did not mention the soybean as a crop in their journals for example Marco Polo (Hymnowitz, 1997).

The soybean was imported to America around 1766 by Samuel Bowen, a British seaman who grew a soybean crop on his farm in Georgia (Anonymous 1993). Although the soybean was first mentioned in US literature in 1840 the expansion of soybean production in USA did not come about until the third decade of the 20^{th} century. Soybean was first introduced to North America in 1765 (Hymowitz and Harlan 1983) and then spread to Canada and Latin America. The earliest known date for introduction into Brazil is 1882 (Hymowitz 1976).

Success Story

The success story of soybean production was initiated in 1963-64 when Mr. Edwin Bay, USAID/Illinois team, Extension advisor obtained yield of 0.68 t ha^{-1} in 1965. Dr. Earl Leng and Dr. S. D. Buddemeier both agronomists from University of Illinois, USA did more extensive trials using US soybean at UP Agricultural University, Pantnagar (now Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar, Uttarakhand and JNKVV, Jabalpur, Madhya Pradesh, respectively and demonstrated promising yields (1.44 t ha^{-1} at Pantnagar and 1.57 to 1.64 t ha^{-1} at Jabalpur). Subsequent trials during 1966 established agricultural feasibility of soybean in India with yields up to 3-3.6 t ha^{-1}, which was higher than average yield in USA (1.87 t ha^{-1}) at that time. The additional impressive fact was the drastic reduction in maturity period to 100-125 days as compared to 134-139 days in southern USA and Brazil.

Although these exotic introductions performed extensively well in Madhya Pradesh and Uttar Pradesh with yield levels between 1.5 and 3.0 t ha^{-1}, the crop suffered from limitations of adaptability, seed viability, and susceptibility to yellow mosaic virus (Menon, 1985). Nevertheless, considering the yield potentials and nutritional richness and impetus from the general food security particularly protein and edible oil in India, a fresh attempt was initiated to popularize soybean. In 1967, Indian Council of Agricultural Research (ICAR) launched interdisciplinary multi-location trial in All India Coordinated Research Project on Soybean (AICRP-Soybean) with cooperating centers spread all over the country. The success of AICRP-Soybean in identification and development of high yielding varieties (> 110 at present) and standardization of production technology suitable for different agroclimatic conditions of the country was phenomenal which resulted in substantial increase in negligible area in 1968 (3000 ha) to about 2.2 million hectare by 1991to about 11.4 mha at present.

To further strengthen the soybean research, with basic technologies and breeding material, ICAR established National Research Centre for Soybean (NRCS) in the heart of soybean state Madhya Pradesh at Indore in 1987. At present 8 main centers, 14 sub-centers, and 111 other need based centers are working under AICRP (Soybean). The ICAR also launched a soybean processing and utilization project at Bhopal in 1983-84 under Indo-US agricultural sub-commission on agriculture. Once convinced about the bright prospects of soybean in India and initiation of systematic research through these establishments, the research information started flowing in on various aspects of production and crop improvement and the area under soybean increased at a spectacular growth rate. At present, the well-established crop covers more than 11 million ha in India. Looking at the potential of the crop in non conventional regions and the growth pattern in major soybean command area over the years, it has been projected that the area under the crop is estimated to stabilize around 12-13 million ha (Billore and Joshi, 1998) in near future with expected production of about 16-18 million tonnes. The projected expansion appears to be logical as the overall compound growth rate in area and production works out to be above 20% (Sadeesh *et al*., 2006) for the period 1971 to 2003, which is highly significant. The simple growth rate in area works out to be 0.32 million ha per annum.

Soybean in India

The opinions on introduction of soybean in India are not coherent since there is probably no mention of soybean in the ancient Indian literature. Soybean introduction to Indian subcontinent is date back to 1000 A D (Hymowitz and Kaizuma 1981). The crop is thought to have been introduced in northern half of the Indian subcontinent from Central China and entered through the silk route running across the top of the Tibetan Plateau and subsequently to northern India from the northwest or directly through the northeastern region of India (Assam) and Burma (Tedia *et al*. 2001). Soybean was thus adopted for cultivation in foothills or in Manipur. It is belived that this crop reached India through Chinese vistors in 1882 (H.K. Sharma, Jawaharlal Nehru Krishi Vishwa Vidyalaya JNKVV, India, and Personal Communication 2002). Cultivation of black seeded soybean in Naga Hills was practiced. The black seeded soybean has been traditionally grown in North and northeastern regions of India and further spread to different parts of the country. This black seeded soybean, Kalitur, was the vehicle for soybean revolution in India. Soybean as food plant is being grown in the country since last century under various names in different parts of the country as Bhat, Bhatman, Bhatmas, Ramkulthi, Bhut, Kalitur, Teliakulth and Garryakalay (Singh and Saxena, 1979). The versatile adoption of soybean was adjudged and conceived that it can be grown successfully in areas wherever the rainfall does not exceed 35 inches. Hence the extensive growing of soybean was feasible throughout India, chiefly in the North Indian tract extending from Punjab to Khasi and Manipur Hills in Assam and in Sindh. It was also grown on the slope of the Himalayas up to an altitude of 6000 feet in Uttar Pradesh, Uttarakhand, Bihar and West Bengal.

Hymowitz (1969) postulated that the soybean is a recent introduction to India. His hypothesis is based on the fact that soybeans are not used in any of the indigenous systems of medicine or in any religious ceremonies of any of the major religions in India. He further stated that it was probably introduced into India from Burma via Naga Hills and Manipur. But the fact that a small black seeded variety was grown since 1882 at Nagpur farm of erstwhile Central Provinces indicates that the crop was introduced in India much earlier. Other authors suggested that the crop has been in India for a long time and perhaps was introduced directly from China (Motiramani *et al.*, 1972). Lal (1968) also reported that investigations of Hooper (1911) and Woodhouse and Taylor (1913) showed that soybean was cultivated from the borders of Afghanistan eastward to Burma. Although time of introduction of soybean into India and USA is more or less same, however it could not be so much popular in India because of certain problems within the cultivars.

Although not many references of soybean are available in earlier literature, its cultivation was possibly age old in hills of Assam, Bengal, Manipur, Khasi and Naga hills as well as hill region of Kumaon (CSIR, 1956). However, William (1832) mentioned about the cultivation of soybean in India in 1798 for which the source was Moluccas (today’s Indonesia) because of better quality of terrain (Anoymous, 1909).

Even though the earlier attempts to popularize soybean cultivation were not encouraging the work carried out at Sehore (1909-10), Assam (1913), Orissa (1918), Pusa (1923), Baroda (1933-35) and Uttar Pradesh (1934-35) paved the way for soybean cultivation in India (Kale, 1936; Kaltenbach and Legros, 1936). The subsequent attempt at Yavatmal (Maharashtra) in 1953-63 and at Jabalpur as well as Pantnagar (1963-64) reconfirmed the possibility of commercial cultivation of this crop under Indian conditions.

The major initiative on soybean cultivation was undertaken during 1963-64 under the ageis of Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar and Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur in collaboration with University of Illinois, USA. The cultivation was further picked up after the researchers took advantage of yellow seeded material to develop high yielding varieties that suited Indian conditions. Soybean cultivation picked its momentum during the 1970s as the vast monsoon fallow lands of Madhya Pradesh provided appropriate niche for its cultivation. Presently it is cultivated on nearly 11.4 million ha land with likely production of above 14.125 million tonnes. At the global level India ranked fourth and fifth in terms of area and production, respectively. It has acquired premier position in oilseed production in the country. It plays a significant role in national economy by amending about 30% of the edible oil produced in the country and fetches around Rs. 40000 million foreign exchange by way of export of soya meal. Such a high striking growth rate is yet to be experienced in India for any other crop. On account of its resilience to withstand aberrant climatic conditions and it's contribution to transform socioeconomic conditions of Indian farmers, the crop has come to stay in India. Based on the analysis of continued unabated growth, it is projected that the area under the crop will stabilize around 12 to 13 million ha in near future. Soybean is not only the number one oilseed crop of the world, but also of India. Among the major oilseeds-soybean and sunflower –introduced for commercial cultivation in late 1960s, soybean has exhibited unparallel growth in area and production during last 57 years.

Most of the people consider soybean crop as an introduced one in spite of evidence of acquaintance of cultivating soybean as a crop plant since ages in India. Indian subcontinent is the secondary center for domestication of the crop after China (Hymowitz, 1990; Khoshoo, 1995; Singh and Hymowitz, 1999). Introduction of soybean to Indian subcontinent dates back to 1000 AD through silk route from northeastern India and Himalayan mountains.

Taxonomy of soybean

The genus *Glycine* (wild soybean) is a member of family leguminosae and tribe Phaseolae. The phaseolae is one of the most economically important tribe of leguminosae. *Glycine* has a confused taxonomic history from its inception. The name *Glycine* was first introduced by Linnaeus in the first edition of his Genera Plantarum. *Glycine* is derived from the Greek Glykus and probably refers to sweet tubers produced by *G. apios*, which he classified in this genus. Linnaeus listed eight *Glycine* species in the species Plantarum of 1759. All of these were subsequently moved to other genera.

Soybean was described by Linnaeus both as *Phaseolus max* based on the specimens has seen and *Dolichos soja* based upon the description of other writers. Since then correct nomenclature of the soybean has been the subject of much debate (Ricker and Morse, 1948). Currently the classification of *G. max* proposed by Merrill in 1977 is widely accepted.

Hermann (1962) published a revision of genus *Glycine* and its allies. According to his classification genus *Glycine* consisted of three subgenera: (i) *Leptocyamus* with six Australian species; (ii) *Glycine*, which included complex from Southeast Asia and Africa; and (iii) *Soja* which comprised soybean and its wild annual counterpart described as *G. ussuriensis* by Regel and Maack (1861). Verdcourt (1966) revised this classification putting species earlier included in subgenus *Leptocyamus*, in subgenus *Glycine*. He reclassified subgenus *Glycine* as *Bracteata* and renamed the only species *G. javanica* of erstwhile subgenus *Glycine* as *G. weightii*. Verdcourt (1970) proposed that wild annual relative of soybean be designated *G. soja* as described by von Siebold and Zuccarini (1846).

The genus *Glycine* as currently delimited is divided into two subgenera viz., *Glycine* and *Soja*. According to Hymowitz (2004) the subgenus *Glycine* comprises 22 wild perennial species. The subgenus *soja* includes *G. max* (L.) Merrill and its wild annual counterpart *G. soja* Sieb. and Zucc. The subgenus *soja* contains in addition, a form known as *G. gracilis*, which is somewhat intermediate in morphology between *G. max* and *G. soja*. Hermann (1962) considered *G. gracilis* a form of *G. max* with some *G. soja* genes.

Botanical Description

(a) Root: It consists of a tap root and a large number of secondary roots which are further divided into several smaller roots. The bacterial root nodules are visible after about 20 days of planting fixes the atmospheric nitrogen.

(b) Stem: The stem is usually erect (50-200 cm) in height. In wild and indeterminate soybean the stem may be prostrate / trailing / wining type. Stem sparsely or densely branched, sparsely or densely pubescence.

(c) Growth Habit: There are three discrete phenotypes based on stem termination (determinate, semi-determinate and indeterminate).

i. Determinate: - stem growth terminates abruptly at onset of flowering. These produce a short stem with few nodes comparatively long inference at terminal node.

ii. Semi determinate: - Stem growth terminates fairly abruptly after a period as long as that of indeterminate plants. It poses a long tapering stem but distantly shorter and thicker at the tip than the inveterate and with a few lines nodes. There is normally a fairly long inflorescence at terminal nodes.

iii Indeterminate: - Flowering begins before stem elongation ceases. Flowers are born on auxiliary's racemes. The stem and the upper leaves become progressively smaller towards the very slender top internodes. The number of pods per node usually decreases near the top at terminal node.

(d) Soybean Growth Stages: There are two growth stages in soybean vegetative and reproductive. The various stages are given below-

Vegetative stage	**Reproductive stage**
VE-Emergence	R1-Begin bloom
VC-Cotyledons	R2-Full bloom
V1-First node	R3- Begin pod
V2-Second node	R4- Full pod
V3-Third node	R5-Begin seed
———	R6-Full seed
———	R7-Begin maturity
V_n-n^{th} node	R8-Full maturity

(e) Leaf: There are four kinds of soybean leaves: (i) The first pair of simple cotyledons or seed leaves. (ii) The second pair of simple primary leaves. (iii) Trifoliate foliage leaves and (iv) Prophylls

The simple leaves are oppositely arranged. They occur at first node above the cotyledons, the trifoliate leaves are arranged alternately. The prophylls occur as first tiny tare of simple leaves at the base of each lateral branch.

(f) Inflorescence: In indeterminate soybeans, the inflorescences are axiliary racemes and at maturity plant has a sparse and distribution of pods on all branches. The stem may appear to have a terminal inflorescence crowded together by the very short internodes at stem tip. The determinate soybeans have both axiliary racemes and a terminal raceme. At maturity pods are distributed along the stem. About 20-80 % of the flowers drop depending upon the cultivars. In general, the earliest and latest flowers produced drop often.

(g) Flower: Soybean has a typical papilionaceous flower with a tubular calyx of five unequal lobes. The corolla consists of posterior banner petal, two lateral wing petals and two anterior keel petals. The keel petals touch each other, but are not fused. The 10 stamens (androecium) are in diadelphous pattern (9+1). The single pistil is unicapellate and has one to four campylotropous ovules. The style is about half the length of ovary and curves backward toward the free posterior stamen. The stigma is capitate. Hairs are present on the pistil, and the outer surface of the calyx tube.

(h) Pod: The number of pods varies from two to more than 20 in a single inflorescence and up to 400 on a plant. Number of seeds per pod varies from one to five but two to three seeds per pod are common. The pods are straight or slightly curved and the colour may vary from light yellow to yellow grey, brown, or black.

(i) Seed: The mature seed is devoid of endosperm. A large embryo (two large fleshy cotyledons, a plumule with two well developed primary leaves and a hypocotyl-radicle axis) is surrounded by seed coat. The seed coat is marked with hilum (seed scar varying in shape from linear to oval). At one end of the hilum, there is a tiny hole formed by the integuments. This is called micropyle. The tip of the hypocotyls-radicle axis is located just below the micropyle. At the other end of the hilum, there is a small groove extending to the chalaza. This is known as raphe. The seed shape is usually oval but may vary from almost spherical to strongly flattened and elongate. The seed coat colour may be yellow, green, brown, black and solid coloured, bicoloured or variegated. The details of the vegetative and reproductive morphology including anatomy of soybean are available in Carison and Lersten (1987).

(j) Emasculation and Pollination: The pollination often occurs before the opening of flowers. The pollen does shed directly on stigma. Due to cleistogamy nature of flower, there is a very high percentage of self-fertilization in crop. The natural out-crossing is generally less than 1.0%. The time from pollination to fertilization is within 8-10 hours. The day of opening of flowers is likely on the day of fertilization or one day after it. Special care is needed while emasculating the flower buds as they are very small. A floral bud at the appropriate stage is swollen and the corolla is visible through the calyx. Five sepals are removed with forceps to expose the corolla. Corolla is removed with forceps by jerking one stroke operation. In this process, 10 stamens are usually removed and if a few are left; they are removed with the help of forceps. Pollination is carried out immediately after emasculation. Open flowers are collected from male parent. Corolla is removed and the emasculated flower bud stigma is brushed with the anthers of the male flowers. A pod is visible in about seven days after pollination.

Microbiology

Soil microflora in the rhizophere plays a vital role in dictating the growth and yield of the plants as it is known that the soil microbes dictates the various biogeochemical cycles and also the ecology. The symbiotic association between legumes and a diverse group of bacteria belonging to the genus *Rhizobium* is of enormous practical importance to agriculturalists as well as ecologist around the world.

With respect to soybeans, when cultivated for the first time in the field they did not formed the nodules on its roots, either due to lack or very low number of the specific *Rhizobium,* depriving the plants from the benefit of symbiotic association in terms of the fixed nitrogen. The threshold population of rhizobia in soil needed for maximal dry matter production and N accumulation in legumes is widely believed to be around 10^3 colony forming units (cfu) g^{-1} soil. Biological nitrogen fixation makes a very crucial and important contribution to the nitrogen economy of soybean-based cropping systems. *Bradyrhizobial* inoculants were introduced along with soybean cultivation during sixties and seventies of 19^{th} century. The inoculation of legumes with specific, efficient rhizobial inoculants significantly reduces the applications of expensive chemical nitrogen fertilizers. However, in soils containing compatible, naturalized rhizobia the efficiency of the symbiosis cannot be ensured with seed inoculation due to competition for nodule sites between indigenous and inoculum rhizobia, thus there is a continuing need to look for the more efficient and competitive rhizobial isolates for different legumes. Similarly, inspite of inoculation with rhizobial inoculants over the years the inoculation of soybean with *Rhizobium* every year benefits the crop. The combined effect of high temperature and desiccation on survival of rhizobia is harsher than their individual effects (Raverkar *et al.,* 2005).

Various plant growth promoting rhizobacteria are also known to influence the growth of soybean plants vis-à-vis production because of their ability to synthesize various plant growth substances, HCN, and various enymes to mitigate an array of biotic and abiotic stress. Differnet varities support the variable microflora and interactions in their rhizosphere.Thus rhizosphere microbiology of various soybean lines/ varities could be one of the factors to consider in breeding programme for the development of varities to derive the optimum benefits of microbe-plant interaction.

Utilization of soybean

The crop is known for its high food value from centuries and it was used for food purposes like milk, douche, hamanatto, miso, shoyu, doufu, natto, tempeh, soya flour, green beans, roasted soy nuts, and soybean sprouts with the dawn of civilization. For Asians who did not drink animal milk due to lactogen intderence the soybean quickly became indispensable. The beans, which were soaked in water to yield a white liquid, were known affectionately as 'The Cow of China'. Soya flour, powder, or curd were fermented to make miso (soy paste), shoyu (soy sauce), doufu (soy curd), natto (soy cheese) and tempeh (a soybean cake invented in Indonesia), as well as yuba, kinak, hamanatto, and kochu chang. Steamed green beans, roasted soy nuts, and soybean sprouts were also favored and were highly nutritious (Warshall and Imhoff, 1999).

Around the 7^{th} century AD, Japan's miso tradition emerged. Miso seems to have evolved from chiang, a soybean paste that Buddhist monks brought from China, and jang, a similar soybean product that Korean farmers introduced to Japan's countryside. Miso tradition emerged. Miso remained a delicacy of the privileged classes made almost exclusively by monks until the 10^{th} century. Today, while miso is served throughout the country in households nearly every day as a broth for soup, or a dressing or sauce for grilling fish and other meats. It's production has been largely relegated to giant factories (Warshall and Imhoff, 1999). It is used as alternative in the preparation of meat and cheese in the western countries due to its high protein content and thus historically soybean has been recognized as "meat of the field" or "meat without bones".

Production of Nucleus and Breeder Seed

Seed production of soybean has several problems. Soybean seed is classified in the least storable group. Besides its inherent low viability, soybean seed is also highly prone to mechanical injury during processing and transportation. The seed is so sensitive that even before its harvest; it can be adversely affected by field weathering. These factors affect seed germination and vigor severely and at times even maintaining the minimum germination standard (70 %) till next season becomes difficult. The seed multiplication ratio in soybean is very low (1:10) and this coupled with high seed requirement, from the major bottleneck in augmenting the availability of quality seed. Further, large quantities are prone to be rejected as either being undersized or on the basis of presence of other distinguishable varieties (ODVs).

The availability of breeder seed of high genetic purity determines the success of entire seed production programme. Breeder seed should be genetically so pure as to guarantee that subsequent generation i.e. foundation seed conforms to the prescribed standards of genetic purity. The production of nucleus and breeder seed is personally supervised by a qualified plant breeder. The genetic purity of breeder seed is maintained by the nucleus seed. Nucleus seed is itself produced by bulking the genetically pure and 'true to type' single plant progenies. The norms of genetic purity can only be ensured by applying rigorous efforts and uniform seed production techniques. The guidelines for efficient production of nucleus and breeder seed are as below:

Nucleus seed production (stage I)

Base population

Natural population of most autogamous cultivars is made up of mostly homogenous plants. Oka (1975) has suggested that population size suitable for maintenance and seed production of a self-pollinated species should be 300 plants. However, for soybean crop it is better to start with higher number.

In soybean, a minimum of 500 plants should be selected for planting progeny rows. The plants should be selected uniformly true to the type from the entire population of breeder/nucleus seed plot of one acre (0.4 hectare). The actual number of plants to be selected will depend upon seed multiplication ratio and target quantity of breeder seed. The source of base population for pre-released varieties may be plots of advanced varietal Trial II. The steps involved in nucleus seed production are given in Fig. 2.

Selection from base population

The selection of plants should be on the basis of morphological identity, uniformity and genetic purity. The selected plants should be true to type of the variety.

Harvesting/threshing of single plant

The plants are harvested at the time of maturity and dried for two to three days in the field. Thereafter they are tied in bundles of 50-100 plants and allowed to shade dry for 4-5 days. Individual plants are threshed manually to avoid mechanical damage and mixture to the seed. The seed is kept in paper packets and dried as to 9% moisture before storage.

Table examination of seed

Individual plant seeds are examined for testa color, hilum color, seed size and seed shape. The seed of any plant not conforming to the standard is rejected. Hilum color in soybean is subject to occasional variation; therefore any variation from the original variety should be specially looked for and discarded. The seeds with poor appearance and showing symptoms of seed borne diseases (purple seed stain and Soybean Mosaic Virus) should also be discarded. Properly labeled seed packets are kept in cloth/gunny/polythene bags and stored at 25°C with 50-60% RH.

Sowing of nucleus seed

The nucleus seed plot should be well drained, clean and fertile. It should be free from volunteer plants. The single plants seed should be sown in single rows of 3 to 5 meter length. The distance between rows should be 45-60 cm.

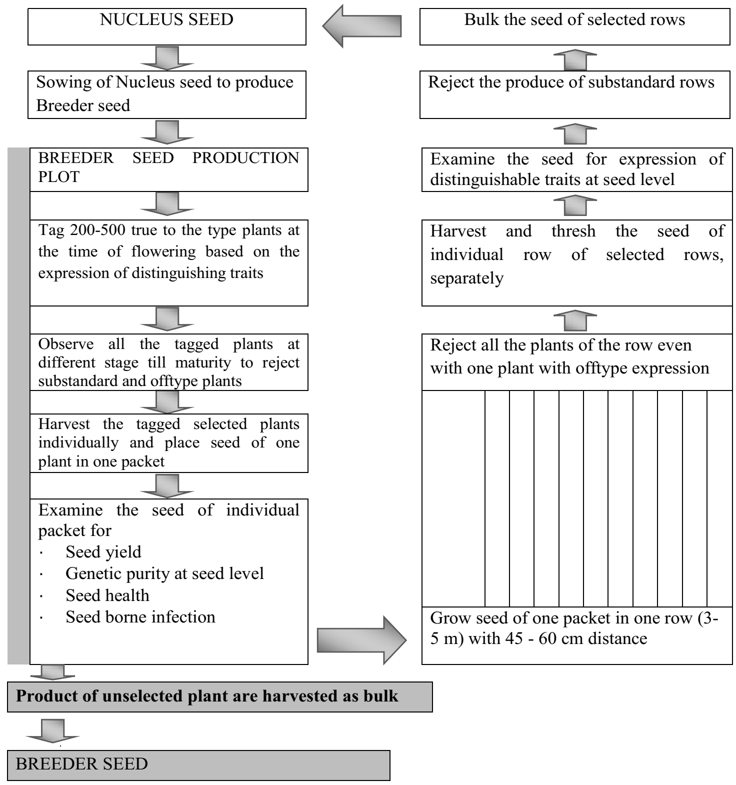


Fig. 2: Sketch diagram of nucleus and breeder seed production

Sowing season

The normal planting season for soybean is *kharif*. The plot should be sown during the optimum period recommended for respective location. Soybean is a photo-sensitive and short day crop. Delay in sowing results in forms of poor growth and early flowering particularly in determinate growth habit varieties.

Agronomic practices

The plot should received farm yard manure @ 10t/ha. It should be fertilized with 20:60:40:25, N: P_2O_5: K_2O: S and Phorate 10 G @ 10 kg/ha be applied in the furrows at the time of sowing. The seed should be treated with Thiram + Carbendazim (2:1) @ 3g/kg seed followed by inoculation with *Rhizobium* culture @ 5 g/kg seed. The seed should be hand dibbled at 5 cm distance in the rows. Preventive measures should be taken to control insect pests and disease. To control the seed borne fungi 2-3 spray of Carbendazim @ 0.05% or Mancozeb 70 WP @ 0.25% should be sprayed at R_2 (full bloom) and R_6 (full seed development) stages.

Observation of progeny rows

The progeny rows are continually examined for various characters throughout the growing season. The characters, their stage of observation and variation expected are shown in Table 1. The entire rows with off type plants are rouged. If off-type is detected after flowering, adjoining rows are also removed. The purified single plant progenies are harvested in bulk.

Harvesting and threshing

The crop should be harvested when the seed moisture is 17-18% without delay to avoid shattering and prevent seed deterioration due to field weather. It should be threshed manually at 13-15% seed moisture to minimize mechanical injury to seed. The cleaned seed should be dried to moisture of 8-9% before storage.

Nucleus seed production (stage II)

The bulk of individual plant progenies in soybean are often designated as generation zero (G_0). When the demand of breeder seed is limited, this seed can be used directly for growing breeder seed. In case large quantities of breeder seed are required, this seed should be used to grow nucleus seed stage II. The seed is sown in plots of 5 meters width with a tract of 1 meter. The seed rate is kept at 80% of recommended for commercial crop. The crop is grown with standard package of practices. The plot is regularly examined throughout growing season. The rest of the practices are same as in nucleus seed stage I.

Storage

The storage of soybean seed needs special attention and care. The reduction in seed viability is very fast if seed is stored under high temperature and humid conditions. To maintain the viability of seed for 8-9 months, it should be stored at 20-25^0 C temperature and 50-60% RH with 9-10 percent seed moisture.

Breeder seed production

Seed source

The seed source for breeder seed is nucleus seed. It could be nucleus seed stage I i.e. bulk of true to the type single plant progenies or nucleus seed stage II. In exceptional circumstances breeder seed stage I can be used to produce breeder seed provided that the genetic purity is maintained up to the mark.

Season, sowing time and isolation

Soybean is predominantly a *kharif* season crop in India. Optimum planting dates are those that result in prompt emergence and longest vegetative period for adapted cultivars. The most appropriate sowing period for pre-monsoon planting with irrigation is second week of June to second week of July. The planting time in central and southern zones should be completed by first week of July, while in northern plain zone; the optimum time extends up to second week of July. Whereas, in Northern Hill Zone' planting should be completed up to last week of June.

Soybean being a highly self pollinated crop without crossing of less than 1%, the minimum isolation distance required is 3 m.

Seed rate, agronomic management

Seed rate is directly related to plant population which determines the yield. The recommended plant population for grain crop is 3-4 lakhs /ha in different zone, and 4.0 lakh/ha in northern zone. The seed rate to obtain this population is dependent upon seed index and germination percentage. The seed requirement is 65, 80 and 100 kg/ha for small, medium and bold seeded varieties, respectively.

Generally, for every 1 g increase in seed index, the seed rate should be increased by 5 kg. For seed crop production purpose only 80% of the commercial seed rate is to be used. These seed rates are based on 70% germination. The seed rate can be adjusted according to the actual germination percentage of nucleus seed.

Land

The field for breeder seed production should preferably be one compact block, well leveled and well drained. The field should be free from volunteer plants. After field preparation, recommended basal dose of manure and fertilizer should be applied before planting.

Sowing

The seed should be treated with Thiram + Carbendazim (2:1) @ 3 g/kg seed to prevent seedling rot and ensure good stand. This should be followed by inoculation with *Rhizobium* culture @ 5 g/kg seed. The seed plot is sown with a cleaned seed drill in rows 45 cm apart. The seed should be placed at a depth of 3-5 cm. The shallower depths are recommended for heavy and / or wet soils and deeper depth are chosen for dry / light soils. A gap of 1 m is kept after every 18-20 rows for inspection of the plants. The agronomic practices, like weed management, inter-culture operations, disease and pest management should be as per the local recommendations.

Stages of field inspection/rouging

The inspection of breeder seed plot should be undertaken at 3 stages. First inspection should be conducted at flowering stage, second at pod filling and third at maturity stage. The off type plants are identified on the basis of cultivar character enumerated in Table 1 and rouged out. The rouging should be carried out under the supervision of plant breeder and rouged plants should be removed from the field.

Inspection by monitoring team

The breeder seed crop should be monitored twice, first at the time of flowering and second at the time of maturity by certification team.

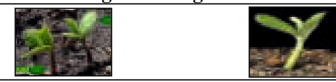
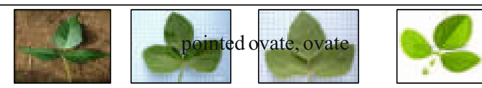
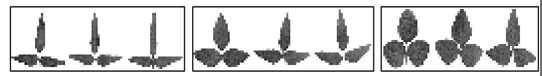
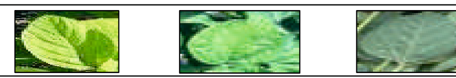
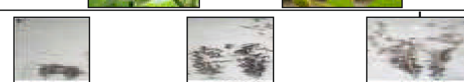
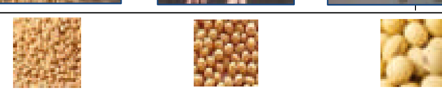
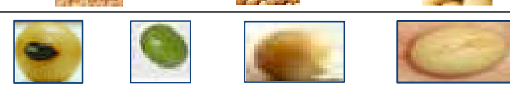
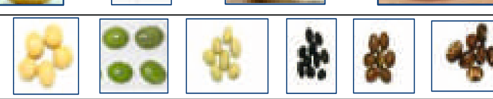
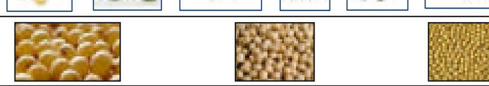
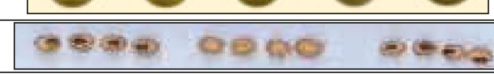
Precautions during harvesting, threshing and processing

The soybean crop reaches at harvestable maturity when the pods have lost their green color and attained the mature pod color characteristic of the variety and seed has become hard. The crop should be promptly harvested at this stage to avoid pod shattering and field deterioration.

The soybean seed is highly prone to mechanical damage during harvesting if the seed moisture is below 13%. Therefore, desiccation should be avoided for the seed crop. If the crop is to be harvested by hand, it should be done, when the moisture is 17-18%. After a few days of drying when the seed moisture reaches 13-15%, the crop should be threshed either by tractor treading or by a multi crop thresher at 300-400 rpm. For direct combining, the seed moisture should be around 14%, the combine should be set carefully to avoid seed damage.

The processing should be carried out at seed moisture of 12-13%. An air screen cleaner is the most effective for soybean seed. The sieves size may vary according to seed size of different varieties. The recommended sieve size for processing is 8.0 mm round for top screen and 4.0 mm oblong for bottom screen.

Table 1. Important morphological characters and stages of observation

Character	Stage	Variation	Figure of stages variance
Hypocotyl: anthocyanin pigmentation	Cotyledons	Absent/present completely unfolded	
Plant: growth type	Vegetative	Determinate/semi-determinate/ indeterminate	
50% plants (*): with at least one flower open	Vegetative	Early, medium, late stage	—
Leaf: shape of lateral leaflet	Vegetative	Lanceolate, triangular, pointed ovate, ovate	
Leaf: size of lateral leaflet	Vegetative	Small, medium, large	
Leaf: intensity of green color	Vegetative	Light, medium, dark	
Plant: growth habit	Vegetative	Erect, semi-erect, semi-erect to horizontal	
Flower: color	Flowering	White/purple (violet)	
Pod: Presence of hairs	Maturity	Present/absent	
Pod: Color of hairs	Maturity	Grey/tawny	
Plant: height	Maturity	Short/medium/tall	
Pod: intensity of brown color	Maturity	Light, medium, dark	
Seed: size	Maturity	Small (<10 g), medium (10-13 g), large (> 13 g)	
Seed: shape	Maturity	Spherical, spherical-flattened, elongated, elongated-flattened	
Seed: ground color of testa	Maturity	Yellow, green, yellow green, black, brown	
Seed coat: luster	Maturity	Shiny, intermediate, dull	
Seed: coloration due to peroxides activity in seed coat	Maturity	Absent/present	
Seed: hilum color	Maturity	Grey, yellow, brown, imperfect black black	
Seed: colour of hilum funicle	Maturity	Same as testa different to testa	
Plant : time of maturity	Maturity	Early, medium, late	—

Packaging/ labelling/ storage

The breeder seed should be dried to 8-9% moisture content and packed in moisture proof bags of 30-40 kg capacity. Polylined (400 gauge) jute canvas bags or HDPE bags are most suitable. It should be properly labelled and stitched.

The color of the labels should be golden yellow No. 356 (IS 5-78) and the size should be 12 x 6 cm. The labels should be correctly filled and stamped with signature, name and designation of the breeder.

Soybean seeds deteriorate rapidly under high temperature and high humidity conditions in tropics. So the seed of soybean therefore needs special storage conditions to maintain their viability. A cool and dry store is recommended for storage of seed. The temperature in storage room should be between 20-27^{0}C and relative humidity 50-60%. The activity of storage insect and fungi is very low at this temperature and RH, and the seeds can be stored for 8-9 months safely.

Grow out test

The breeder seed must conform to the strict standards of genetic purity. For ensuring 99.9% purity, the minimum population required for grow out test is 4000 plants. The sample should be grown in two replications. The optimum number of plants is 30 per meter and row spacing be kept at 45 cm. The plots could be of any convenient size. A minimum of 200 plants of the test sample from originating breeder should be grown along with sample. The plants should be observed for various characters through the growing season. The off type plants are tagged and their number is recorded.

Soybean seed production standard

A. Field

Contaminants	**Minimum distance (meters)**	
	Foundation	**Certified**
Fields of other varieties	3	3
Fields of the same variety not conforming to varietal purity requirements for certification	3	3

Factor	**Maximum permitted (%)***	
	Foundation	**Certified**
Land Requirements	Land to be used for seed production of soybean shall be free of volunteer plants.	
Field inspection (minimum)	2	2
Off-types	0.1	0.5

*Maximum permitted at the final inspection

B. Laboratory

Factors	Standards for each class	
	Foundation	**Certified**
Genetic purity	99.00%	98.00%
Pure seed (minimum)	98.00%	98.00%
Inert matter (Maximum)	2.00%	2.00%
Other crop seeds (maximum)	None	10/kg
Weed seeds (maximum)	5/kg	10/kg
Other distinguishable varieties (maximum)	10/kg	40/kg
Germination including hard seeds (minimum)	70.00%	70.00%
Moisture (maximum)	12.00%	12.00%
For vapour-proof containers (maximum)	7.00%	7.00%

Note: Breeder seed shall be genetically so pure as to guarantee that subsequent generation i.e. foundation seed conforms to the prescribed standards of genetic purity.

Plant Breeding 2

The AICRP on soybean was launched at G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, in 1967 as a special centre on soybean research. Since the inception so far up to now this centre has been one of the leading centers in the soybean research particularly in the development of high yielding and disease free twenty three varieties of soybean released from SVRC and CVRC for the welfare of farming community representing different agro climatic regions of the country. It is the highest number of released varieties from any other station. Three varieties namely Pant Soybean 1092, Pant Soybean 1347 and Pant Soybean 1225 registered under PVP&FR as extent varieties, germplasm PK 515 (*Glycine soja* derived lines) have registered under NBPGR as resistant to YMV and moderately resistance to hairy caterpillar and three varieties of soybean i.e. Ankur, Shilajeet and PK 472 recognized as landmark varieties by ISGPB, New Delhi on 11 February, 2017 in New Delhi along with matching production technologies developed by scientists engaged under various disciplines of the AICRP on Soybean at Pantnagar.

Objectives and mandate

- Collection, evaluation, maintenance and utilization the soybean germplasm
- Breeding varieties for:

A) High yield (35-40 q/ha) with wider adaptation.

B) Early maturity (95-100 days).

C) Photo and thermo–insensitivity**,** suitable for *Kharif*/ *Rabi*/ summer season for plains as well as Hill regions.

D) Disease resistance

- Yellow Mosaic Virus
- Bacterial Pustules
- *Rhizoctonia* Aerial Blight
- *Cercospora* Leaf Spot
- Rust
- Bacterial Leaf Blight

E) Insect resistance

- Hairy caterpillar
- Tobacco caterpillar
- Stem fly
- White fly
- Girdle beetle and
- Green semi looper
- Green stink bug

F) High germinability and better seed longevity (comparable to T 49 /Kalitur/ Bhatt).

G) High oil (>20%) and protein (>40%) contents.

H) Resistant to seed damage.

I) Development of mapping population for seed longevity, YMV and RAB.

- Broadening the genetic base of soybean varieties/prebreeding
- Basic genetic studies
- Nucleus/Breeder seed production of promising varieties

Germplasm Evaluation and Selection of Parental Cultivars

More than 6500 germplasm lines have been evaluated so far since inception and 2830 accessions are still maintained at the centre. These have been evaluated over the years as per NBPGR disopter for agronomic traits and reaction to diseases particularly Yellow Mosaic and Bacterial Pustules. A detailed germplasm catalogue was brought out in 1971 (1014 Germplasm accessions screened for early, late, medium maturity and vine type for 18 morphological and agronomical traits) and during 1988 (6175 germplasm accessions with 16 descriptor, Ram *et al*., 1988). Based on consistent performance over years specific donors (about 150 accessions) have been identified and form the core of the crossing block. Through systematic screening, large number of germplasm lines were identified as donor and are being utilized for soybean improvement programme and also distributed to various AICRP centres.

Breeding For Resistance to Yellow Mosaic

Mungbean Yellow Mosaic Virus transmitted by whitefly (*Bemicia tabaci*) has been a prominent disease in Northern Plain Zone. Systematic screening of about 4000 lines carried out in 1970 and 1971 established that only two lines *viz*., UPSM 534 (PI 171443) and *Glycine formosona* (a wild soybean) were resistant to yellow mosaic. These two donors were reported for the first time in 1974 from this centre. Genetic studies revealed that resistance to Yellow Mosaic in UPSM 534 was controlled by 2 pairs of recessive genes *rym*1 *rym* 2 (Singh and Malik, 1978) and one dominant gene *Rym* conformed resistance in *Glycine soja*.

These two sources were widely used in the hybridization programme and single cross F_1's (in case of UPSM 534) and BC_1's /BC_2's (in case of *G. formosana*) were routed through pedigree selection under 'hot spot' situation of Pantnagar and the first YMV resistant soybean variety i.e. PK 416 using UPSM 534 as a donor was released in 1985, followed by Pant Soybean 564, PS 1042, PS 1092 and PS 1347. While PS 1225 was released through inter-specific hybridization using pre breeding line i.e. PK 515 (*Glycine soja* x Bragg) x Bragg). Now all our breeding lines having a PS number carry YMV resistance either from UPSM 534 or *G. formosana* or any other pre breeding lines having derived its resistance from one of these two donors. Efforts are being made to accumulate / pyramiding resistant genes existing in both the donors, PI 171443 (two recessive genes, *rym*1 and *rym*2 and *G. soja* one dominant genes, *Rym*) through conventional as well as integration of biotechnological approach.

Breeding for Resistance to Rust

Soybean rust was first noticed at Pantnagar in 1970. The disease always appeared in the middle of September to first week of October when temperature was milder. That coincided with the rapid pod filling stage and consequently there was drastic reduction in grain size and yield. Field screening of soybean germplasm was carried out in 1971. The incidence of rust was very severe permitting identification of resistant lines. The lines identified to be resistant were PI 200 465, PI 200 466, PI 200 477, PI 200 490, PI 200 492 and PI 224 268 all having a Japanese origin. The genetic data on segregation for resistant and susceptible plants indicated that resistance to rust was controlled by a single dominant gene. Ankur is a first variety released in 1974 from this University apart from having other desirable features was resistant to rust and latter on varieties like PS 1024, PS 1029 were also released to have rust tolerance.

Resistance Breeding for Fungal Complex

Fungal complex (premature drying) has been a menacing disease of *Tarai and Bhabar* area of UP and Uttarakhand during 1994-1998 which shattered the cultivation of soybean in this area. This disease problem occurs due to number of fungi *viz. Macrophomina phaseolina, Fusarium spp. Colletotrichum dematum* and *Rhizoctonia* blight were found to be associated with this fungal complex. The genotypes *viz*., PK 1241 and PK 1242 were considered resistant genotypes to this fungal complex disease under hot spot whereas; PS 1241 was released for cultivation in the problematic area by the State Variety Release Committee Uttarakhand during 2003.

Breeding for Better Seed Storability and Germinability

Information on genetics of seed quality characters particularly longevity will greatly help expanding soybean to the tropical and sub-tropical regions where farmers face the problem of poor germination after sowing their own seeds stored under ambient conditions. Three indigenous soybeans T 49, Bhatt and Kalitur and one improved variety Ankur were identified as donors to improve seed storability and germinability. Recently 21 additional lines were identified to have superior seed storability. These are EC 11740, EC 13006, EC 36372, EC 39225, EC 93320, EC 93404, EC 172621, EC 241868, EC 251330, EC 251874, EC 11739, V 14, V 19, V 61, WT 189, TGX 342367, L 586, WT 10, WT 34, WT 60, WT 129. Generally these lines are small seeded semi determinate /indeterminate and late in maturity.

Usually there is negative correlation between seed size and germinability. Therefore, we selected only the medium sized (100 seed weight 10-12 g) genotypes while advancing the generations. Genetically investigations have been carried out on the inheritance of seed impermeability and electrical conductivity of seed leachate besides that of seed longevity. Segregation patterns for impermeability (hard seededness) have shown the involvement of 1-4 dominant gene pairs for hard seededness in various crosses (Verma and Ram 1987a). Two dominant genes were involved in controlling low EC or the seed leachate. It is suggested that low EC may be incorporated in soybean varieties which are otherwise promising but lose seed viability rather rapidly (Verma and Ram 1987b).

The segregation pattern for seed longevity in the F_2 and F_3 generations indicated that the trait was governed by major genes, high longevity being recessive. The number of recessive gene pairs controlling seed longevity varied from 2 to 4 depending on the cross (Singh and Ram 1986).

Breeding for Resistance to Bihar Hairy Caterpillar

Hairy Caterpillar is serious pest of soybean although the infestation is not a regular feature. During the rainy season of 1988 the infestation by this defoliator was very severe. *Glycine formosana* (*G. soja*) planted in the hybridization block remained completely free from damage by this insect while all around there was complete defoliation in other entries. Not only that *G. soja* was free from this insect but a breeding line PK 515 having *G. soja* in its parentage was only partially damaged and could be spotted easily in the field. The basis of resistance appears to be chemical as no physical factors (pubescence etc.) appeared to be involved. The preliminary inheritance data indicate that this resistance is controlled by one dominant gene (Bhattacharya and Ram, 1995 and 2001). The use of *G.*

soja as a source of resistance to hairy caterpillar in our breeding programme is on increase. Earlier this wild soybean was known to be a donor only for resistance to yellow mosaic. Large number of *Glycine soja* derived breeding lines was generated for resistance to hairy caterpillar as well as basic genetics studies.

Selection Criteria

The procedure usually followed in soybean breeding is the pedigree method where rejection of lines in the early generations of a cross is often based on visual evaluation for seed yield and overall agronomic characteristics. Visual selection for yield in soybean has not been very successful.

Parental and early generation performances were usually reliable indicators of later generation performances for days to flowering, maturity and plant height. F_2 bulk yields turned over to be good indicator for rejecting poor crosses in the F_2 itself. Visual selection for phenotypically superior plant in early generation *viz*., F_2, F_3 and F_4 was ineffective. In addition to visual selection for yield in early generations yield components and dry matter yield were also used as selection criteria. The results indicated that dry matter as an effective selection criterion when results from selections *vs.* bulks are compared (Singh and Ram 1989 and Pushpendra and Ram 1990). Therefore, looking into these results and practical difficulties it is suggested that in case of large number of unproductive crosses could be rejected in F_2 based on overall relatively low yields. While advancing generations from F_2 through F_5 adherence to the strict pedigree system of breeding may not be followed. Instead selected F_2 plants (based on days to flowering, plant height, lodging, shattering reaction to diseases) should be planted in F_3 progeny rows. Again superior row based on the above criteria should be marked and harvested in bulk but for threshing only heavier plants (more dry matter yield) should be selected. F_4 would again be planted as progeny rows. Again superior rows would be marked harvested in bulk followed by separate threshing of individual plants after the rejection of low dry matter yielding plants. If in F_5 itself adequate uniformity has been seen within the rows or else could be carried forward to F_6 generation. This system is in use at this station for the last few years. A few crosses are being handled as per single seed descent method.

Generation of Breeding Material

Keeping in view the mandate of soybean breeding at Pantnagar following pedigree /bulk/ single seed descend method, more than **1620 breeding lines** have been generated from diverse crosses out of soybean breeding programme whereas, some of the improved breeding lines have been released as a variety for various ecological situations in India and other lines are being used as pre breeding lines for further genetic enhancement.

Basic Genetic Studies

Through the assistance of graduate students' basic studies on inter-specific hybridization, male sterility, natural crossing, heterosis, seed quality, heritability genetic divergence, adaptation, seed quality, hard seededness, germinability, mutation breeding/prebreeding utilizing *G. soja* for yield and yield components; and selection parameters etc. have been conducted. They have been of great help to soybean breeding programme. The salient results are as follows.

- Through systematic screening of germplsam UPSM 534 (PI 1711443) and wild species (*Glycine formosana*) were identified as immune to yellow mosaic. The resistance in PI 171443 is controlled by 2 pairs of recessive genes rym_1 rym_2. The resistance in wild species appears to be controlled by dominant gene *Rym*.

- A number of male sterile lines were obtained at this station through gamma irradiation. One of these mutants "semmes MS-2" did not produce pollen but was female fertile. This was controlled by a single pair of recessive gene. With the use of these lines it would be possible to use efficient breeding methods such as recurrent selection.
- A natural black seeded mutant has been detected in variety Bragg. The black and yellow seeded plants look identical in all respect except for seed coat color. This line (true isogenic line of Bragg) has already been released as VLS 1 for cultivation in UP hills by VPKAS, Almora.
- A detailed study on seeds of yellow and black seeded Bragg has indicated that black colour does not have any beneficial effect on germination. In fact it has rather negative effect by increasing percentage of hard seeds.
- Crinkled leaf and transformed flower mutants have been shown to be due to single recessive gene.
- Effect of 8 qualitative genes namely narrow leaf pentafoliate, phytophthora resistance, non nodulating, glabrous pubescence, curly pubescence, sparse pubescence and dense pubescence on yield, yield contributing characters and quality characters has been studied. No significant differences were observed between narrow leaf and normal type for yield, yield components and quality characters. The reduction in leaf size may be desirable from agronomic points of views.
- The extent of natural crossing in soybean has been about 0.3% in *kharif* season and 2.2% in spring season.
- Based on stability parameters 'Bragg' and 'Hood' appeared to have characteristics of a widely adapted variety having high mean regression coefficient approaching unity and deviation from regression around zero.
- Mutation breeding experiments have shown that LD_{50} for Bragg was between 25 to 35 Kr whereas in case of T 49, it was about 40 Kr.
- Based on genetic divergence and performance of advanced breeding lines derived from various crosses, it has been shown that the crosses involving Bragg, Punjab 1, Shilajeet, Ankur, Type 49, PK 317, PK 327, PK 369, PK 442 and PK 416 as parental cultivars were promising from breeding point of view.
- Accelerated aging stress (40^0C, 96 hrs, 100% RH) can successfully be applied on freshly harvested seed to distinguish lines which have better inherent seed storability.
- Strong maternal effect along with some role of genotype of seed for seed germinability has been shown. Better germinablility was under the control of few genes (2-4 recessive gene pairs) depending upon cross. In some crosses genes for storability found dominant and in some crosses recessive.
- Seed impermeability (hard seed) has been shown to be governed by 1-4 pairs of dominant genes.
- Segregation pattern in Bragg x WT 125 and Ankur x WT 125 has shown the involvement of 2-3 recessive gene pairs for high electrical conductivity of seed leachate.
- Results on selection experiment have indicated that in early generations (F_2 to F_4) of soybean crosses, greater reliance may be kept on visual selection of phenotypically superior plants as is practice presently. However, if the facilities and resources permit or there are less number of

Varieties released from Pantnagar

Brief discussion of soybean varieties developed from Pantnagar are given below-

Variety & year of release :	**Bragg; 1968**
Area of adaptation :	All India including Hills and Plains of Uttarakhand
Yield :	20 – 25 Q/ha (40 – 50 kg/nali)
Maturity :	120 – 125 days
Characters :	**Flower colour –** White **Pubescence –** Brown, **Seed –** Light Yellow, **Hilum** – Light black, **Plant type** – Erect determinate.

Variety & year of release :	**Ankur; 1974**
Area of adaptation :	Mid India
Yield :	20 – 25 Q/ha (40 – 50 kg/nali)
Maturity :	100 – 105 days
Characters :	**Flower colour –** White **Pubescence –** Brown **Seed –** Light Yellow **Hilum** – Light brown **Germination-** Good **Plant type-** Semi-determinate.

Variety & year of release :	**Alankar; 1977**
Area of adaptation :	Plains of Uttarakhand and Uttar Pradesh
Yield :	20 – 25 Q/ha (40 – 50 kg/nali)
Maturity :	120 – 125 days
Characters :	**Flower colour –** White **Pubescence –** Brown **Seed –** Light Yellow **Hilum** – Light Black, **Plant type-** Semi-determinate

Variety & year of release :	**Shilajeet; 1980**
Area of adaptation :	North India/ Hills of Uttarakhand
Yield :	25–30 Q/ha (50–60 kg/nali)
Maturity :	100 – 110 days
Characters :	**Flower colour**–Purple, **Pubescence**–Brown **Seed**–Yellow **Hilum**– Light Brown, Good food qualities **Maturity**–Early maturing **Plant Type**–determinate

Variety & year of release :	**PK- 262; 1982**
Area of adaptation :	North India/ lower Hills and Plains of Uttarakhand
Yield :	25 – 30 Q/ha (50 – 60 kg/nali)
Maturity :	120 – 125 days
Characters :	**Flower colour** – White **Pubescence**–Gray **Seed**–Yellow **Hilum**–Brown **Plant type**–Sturdy determinate Tolerance to BP.

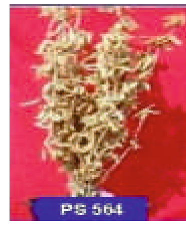
Variety & year of release :	**PK-327; 1982**
Area of adaptation :	Plain of North India and Hills of Uttarakhand
Yield :	25–30 Q/ha (50–60 kg/nali)
Maturity :	100 – 110 days
Characters :	**Flower colour**–Purple, **Pubescence**– Gray **Seed**– Yellow **Hilum**–Light Brown **Maturity**–Early **Plant type**–Determinate

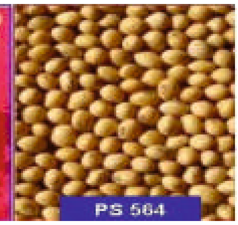
Variety & year of release :	**PK 308; 1984**
Area of adaptation :	Plain of North India and Hills of Uttarakhand
Yield :	25–30 Q/ha (50–60 kg/nali)
Maturity :	100 – 110 days
Characters :	**Flower colour**–White **Pubescence**–Gray **Seed**–Yellow **Hilum**– Light Brown, Good food qualities **Maturity**–Early maturing **Plant Type**–narrow and lenceolate leaf.

Variety & year of release :	**PK-416, 1985**
Area of adaptation :	Plains of Uttarakhand and North India
Yield :	25-30 Q/ha (50–60 kg/nali)
Maturity :	115 – 120 days
Characters :	**Flower Colour**– White **Pubescence** –Brown **Seed** – Yellow **Hilum**–Light Brown **Plant type**-Semi-determinate, First YMV resistant variety.

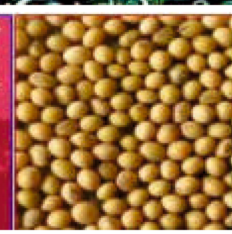
Variety & year of release :	**PK-472; 1986**
Area of adaptation :	Central India
Yield :	25–30 Q/ha (50–60 kg/nali)
Maturity :	100 days in Central India 120 days in North India
Characters :	**Flower colour**–White **Pubescence**–Gray **Seed**–Yellow **Hilum**–Light Brown **Plant type**-Determinate sturdy short **Resistance to diseases**– YMV, BP and Tolerance to RAB.

Variety & year of release :	**PK-564; 1990**
Area of adaptation :	Hill and Plain of Uttarakhand
Yield :	25–32 Q/ha (50–64 kg/nali)
Maturity :	115 – 120 days
Characters :	**Flower colour**–White **Pubescence**–Brown **Seed**-Yellow **Hilum** –Light Black **Resistance to diseases** –YMV, BP and Tolerance to RAB **Plant type** –Determinate.

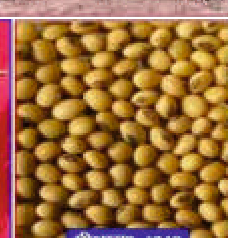




Variety & year of release :	**Pant Soybean 1024; 1994**
Area of adaptation :	*Tarai* and *Bhabar* of Uttarakhand
Yield :	25–35 Q/ha (50–70 kg/nali)
Maturity :	115 – 120 days
Characters :	**Flower colour** –White **Pubescence–**Brown **Seed–**Yellow **Hilum–**Light Brown **Plant type–**Determinate Multiple disease resistance, Suitable for inter cropping. Narrow leaflets.



Variety & year of release:	**Pant Soybean 1042; 1996**
Area of adaptation :	*Tarai / Bhabar* of Uttarakhand and North India
Yield :	30–35 Q/ha (60–70 kg/nail)
Maturity :	115 – 120 days
Characters :	**Flower colour–**White **Seed–**Yellow **Hilum–**Dark Brown **Plant Type–**Determinate Multiple Disease Resistance



Variety & year of release :	**Pant Soybean 1029; 1997**
Area of adaptation :	South India
Yield :	25 – 30 Q/ha
Maturity :	95 -100 days South India. 120 – 125 days North India
Characters :	**Flower colour**–White **Pubescence**–Brown **Seed**–Yellow **Hilum**–Black **Plant type**– Determinate **Resistance to diseases** –YMV, BP and Tolerance to RAB and Rust.

Variety & year of release :	**Pant Soybean 1092; 1999**
Area of adaptation :	Hill and Plain of Uttarakhand
Yield :	25–30 Q/ha (50–60 kg/nail)
Maturity :	110 -115 days
Characters :	**Flower colour**–Purple **Seed**–Yellow **Hilum**–Light Black **Plant type**–Determinate Multiple Disease Resistance, Wider adaptability Tolerant to *Cercospora* leaf spot

Variety & year of release :	**Pant Soybean 1241; 2003**
Area of adaptation :	*Tarai* and *Bhabar* of Uttarakhand
Yield :	25 – 35 Q/ha (50 – 70 kg/nail)
Maturity :	120 – 125 days
Characters :	**Flower colour**–White **Plant Height**–Tall **Seed**–Yellow **Hilum**–Black **Resistance to diseases** – YMV, BP and Tolerance to RAB & premature drying. Semi-determinate plant type.

Variety & year of release :	**Pant Ranichauri 1 (PRS 1); 2004**
Area of adaptation :	Uttarakhand Hills
Yield :	20 – 25 Q/ha
Maturity :	100 – 110 days
Characters :	**Flower colour**– White **Plant Height**– Tawny **Seed**– Yellow **Hilum**– Light Brown Early maturity, determinate plant type

Variety & year of release :	**Pant Soybean 1347; 2006**
Area of adaptation :	Uttarakhand, Uttar Pradesh, Haryana, Punjab and Delhi
Yield :	30 – 35 Q/ha (60 – 70 kg/nail)
Maturity :	120 – 123 days
Characters :	**Flower colour** –White **Seed** –Yellow **Hilium**–Light brown **Resistance to diseases & Insect**– Yellow Mosaic Virus (YMV), Bacterial Pustules (BP), Tolerance to Rhizoctonia Aerial Blight (RAB). Resistance to Girdle Beetle. Determinate sturdy plant type, Suitable for inter cropping.

Variety & year of release :	**Pant Soybean 1225; 2007**
Area of adaptation :	Uttarakhand plains and tarai bhabar
Yield :	30-35 Q/ha
Maturity :	120-125 days
Characters :	**Flower colour**– White **Plant Height**– Tall **Seed**– Yellow **Hilum**– Brown **Resistance to diseases** – YMV, BP and moderately resistance to RAB

Variety & year of release :	**Pant Soybean 19; 2010**
Area of adaptation :	Plains and lower hills of Uttarakhand
Yield :	30-35 Q/ha
Maturity :	122-125
Characters :	**Flower colour**– White **Seed**–Yellow **Hilum** –Black **Resistance to diseases**– YMV, BP and moderately resistance to RAB

Variety & year of release :	**Pant Soybean 20; 2015**
Area of adaptation :	Plains, Tarai Bhabar area of Uttarakhand
Yield :	30-36 Q/ha
Maturity :	120-124
Characters :	**Flower colour**–White **Seed**–Yellow **Hilum**–Black **Resistance to diseases**– YMV, BP and moderately resistance to RAB

Variety & year of release :	**Pant Soybean 21; 2015**
Area of adaptation :	Plains, Tarai Bhabar area of Uttarakhand
Yield :	30-38 Q/ha
Maturity :	120-125
Characters :	**Flower colour** –White **Seed** –Yellow **Hilum**–Black **Resistance to diseases**– YMV, BP and moderately resistance to RAB

Variety & year of release	:	**Pant Soybean 22; 2015**
Area of adaptation	:	Plains, Tarai Bhabar area of Uttarakhand
Yield	:	30-35 Q/ha
Maturity	:	115-120
Characters	:	**Flower colour**–White **Seed**–Yellow **Hilum**–Black **Resistance to diseases**–YMV, BP and moderately resistance to RAB

Variety & year of release	:	**Pant Soybean 23; 2015**
Area of adaptation	:	Plains, Tarai Bhabar area of Uttarakhand
Yield	:	30-40 Q/ha
Maturity	:	112-115
Characters	:	**Flower colour** –White **Seed** –Yellow **Hilum**–Black **Resistance to diseases**–YMV, BP and moderately resistance to RAB

crosses to be handled the early generations may be subjected to artificial selections for dry matter yield (mature plant weight).

- Isolation of both positive and negative mutants for yield and yield contributing characters indicated the role of induced polygenic mutations in soybean improvement. The effective dose of the physical mutagen was 25 Kr gamma rays.

- Early flowering and early maturity showed complete dominance over late flowering and late maturity respectively. This was in contrast to the results from temperate regions where late flowering and late maturity were shown to be partially dominant over earliness. The segregation pattern for vegetative phase and maturity duration in the F_2 and F_3 generations indicated the involvement of 1-2 genes. Reproductive phase was controlled by a single gene with dominance of longer phase over shorter phase.

- On the basis of genetic diversity analysis, the genotypes PS 1225, AMS 100-16-4-1-3, JS 20-79, Jupiter, Cat 2009, SL (E) 1 and AMS 50B were identified as superior donors for yield contributing traits.

- The ISSR analysis revealed that primer 50SS (Genei company code) was linked to gene resistant to YMV in soybean.

- The morphological characterization and inheritance revealed that flower color, pubescence, pubescence color, seed coat color, were segregated in 3:1 ratio and governed by single gene where as inheritance of YMV resistance was found to follow 15 (susceptible): 1 (resistant) pattern and governed by two recessive genes.

- Analysis of path coefficient indicated major role of number of pods per plant, total dry matter weight, number of primary branches per plant, seed yield efficiency and 100-seed weight both directly and indirectly influenced seed yield in soybean..

- On the basis of genetic divergence analysis, the genotypes viz. Shilajeet, TGx 1681 3F, Bhatt, Jupiter, PK 416, PK 1351 and PK 1347 were found to be useful donor to get better sergeants for yield and its components and on the basis of character association and path coefficient analysis at phenotypic, genotypic and environmental level, it is evident that reproductive phase, number of pods per plant, total dry matter weight per plant, number of seeds per plant, harvest index and seed yield efficiency had major contribution in determining seed yield in soybean.

- Three rare alleles, one of 200bp with primer Satt 197 in DOKO and second of 100bp with EC 389148 with primer Satt 577 and third of 250bp with primer Satt 586 in TGX 16813F were also identified, which can be used for identification and characterization of the genotypes. The UPGMA (Unweighted Pair Group Method with Arithmetic Mean) dendrogram constructed using Jaccard's similarity coefficient of SSR marker data divided twenty soybean genotypes into two main groups namely group A and group B and seven cluster. On the basis of dendrogram, genotypes TGX 1681-3F and DS 9814 was found to be most distant.

- Jaccard's similarity coefficients based on SSR data of 22 genotypes were found to vary from 0.19 (PS 1225 and ABL 55) to 0.85 (PK 327 and ABL 61). Total of 87 alleles were detected across the 26 polymorphic loci with n average 3.35 alleles per locus.

- The UPGMA based dendrogram constructed using Jaccard's similarity coefficient of SSR marker data divided twenty two genotypes into five cluster and four sub-cluster. Cluster strength varied from minimum of two to maximum of ten members. Clustering patterns in general did not corroborate with quantitative data of oil and protein contents.

- Based on variability, correlation and path coefficient analysis, number of nodules per plant, nodules mass and dry weight per plant, plant height, pods per plant and oil content were found to be important yield attributing characters for selection procedure in soybean improvement.

- Based on heterosis, the crosses JS 335 x DS 98-14, PK 515 x EC 389148, PK 472 x JS 71-05, PS 1029 x AGS 129, PS 1241 x PS 1330, PS 1241 x PS 1347 and PS 1241 x PS 1428 have been identified promising ones. These F_1s have been suggested to be utilized to get higher productivity. Whereas, correlation and variability studies revealed that plant height and dry matter weight per plant contributed the most to yield in soybean.

- Out of 15 crosses 9 crosses expressed high magnitude of residual heterosis for various characters over respective mid parent, better parent and standard parent and four crosses i.e. PS 1241 x PS 1042, PK 1029 x PK 1162, PS 1241 x PK 317 and PS 1241 x Jupitor were promising for expressing high frequency of transgressive segregants for basal plant height, number of nodes per plant, number of pods per plant, harvest index, seed yield efficiency and seed yield per plant. These promising crosses exhibited high magnitude of residual heterosis as well as high frequency of transgressive segregants may be exploited in breeding programme to improve economical yield and other economically important traits in soybean through selection.

Seed Production

Owing to phenomenal spread of soybean cultivation in India, the demand for its seed has increased tremendously. Breeder seed of improved varieties of soybean released at National and state level and notified is produced at Seed Production Centre, GBPUA&T, Pantnagar to meet the requirement of DAC Ministry of Agriculture Government of India, Seed corporate companies in public and private sector. The seed requirement for present area is 75.15 lakh quintals while the availability of quality seed is only about 8.96 lakh quintals. The seed replacement rate is about 10%. The average annual breeder seed production of soybean under the aegis of AICRP on soybean, during last one decade (2005-2014) is nearly 146753 quintals (Table 1). There are 32 varieties in the seed production chain. About 40 % short fall of breeder seed on corresponding year 2014. So, need of the hours is to increase breeder seed production of soybean's released and notified varieties to full fill the demand of the country. Out of total demand in one decade the contribution of Pantnagar University is about 19 %.

Table1. DAC indent, target and production of breeder seed during 2005-2016

S. No.	Year	National			Pantnagar		
		DAC indent (q)	Target (q)	Production (q)	DAC indent	Target (q)	Production (q)
1	2005	11505.1	13277	15448.2	311.46	366	235
2	2006	12986.9	15034	16814	450.1	590	797
3	2007	14210.9	16309.3	16738.8	428.3	562	671.5
4	2008	17177.9	18861	13803.5	609.4	504	51.2
5	2009	21625	22442.2	12516.9	318	324	338.5
6	2010	22292.8	21730	18327.2	290	330	326
7	2011	21701.8	23273.5	15409.2	136	148	146.95
8	2012	27421.4	24687.5	20717.8	105.5	131	230
9	2013	18130	19509	8018.44	146.24	165	125
10	2014	15210	14918.5	8959.62	102.72	124	168.75
11	2015	16941	16614	6905.5	103	125	175
12	2016	17766.4	18222	15291	87	104	175
Grand Total		**216969**	**224878**	**168950**	**3087.72**	**3473**	**3439.9**

Future Research Priorities

There is a need to enhance the genetic potential for yield in soybean. This is different from checking the yield crossing due to insect and shattering loss etc. and also from minimizing the yield gap. Long durability i.e. delayed flowering under short day condition is important for obtaining high biomass and high yield in context that growing period in India about 100 days in comprision to 130 to 140 days in USA. The yield potential in Indian varieties could be further increased by incorporation of longevity traits in crosses using sources *viz.*, PI 159925, PI 240664, Samita Maria, Occpar 8, and

Pccpar 9 introduced from Brazil and USA. Soybean is classified under least storable germplasm, its seed is highly sensitive to mechanical and thermo injury. Bold seeds are poorer in compression to small seed for longevity. The future thrust area are given below-

1. Having achieved a phemenonal success in terms of varietal improvement as well as basic genetic studies even our experimental as well as national productivity has been low. Stagnant potential for yield due to narrow genetic base of Indian Soybean varieties has been a major constraint for low productivity of soybean.

2. Facing these constraints, enhancement in productivity *per se* by enrichment of genetic resources, development of matching production technologies and its transfer to the clientele would be the first priority. Hills are the great reservoir of genetic resources; efforts will be made for collection, conservation, evaluation and utilization of genetic resources of soybean for Uttarakhand hills for strengthening the genetic resources for soybean AICRP on soybean programme. Similar efforts in terms of consolidation in germplasm enhancement will be made from national and international institute of soybean.

3. The intensification of developing varieties resistant/tolerant to biotic (YMV, RAB, rust and insect) stresses.

4. Breeding varieties that could cope with a biotic stress like water deficit and excess

5. Exploitation of new biotechnological tool in exercising efficient selection in reduced time frame.

6. Development of speciality soybean for major food rises and industrial exploitation.

Agronomy

Preliminary studies on soybean Agronomy were initiated during 1963-64 with soybean varieties imported from U.S.A which did not yield very encouraging results. However trials of 1965 appeared to be quite encouraging which led to more explanatory trials during 1966. The grain yield of Bragg was recorded as high as 35.56 q/ha when planted at the onset of monsoon.

Systemic research on soybean agronomy started since 1967 when Pantnagar became the special centre of All India Coordinated Research Project on Soybean under ICAR. In First five years (1967-72) efforts were made to find out agronomic suitability of soybean cultivation. High potentiality of soybean was established for "*Bhabar*" tract of UP when it was sown in first week of July. During this period optimum date of planting, seed rate depth of sowing, row spacing, fertilizers and irrigation requirements for maximum yield of soybean were studied. Next ten years (1972-82) were devoted to solve new production problems which came out as a consequence of change in genotypes. Since then research is being intensified to solve various agronomic constraints of soybean productivity and to develop soybean based production technology.

Phenomenal success in increasing soybean area and production was possible because of timely development of production technology for new varieties. The suitable package and practices of cultivation are being recommended from time to time as a result of intensive research in Agronomy. Mandate of soybean agronomy included to evolve and standardize integrated methods of nutrient and weed management for removing productivity constraints and to exploit genetic potential of soybean cultivars. The research has been intensified to solve various agronomic constraints of soybean productivity and to develop production technology on soybean based cropping systems.

Objectives and Mandate

(i) To evaluate the yield potential of pre- released soybean varieties at varying plant populations and planting geometries under recommended agronomic management.

(ii) To find out suitable integrated method of weed management.

(iii) To find out suitable integrated plant nutrient management for sustainable soybean based cropping system.

(iv) To study the effect of growth regulators for promoting soybean yield.

(v) To find out suitable soybean varieties for moisture stress conditions.

(vi) To study the effect of land configuration and nutrient management on soybean yield.

(vii) To study the effect of organic and inorganic sources of nutrient management on productivity of soybean based cropping systems.

The AICRP on Soybean was launched at G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (then Uttar Pradesh), in 1967 as a special centre on soybean research. Since the inception so far up to now this centre has been one of the leading centers in the soybean agronomic research particularly in the development of various production technologies as mentioned below.

Integrated Nutrient Management

In 1993 experiment on micronutrient application was conducted with 12 treatments in RBD design. The treatments were, zinc@5.0 and 10.0 kg/ha, boron@ 0.5 and 1.0 kg/ha, seed treatment with 4.0 g Na molybdate/kg seed, zinc @5.0 kg+ FYM @10 t/ha, boron 1.0 kg + FYM@ 10 t/ha, FYM @ 10t/ha and control with recommended NPK (20:80:40 kg/ha) were tested. Application of boron @0.5 kg/ha resulted in highest grain yield (30.2 q/ha) which was 12.6 per cent more compared to control followed by application of zinc @10 kg/ha. Application of boron @ 1.0 kg/ha + FYM alone @ 10 t/ha improved the seed quality of soybean, while application of FYM @ 10 t/ha resulted in lowest grain yield.

In 1994 the the same experiment was repeated. The treatment effects were non-significant on grain yield of soybean. Application of 5.0 kg zinc resulted in highest grain yield (27.32q/ha) which was 15.5 per cent greater than control followed by zinc@10 kg/ha. Aplication of boron also slightly improved grain yield and FYM @ 10t/ha resulted in lowest grain yield.

Phosphorus nutrition

In 1994 the effect of various levels of phosphorus application (0, 30, 60, 90, 120 and 150 kg P_2O_5/ha through SSP) on growth and yield of soybean was studied. Application of 30 kg P_2O_5/ha gave higher yield (9%) and with subsequent increase in the phosphorus levels there was reduction in grain yield and lowest grain yield was recorded at 150 kg P_2O_5/ha.

Copper Nutrition of Soybean

The experiment was conducted in 1997 with objective to study the response of copper application on different soybean varieties (Bragg, PK-262, PK-416, and PK-1042). Four rates of Cu *viz*., 0, 2.5, 5.0 and 10.0 kg/ha as copper sulphate was used as basal application. Different varieties responded varingly to copper application at different levels. PK-416 recorded significantly highest (19.84q/ha) seed yield over other varieties due to basal application of copper @ 2.5kg/ha.

Foliar application of urea

Effect of foliar spray of urea (2%) in different varieties of soybean (PK-317, PK-262 and PK-1042) was evaluated employing split plot design with urea spray as subplot treatment. Control plots received water spray while 2% urea was sprayed either at 30DAS or 60 DAS as different treatments. Varietal effect on grain yield was non-significant however foliar application of 2% urea produced the significant effects. Significantly higher grain yield of soybean was registered due to foliar application of 2% urea at 30 DAS than control i.e. water spray. In general, all the varieties tested showed increase in grain yield due to foliar application of 2% urea.

Effect of organic and inorganic nutrient management on productivity of soybean based cropping systems

A long term experiment was initiated in 2012 to study the effect of nutrient management through 100% organic, 100% inorganic and 50% organic + 50% inorganic nutrient management in soybean under two cropping systems *viz*., Soybean-wheat and soybean- chick pea. Highest soybean grain yield (3445kg/ha) was recorded with 50% organic and 50% inorganic nutrient management which was significantly higher than 100% organic and 100% inorganic nutrient management.

Among cropping sequence soybean-chickpea was superior over soybean-wheat. The salient observations emerged from the study were:

- The integration of organic sources with inorganic fertilizer (50% RDF) produced comparable yields to the application of fertilizers at RDF level in soybean – wheat cropping system.
- Integration of poultry manure (2.5 t/ha) with RDF (20:60:40:30::N:P:K:S) and Zn @ 5.0 kg/ha significantly enhanced dry matter production and seed yield of soybean.
- In the absence of balanced fertilization sewage sludge is a good source for soybean nutrition.
- Integrated use of crop residues @5 t/ha + FYM @5t /ha + Zn @ 5.0 kg resulted in 22 % higher yield compared to control.

Planting Geometry

Planting geometry, time and method of planting is one of the major non-monetary input to enhace soybean yield. Experiment was conducted in 1993 to find out the optimum plant population under different varieties *viz.*, Bragg, PK-416, PS-564, PK-1042, PK-1046, SL-238, PK-1029, PK-1053. Three plant population *viz.*, 0.2, 0.5 and 0.6 million/ha were tested. Plant population was maintained after a week of germination by thinning extra plants and keeping row-row distance constant at 60 cm. Increasing plant population from 0.2 to 0.4 millions per hectare decreased dry matter production per plant by 64 per cent, further increase in plant population from 0.4 to 0.6 million per hectare resulted in decrease in dry matter per plant by 8.8 per cent. Different varieties have differential requirement of plant population to yield maximum. Variety PS-564, PK-1042, SL-238, and PK-1029 yielded highest at 0.2 million/ha, varieties PK-416, and PK-1053 yielded highest at 0.4 million/ha whereas Bragg and PK-1046 yielded maximum at 0.6 million /ha.

In 1994 six varieties (PK-1055, PK-1060, PK1091, PS-564 and PK-416) were tested with same three levels of plant population (0.2, 0.4 and 0.6 million/ha). Varieties PK-1060, PS-564, PK-416 and PK1069 yielded highest at 0.2 million/ha, variety PK-1055 at 0.4 million/ha and PK-1061 at 0.6 million/ha population. Among different plant population 0.2 million plants /ha resulted in significantly higher grain yield over 0.4 million/ha including yield contributing parameters.

In 1995 under similar three plant population levels (0.2, 0.4 and 0.6 million/ha) seven soybean varieties were tested. The effect due to varying levels of plant population was non-significant on grain yield. Maximum grain yield of soybean was obtained from variety PK-1109 which was at par with PS-564 and significantly greater than the rest of the the varieties (PK-1092, SL-296-A, Bragg, PK-416, SL-231).

In 1996, with similar three plant population levels (0.2, 0.4 and 0.6 million/ha) eight soybean varieties were tested. Grain yield of soybean was significantly affected by different varieties but the effect of plant population was non-significant. On an average PK-1133 gave highest yield which was on par with SL-295, PK-416, and PK-1135 and significantly higher than rest of the varieties (PK-1134, PK-1137, NRC-20 and PS-564). The salient findings in respect of the palnt geometry are:

- Paired planting of soybean on ridge resulted in to higher germination as compared to flat planting.

- Seed placement more than 4-5 cm depth resulted in to poor germination.
- 45 cm row spacing was found to be more productive than 60 and 75 cm spacing, respectively
- Most of the soybean varieties performed better at 0.35-0.4 million plants /ha population.

Anti transpirant and Mulches

The effect of anti-transpirant and mulches for enhancing water stress tolerance in soybean variety PS-1347, was studied during 2012 and 2013. Two mulch treatments *viz.*, no mulch (control) and mulch with straw @5 t/ha and; 5 anti-transpirant treatments *viz.*, $MgCO_3$@5%, Glycerol @5%, Na_2CO_3 @ 5%, KNO_3, and Control were tested. Anti-transpirant application was done at the time of flowering. Significantly greater grain yield of soybean during both the years (2054 and 2043 kg/ha) over control was produced with the straw mulch. Among anti-transpirant treatments maximum grain yield (1755 and 1787 kg/ha) was obtained with $MgCO_3$ @5% application. In 2014 similar results were obtained, where mulch application resulted in 1511 kg/ha soybean seed yield which was significantly higher than no mulch treatment. Among anti-transpirant treatments application of $MgCO_3$@5%, resulted in highest soybean seed yield (1728 kg/ha).

Tillage

The experimentation was also carried out to study the effect of tillage practices on the soybean production. The salient outcomes of the studies were:

- Minimum tillage was found more productive and energy efficient than conventional or zero tillage.
- Breaking of crust after rain helped in increasing soybean plant stand.
- High temperature and high humidity were found detrimental on seed quality.

Weed Management

Weed infestation results in loss of yield due to competition for space, water, light, nutrients and certain weeds also has certain allelopathic effects. The major weed floras found in soybean are *Echinochola colonum, Celosia argentia, Cyperus rotundus, Sorghum halepense, Celome viscose, Cucumber spp, Elusine indica, Mollugo pentaphylla.* To find out the best management practices for the control of the weeds number of experiments were carried out over the years.

In 1993 ten treatments *viz*., Alachlor @2.0 kg/ha, Fluchloralin @1.0 kg/ha, Alachlor @2.0kg/ha 10% granules, Lectofen @0.15 kg/ha , Clomozom @1.0kg/ha, Sethoxydim @1.5l/ha post emergence 20 days after sowing , Sethoxydim @1.5l/ha pre emergence, two hand weeding at 3rd and 6th week after sowing, weed free and weedy check were evaluated for the control of the weeds in soybean. Among the herbicidal treatments lowest weed density was recorded due to application of Sethoxydim @1.5l/ha as post emergence, followed by Clomozom @1.0 kg/ha as pre emergence. Minimum reduction in weed density was recorded due to Sethoxydim @1.5l/ha as pre emergence. Grain yield of soybean was significantly affected by various weed control treatments. Post emergence spray of Sethoxydim @1.5l/ha yielded highest (20.5q/ha) which was at par with two hand weeding and weed free treatments and recorded significantly higher grain yield over remaining treatments.

In 1994, twelve treatments *viz*., Alachlor @2.0 kg/ha, Basagran @2 l/ha, Fluchloralin @1.0 kg/ha, Trifluralin @1.0kg/ha, Lectofen @0.15 kg/ha, Clomozom @1.0kg/ha, Sethoxydim @1.5l/ha post emergence 20 days after sowing , Metribuzin @0.25 kg/ha, Anilophos 5G @1.5 kgai/ha as PE, two hand weeding at 30 and 45 days after sowing, one hand weeding at 30 DAS and weedy check were evaluated for weed control.Treatment effects on grain yield were significant. Two hand weedings resulted in highest grain yield (23.74 q/ha) which was at par with Alachlor @ 2.0 kg/ha application and greater than the rest of the treatments.

In 1995, experiment was conducted with 13 treatments *viz*., Alachlor @2.0 kg/ha, Fluchloralin @1.0 kg/ha, Pendimethalin @1.0kg/ha, Metolachlor 5G@ 1.0kg/ha, Alachlor 10G @2.0 kg/ha, Anilophos @1.5 kgai/ha, Clomozom @1.0kg/ha, Metribuzin @ 0.25 kg/ha, Anilophos 5G @1.5 kgai/ha, two hand weeding at 3rd and 6th weeks, Alachlor @2.0kg/ha+ 1 hand weeding at at 30 DAS , weed free and weedy check for the control of weeds. Clomazone @1.0 kg/ha resulted in highest grain yield (31.71 q/ha) which was significantly greater than Pendimethalin @1.0 kg/ha, Metolachlor @1.0 kg/ha, Metribuzin @0.25 kg/ha followed by weedy check (17.55 q/ha).

In 1996, twelve treatments *viz*., Alachlor @2.0 kg/ha, Trifchloralin @1.0 kg/ha, Pendimethalin @1.0kg/ha, Fenoxaprop-P-ethyl@ 50g ai/ha as post emergence, Fenoxaprop-P-ethyl@ 70g ai/ha as post emergence, Propaquizafop @ 50g ai/ha, Propaquizafop @75g ai/ha, Anilophos @1.5kg ai/ha, Imazethapyr @75g ai/ha post emergence, Imazethapyr @100g ai/ha post emergence two hand weeding at 30 and 45DAS and weedy check were evaluated for weed control. Highest grain yield was recorded with two hand weedings which was at par with Propaquizafop @50 and 75g ai/ha, Anilophos @1.5 kg/ha, Imazethapyr @50 and 75g ai/ha and Alachlor @2.0 kg/ha, however remained significantly greater than rest of the treatments.

In 1997 weed control experiment was conducted with 14 treatments and application of Imazethapyr @ 100 g ai/ha resulted in highest grain yield (16.42q/ha). The salient observation from the weed control experiments in soybean were as:

- Weed comptetion resulted in 41-60% yield reduction in soybean.
- Two hand weedings at 30 and 45 DAS were found at par with weed free conditions.
- One hand weeding at 20 DAS + 1 spray of POE herbicide is able to control weeds during rainy season.
- Among the various herbicides tested S-Metolachlor, quizalofop ethyl, quizalfop, p-tefaryl were more effective, while persuit plus as post emergence herbiside on soybean was proved to be effective on weed control during rainy season.
- Alachlor as pre-emergence was found to be a good herbicide.

Cropping System and Intercropping Studies

During 1993 and 1994 four soybean based cropping systems *viz*., Soybean-Wheat, Soybean-Mustard, Soybean-Lentil and Soybean-Gram were evaluated to find out the most remunerative crop sequence. Highest net return of Rs 25,835/ha was recorded in Soybean-Lentil followed by Soybean-Wheat sequence.

In 1994, an experiment was also planned to study the suitability of different '*kharif'* cereal crops combination with soybean. Nine treatments *viz*., pure maize, pure sorghum, pure ragi, pure arhar, pure soybean and their intercropping with soybean in alternate row were evaluated. Yield and yield attributes of soybean as number of branches per plant, number of pods per plant and thousand grain weight were significaltly affected by intercropping. Maximum grain yield of soybean was recorded in pure soybean (14.42 q/ha) which was significantly greater than all other intercropping treatments.

Varietal evaluation, planting and other management practices

- PK 327, Shilajeet, PK 1029 and PS 1024 varieties of soybean were found more suitable for intercropping with *kharif* cereals/ legumes.
- PK 416, PK 262 and JS 90-41 varieties of soybean have better potential for moisture stress conditions.
- Under late planting high seed rate @ 100 kg/ha was found to give good yield.
- Under North plain zone soybean planting beyond 2nd fortnight of July resulted in drastic decline in yield.
- For the management of fungal complex/ disorder seed treatment with thiram + carbendazim (2:1) and integration of all other agronomic practices including deep summer ploughing was found to solve the problem of fungal complex in soybean in Tarai and Bhabar area of Uttarakhand.
- Spray of Biovita @ 500ml/ha at flowering and pod filling stage with 50% RDF increased seed yield up to 30 % over control.
- Application of biozyme^{+} @ 400ml + ½ of RDF gave significantly higher yield than other treatments.
- Seed treatment with neem cake solution @50 g/kg seed resulted in better germination and healthy seedlings.
- To mitigate the Zn deficiency, application of RDF + poultry manure @2.5t/ha was found to be effective for higher yield of soybean.

Evaluation of production potential of soybean in *Rabi* season

In 1993 an experiment was planned to study the yield potential of different varieties of soybean when planted in *rabi* season. Planting of 10 varieties *viz*., PK-416, Pusa-22, Clark-63, PK-317, Monetta, PS-564, PK-472, Hardee, PK-1024 and PK-327 were planted on 26 November and harvesting was done from 10-20 April. Soybean variety PK-472 yielded highest (17.1 q/ha) and was significantly higher than rest of the varieties. In 1994 again ten varieties were tested in *rabi* season *viz*. PK262, PK-472, PK-327, Monetta, PS-564, Green Soybean, Hardee, PK-317 and Bragg, sowing was done on 7 December and harvesting was done in last week of April to first week of May as per maturity. Highest yield was recorded from Monetta (30.6q/ha) followed by PK-416 and PK-262.

Salient Achievements

1. Soybean-wheat cropping system has been recommended for north plain zone as one of the most remunerative one.
2. Higher plant dry matter of soybean was found with soybean-wheat cropping system than soybean-lentil.

3. Maximum grain yield of soybean was found with soybean-wheat under 100% inorganic nutrient management which was as par with 50% inorganic + 50% organic management. Wheat yield was also found higher in 100% inorganic management practices.
4. Minimum tillage (two harrowing) is recommended for soybean-wheat cropping system.
5. Summer deep ploughing is recommended for effective weed and pathogen control for soybean cultivation during *Kharif* season.
6. Basal application of 5 kg Zn + 0.5 kg B + 10 t FYM/ha was recommended for increasing soybean productivity in Zn deficient soils.
7. Incorporation of crop residues @ 5 t/ha with FYM @5 t/ha + Zn @ 5kg /ha was recommended to improve soybean yield and soil physical /biological properties.
8. Quizalofop ethyl @ 50 g ai/ha as PoE herbicide (15-20 DAS) was recommended for weed control in soybean.
9. Acetachlor 90 EC @ 2.0 kg ai/ha as PE is recommended for weed control.
10. For weed management in soybean-weeding at 30 & 45 DAS resulted higher seed yield than herbicides tested subject to weather conditions.
11. Application of diclosulam 84 WDG @ 30 g ai/ha as PPI/PE gave effective weed control of dicet weed and also gave highest WCE.
12. Use of weeds as mulch at 25-30 DAS gave effective weed control in soybean and also helped in soil and water conservation, least expensive than other methods of weed management.
13. Integrated weed management practices, use of Pendimethaline 30EC @1.0 kg ai/ha as PE +1 intercultural operation at 30 DAS resulted in highest soybean yield.
14. 100% WCE at 30 & 60 DAS was observed with diclosulam 84 WDG @ 22 or 30 g ai/ha as PE.
15. Use of fluchloralin 1.0kg ai/ha (PPI) +diclosulam @ 26.0 g ai/ha (PE) gave effective weed control of monocot and dicot weeds in soybean and resulted into highest yield. Whereas, haloxyfop (100g/ha) + fluchloralin (1.0 kg ai/ha) failed to do so.
16. WCE decreased subsequently from 30 DAS to harvest with the use of different herbicides used. However, highest WCE was recorded with fenoxyprop ethyl 9EC @ 100 gai/ha as PoE at different growth stages.
17. Broad bed furrow and application of RDF was approved for deficient moisture areas.
18. Application of sulphur @ 30 kg + 0.5 kg B/ha gave the highest soybean yield and was 30.80 % higher compared to control. Highest B:C ratio was also recorded with the same treatment.
19. The effect of planting geometery for PS 1042 variety of soybean under North plain zone conditions 30 cm row spacing yielded 15% more yield than other row spacings (45 and 60 cm).

20. At pod filling stage, canopy temperature, root-shoot ratio and RWC of leaf (%) could not make any significant difference in various entries tested.
21. Application of S @30kg/ha increased oil content in soybean.
22. In Boron deficient soils, application of 0.5 kg B/ha was found to increase soybean yield.
23. Wheat yield in terms of SYE was significantly affected due to cropping system and nutrient management. 100% inorganic management of nutrients was at par with 50% organic + 50% inorganic and better than 100% organic system.
24. The *Rhizobium* and PSB population increased with 100% organic management practices in soil.
25. PS 1347 gave higher yield than SL 744, PS 1042 and SL 525 at varying levels of plant population (0.3 to 0.6 m plants /ha). After over a period of 7 years, 50% organic + 50% inorganic management system started showing higher soybean seed and wheat yield than other management practices and cropping systems.
26. Application of 125% RDF with FYM @ 5t/ha gave highest seed yield and also seed quality parameters like protein and oil content were also higher in it with PS 1347 variety of soybean.
27. Soybean seed yield was influenced due to varieties, spacing and seed rates. 45 cm gave higher seed yield than 30 and 60 cm with PS 1347 than SL 525. 75 kg seed /ha also gave maximum yield over 55 and 65 kg/ha.
28. Irrespective of the treatments nitrogen balance was negative whereas P balance was highest in control and lowest with 100% RDF + FYM @5t/ha. Negative K balance was recorded in control and positive balance with 125% RDF + FYM @ 5t/ha.

Future Thrust

1. Evaluation of AVT-II entries of soybean for potential production under variable agronomic management practices. eg. Plant population, seed rate, spacing, date of planting, depth of sowing, sowing methods and nutrient requirement.
2. Screening of varieties for abiotic stress.
3. Weed management practices, integrated weed management practices and evaluation of new molecules for PPI, PE and PoE.
4. Use of plant residues as mulch for water and soil conservation.
5. Development of package and practices of soybean production technology with reference to lower /mid/high altitude of hill agriculture of Uttarakhand.
6. Production technology development of soybean under organic mode.
7. Studies on planting genotype and soybean based cropping systems.
8. Studies on micro and secondary nutrients of soybean under hill agriculture.
9. Studies on seed germination under variable environmental conditions.

Entomology

The yield loss due to insect pests and diseases in soybean is about 32% (Sharma and Shukla, 1997) and insect pests alone cause more than 25% yield loss (Harish *et al*., 2009; Oerke, 2006; Sharma and Shukla 1997; Shriram, 1996). Fletcher (1922) reported the incidence of nine species of insects on soybean in India. It provides substratum for about 380 species of insects in the world (Luckmann, 1971); whereas in India more than 100 species belong to Hemiptera, Lepidoptera, Coleoptera, Diptera, Orthoptera, Thysanoptera and Collembola effecting the yield and quality of soybean (Gangrade, 1974).

Soybean provides substratum for large number of insect pests in the field as well as storage. About more than a dozen species of insects like stem borers, defoliators and sucking pests are considered as important insect pests of soybean attacking the crop from seedling to maturity at Pantnagar (Table1); while in storage, *Cadra cautella* and *Lasioderma sarricorne* damage the soybean seeds.

Table1: List of insect pests of soybean

Common Name	Scientific Name	Family	Order	Remarks
Stem fly	*Melanagromyza sojae* (Zehnter)	Agromyzidae	Diptera	The infestation was 95-100% during kharif and 60% during rabi. It causes 16-20% yield loss.
Tobacco caterpillar	*Spodoptera litura* (Fabricius)	Noctuidae	Lepidoptera	-
Bihar hairy caterpillar	*Spilarctia obliqua* (Walker)	Arctiidae	Lepidoptera	-
Green Semilooper	*Thysanoplusia orichalcea* (Fabricius) *Chrysodeixis acuta* (Walker)	Noctuidae	Lepidoptera	-
Pod borer	*Helicoverpa armigera* (Hübner)	Noctuidae	Lepidoptera	-
Leafminer	*Aproaerema modicella* (Deventer)	Gelechidae	Lepidoptera	-
Whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera	19% yield loss
Aphids	*Aphis glyciens* (Matsumura)	Aphididae	Hemiptera	-
Leaf hopper	*Empoasca fabae* (Harris)	Cicadellidae	Hemiptera	-
Girdle beetle	*Obereopsis brevis* (Gahan)	Cerambycidae	Coleoptera	It infests 60-80% soybean and reduce 53, 65 and 56% of pod number, pod weight and grain number respectively.
Ash weevil	*Myllocerus undecimpustulatus* (Faust)	Curculionidae	Coleoptera	-
Green stink bug	*Nezara viridula* (Linnaeus)	Pentatomodae	Hemiptera	-
Leaf folder/roller	*Hedylepta indicata* (Fabricius)	Crambidae	Lepidoptera	-
Pumpkin beetle	*Aulacophora faveicollis* (Lucas)	Chrysomelidae	Coleoptera	-
Bean bug	*Riptortus pedestris* (Fabricius)	Alydidae	Hemiptera	-
Thrips	*Caliothrips indicus (Bagnall)* *Scirtothrips dorsalis (Hood)*	Thripidae	Thysanoptera	-

1. Stem fly, *Melanagromyza sojae*

Plate 1a. Adult

Plate 1b. Maggot

Plate1c. Tunnels in Stem

2.* Tobacco caterpillar, *Spodoptera litura

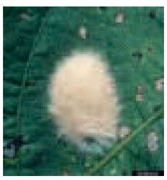


Plate 2a.Egg

Plate 2b.Larva

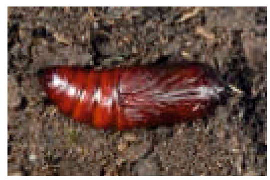


Plate 2c.Pupa

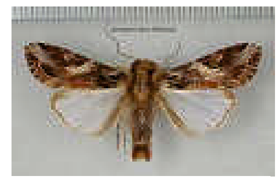


Plate 2d.Adult

Plate 2e.Egg Hatched egg mass

Plate 2f&g. Egg Defoliated soybean leaves

3. Bihar hair y caterpillar, *Spilarctia obliqua*

Plate 3a. Egg

Plate 3b. Larva

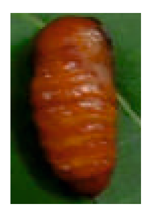


Plate 3c. Pupa

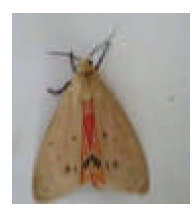


Plate 3d.Adult

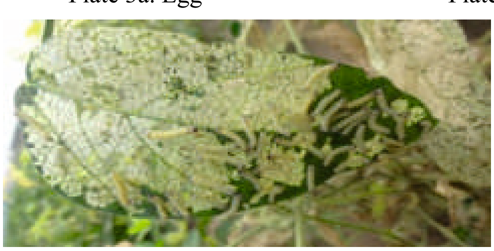


Plate 3e. Papery appearance of leaf

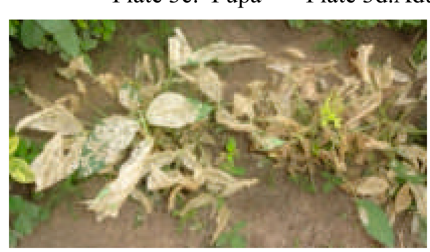


Plate 3f. Damaged soybean plant

4. Leaf folder

Plate 4a&b. Folded leaf by leaf folder

Plate 4c.Larva of leaf folder

Plate 4d. Adult

5. Pod borer, *Helicoverpa armigera*

Plate 5a.Egg

Plate 5b. Larva

Plate 5c. Pupa

Plate 5d . Plate Adult

Plate 5e. Larva feeding on

6. Whitefly, *Bemisia tabaci*

Plate 6a. Nymphs

Plate 6b. Adult

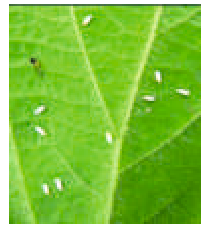


Plate 6c. Whiteflies on soybean leaf

7. Soybean Aphid, *Aphis glycines*

Plate 7. Soybean aphid

8. Girdle beetle: *Oberea (Obereopsis) brevis*

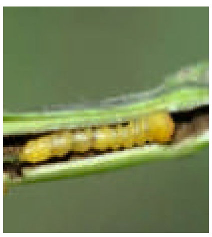


Plate 8a.Grub

Plate 8b. Adult

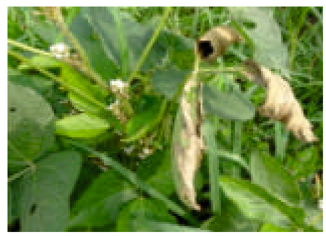


Plate 8c.Damaged plant

Plate 8d&e. Damaging

9. Soybean leaf miner, *Aproaerema modicella*

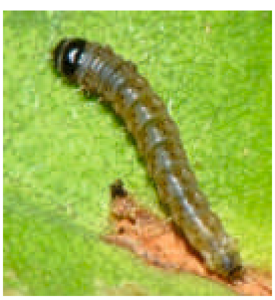


Plate 9a.Larva

Plate 9b.Adult

Plate 9c.Damaged leaf

10. Green semi looper, *Thysanoplusia orichalcea*

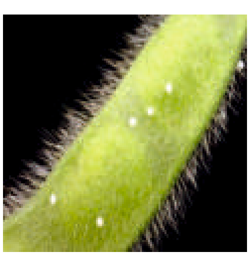


Plate 10a. Egg

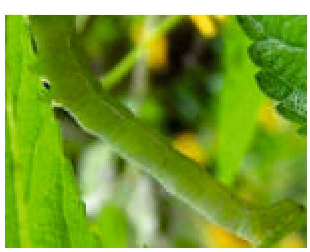


Plate 10b.Larva

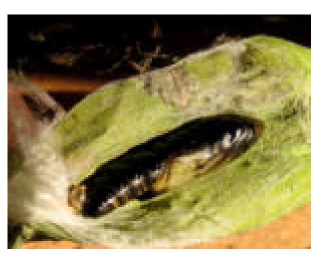


Plate 10c.Pupa

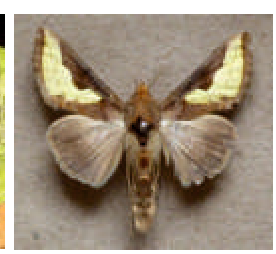


Plate 10d. Adult

11. Green semi looper, *Chrysodeixis acuta*

Plate 11a.Larva

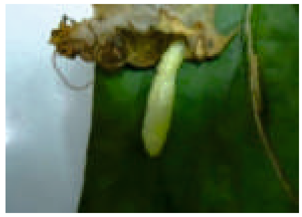


Plate 11b.Pupa

Plate11c.Adult

Plate 11d. Defoliated plant

12. Other insects

Plate12a. Ash weevil

Plate12b. Grasshopper

13. Predators

Plate13a. Spider

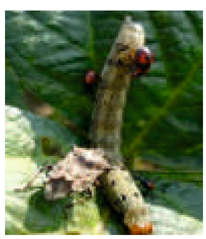


Plate13b. Eocanthecona

Coccinella septumpunctata

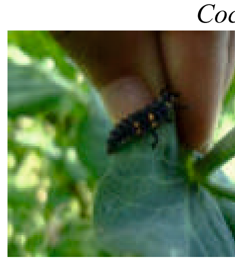


Plate 13c.Grub

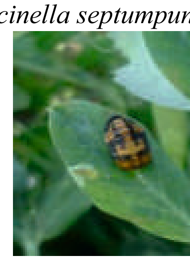


Plate 13d.Pupa

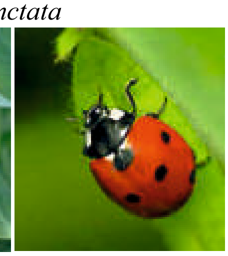


Plate 13e.Adult

14. Microbes

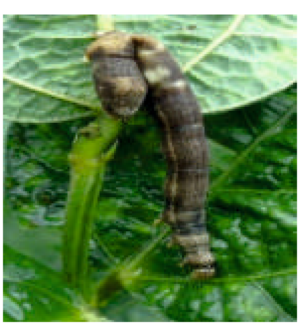


Plate 14a. NPV infected larva

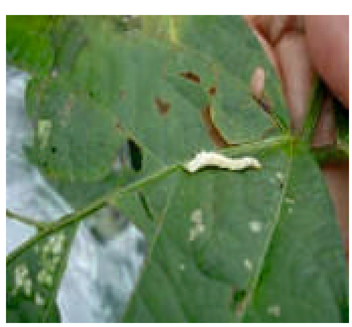


Plate 14b. Fungus infected larva

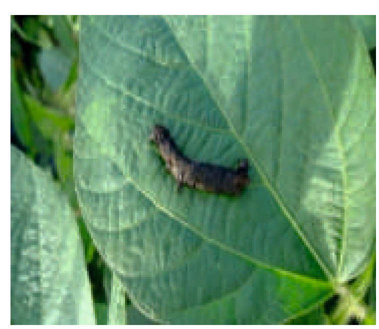


Plate 14c. Bacteria infected larva

The scenario of soybean insect pests and their incidence at Pantnagar, Uttarakhand

The scenario of insect pests infesting soybean was same from 1960 to 2016 except stem fly (*Melanagromyza sojae*), earlier this was known as pea stem borer, *M. phaseoli* and later on the name has been changed as stem fly, *M. sojae***.** The stem fly incidence was recorded from 7 DAG (Days After Germination) to crop maturity and the peak infestation observed during 35 to 63 DAG. The incidence of girdle beetle recorded from 42 to 84 DAG and the peak incidence was observed during 70-84 DAG. Whitefly infestation was recorded from 7 DAG to 105 DAG and the peak infestation was evident during 35 to 84 DAG. The defoliator population builds up slightly late at 28 DAG and continued upto 105 DAG. However, the peak period for defoliator damage was 50 to 80 DAG. Aphid infestation was observed during 35 -105 DAG and the peak population was recorded during 50-90 DAG. The bug incidence was evident from 40 to 112 DAG and the peak population was noticed during 50 to 98 DAG.

Mandate/objectives

1. To study the seasonal incidence of insect pests of soybean
2. Survey of insect pests and their natural enemies associated with soybean crop at farmers fields
3. Collection and identification of insect pests and their natural enemies of soybean
4. To develop an IPM module for insect pests of soybean
5. To screen out the germplasm for identification of resistant source against insect pests of soybean
6. To assess the economic losses caused by major insect pests to soybean
7. To evaluate the efficacy of insecticides, entomopathogens and botanicals against major insect pests of soybean under field and laboratory conditions

Salient Achievements

1. A large variety of artificial diets have been developed for a variety of insects. This major breakthrough as incorporation of various chemical factors responsible for plant resistance in the diet which would indicate the behavior of these chemicals which would greatly helped in developing high yielding resistant varieties either by direct breeding programme or through biotechnology.

2. Intensive survey of insect mycopathogens in the major soybean growing areas of Kumaun region of Uttarakhand was carried out during 2014. The mycosised insect cadavers and soil samples from each location were collected during survey and brought to the laboratory, later on isolated and identified as *Beauveria bassiana*, *Metarhizium anisopliae* and *Nomuraea rileyi.* The prevalence of entomopathogenic fungi was maximum during August- November; mycosis was not reported in *rabi* season, 2014. The maximum mycosised insects recorded from various areas of Nainital district followed by Udham Singh Nagar and Almora districts. The occurrence of *B. bassiana* was observed on some beetles and defoliators of soybean. *T. orichalcea* was more susceptible to *N. rileyi* followed by *M. anisopliae*.

3. **Stem fly resistant varieties:** Himso-558A, Himso-1509, MACS-94, MACS-176, JS-79-295, PK-327, MACS-410, JS 87-24, JS 87-59, PK 416, PK 1069, PK-1079, AMS-4-63, RKS-48, SL-443, MACS 212, JS 81-1625, JS 81-1625, JS8505, PK 1030, PK 1036, PS 564, PK 515, DS2705, DS 2708, JS 20-69, PS 1518, RVS 2007-6, MACS-1442, AMS 1003, MACS 1460, NRC 99, DSb

25, Himso 1685, JS 20-89, MACS 1370, MACS1410, NRC 97, PS 1518 NSO 81, KSO 245, MACS 1311, CSB 08-08, MACS 1336, TS 10 and SL 444.

4. **Defoliator resistant varieties**

1. Pubescence is one of the most important resistance factor in soybean crop and the genotypes resistant to Bihar hairy caterpillar and tobacco caterpillar were DS 2708, DSb 19, DSb 21, JS 20-41, JS 20-69, KDS 693, KDS 705, MACS 1407, MACS 1416, MAUS 612, MAUS 614, NRC 92, NRC 93, RKS 113, RVS 2001-18, SL 958, SL 979, SL 982, SL 688, PS 1092 and PS 1347. These varieties are having dense and pointed pubescence.

2. The soybean genotypes namely JS 20-41, JS 20-69, KDS 708, MAUS 612, RVS 2001 -18, SL 979, SL 688, PS 1347, DS 2708, DSb 19, DS 2706, KDS 693 and PS 1518 contain high amount of phenols, flavonoids, antioxidants and protease inhibitors. They found resistant against *S.litura* and *S. obliqua.*

3. The varieties resistant to girdle beetle were MACS1410, PS1283, DS 2207 and PS1042. The variety DSb 25 is resistant to pod borer.

List of effective insecticides against insect pests of soybean

S.No	Insect Pest	Effective insecticides
1	Stem fly	Anthio 25 EC@ 150g a.i./ha, thimet 10 G@ 2kg a.i./ha, sumithion 50 EC@1.0 kg a.i./ha, disyston 5G, temik 10 G + birlane24 EC@ 1+0.5kga.i./ha, cytrolane 10 G @0.5kg a.i./ha, phorate 10G +3 spray of endosulfan(0.07%) or monocrotophos(0.03%), Neem seed powder at sowing + 3 spray of NSE1%, quinalphos 25 EC @ 1.5l/ha, monocrotophos 36 EC @0.8l/ha, 1.25ml/l and 0.04%; lufenuron 5EC @ 600ml/ha, endosulfan 35 EC @ 1.5l/ha, triazophos 40 EC 0.8l/ha, profenophos 50 EC @ 1.25l/ha, emamectin benzoate 5SG 0.18Kg/ha and thiamethoxam 25 WG @ 100g/ha,
2	Girdle beetle	Triazophos 40 EC @ 0.8l/ha, buprofezin 5EC @ 200ml/ha, monocrotophos 36 EC @0.8l/ha, lufenuron 5EC @ 400ml/ha, ethofenprox 10 EC@ 1l/ha, quinalphos 25 EC@1.5l/ha, ethofenprox 10EC 1l/ha, lambda-cyhalothrin 5EC @ 0.30l/ha, indoxacarb 15 EC @0.3l/ha, methomyl 40SP@ 1kg/ha and Bt.@ 1l/ha.
3	Whitefly	Chlorpyriphos 20 EC 1500ml/ha, lufenuron 5EC @ 400ml/ha, quinalphos 25 Ec 1.5l/ha, endosulfan 35Ec 1.5l/ha, monocrotophos 36 EC @ 0.8l/ha, indoxacarb 15 EC @0.15l/ha, thiamethoxam 25 WG @ 100g/ha, thiamethoxam 500FS@ 4ml/kg seed
4	Defoliators	Cytrolane 10 G @1kg a.i./ha, temik 10 G + birlane24 EC@ 1+0.75kga.i./ha, monocrotophos 36 EC@ 0.04% and 1.25ml/l, phorate 10G +3 spray of endosulfan(0.07%) or monocrotophos(0.03%), lufenuron 5EC @400 ml/ha, endosulfan 35 EC 1.5l/ha, quinalphos 25 Ec @ 1.5l/ha, ethofenprox 10 EC @ 1l/ha, indoxacarb 15 EC @0.3l/ha, profenophos 50EC @ 1.25l/ha and rynaxypyr 20 Sc @ 100ml/ha
5	Leaf tire	Thiamethoxam 25 WG@ 100g/ha and endosulfan 35 EC @ 1.5l/ha
6	Major insect pests	Phorate 10G@ 10 Kg/ha followed by 2 sprayings of endosulfan (0.07%) or monocrotophos (0.04%) or phosphomidon(0.02%) at 45 and 65 days after sowing
7	Seed Maggot, *Atherigona oriedontalis*	Temik 10G@ 1kg/ha

List of chemicals used against insect pests of soybean

S. No.	Year	Insecticides	Dose	Insects
1.	1969-1970	Anthio 25 EC	150 Kg a.i./ha	Pea Stem Borer (*M. phaseoli*)
		Dimecron 100 EC	250 Kg a.i./ha	
		Ekatin 25 EC	150 Kg a.i./ha	
		Metasystox 25 EC	150 Kg a.i./ha	
		Rogor 40 EC	240 Kg a.i./ha	
		Thiocron 30 EC	75 Kg a.i./ha	
		Thimet 10G	0.5,1.00, 1.50 and 2.00Kg a.i./ha	
		Solvirex 5G	1.00, 1.50 and 2.00Kg a.i./ha	
		Rogor 10G	1.00, 1.50 and 2.00Kg a.i./ha	
		Diazinon 20 EC	1.0 Kg a.i./ha	
		Nuvan 100 EC	1.0 Kg a.i./ha	
		Thiodan35 EC	1.0 Kg a.i./ha, 2ml/l water	
		Malathion 50 EC	1.0 Kg a.i./ha	
		Sevin 50 EC	1.0 Kg a.i./ha	
		Sumithion 50 EC	1.0 Kg a.i./ha	
2.	1971	Cytrolane 10 G	0.5, 1.0kg a.i./ha	Pea stem borer, defoliators and whitefly
		Temik 10 G +	1.00+0.5, 1.00+	
		Birlane24 EC	0.75 kg a.i./ha	
		Thimet 10G	0. 0.5kg and 1kg a.i./ha	Whitefly
		azodrin 5G	0.5kg and 1kg a.i./ha	
		disyston 5G	0.5kg and 1kg a.i./ha	
		Solvirex	0.5kg a.i./ha	
		Metasystox	0.025%	
		Sevin	0.1%	
		Temik10G+ metasystox (0.025%) + thiodan (0.035%)	1+0.025+ 0.035 kg a.i./ha	
		Temik 10G+ azodrin 60 EC	1+.06 kg a.i./ha	
		Temik 10G+ metasystox	1+.025 kg a.i./ha	
		Temik 10G+ dimecron	1+ .025 kg a.i./ha	
		Temik 10G+ Anthio 25 EC	1+ .025 kg a.i./ha	
		Temik 10G+ Sevin 50 WP	1+.10 kg a.i./ha	
		Azodrin 60 EC+	0.06+0.025 kg a.i./ha	
		Metsystox 25 EC		
3.	1973	Carbofuran 3G	1kg/ha	Seed Maggot,
		Disyston 5G	1kg/ha	*Atherigona oriedontalis*

		Carbaryl 5G	1kg/ha	
		Tugan 2G	1kg/ha	
		Rogar 5G	1kg/ha	
		Dipterex 5G	1kg/ha	
		Phorate10G	1kg/ha	
		Temik 10G	1kg/ha	
		Carbofuran 50WP	5.0,1.00 and 15.0g/kg seed	
4.	1989-90	Pre-sowing furrow	1.5kg a.i./ha+ 0.04%	Stem fly, Lepidoptera,
		application of phorate10G +		
		Monocrotophos 36 EC		
		Monocrotophos 36 EC	0.04%	
		Phorate + endosulfan	0.07%	
5.	1991-92	Neem seed water	2, 3 and 4%	Stem fly and defoliators
		Neem oil	1 and 2%	
6.	1994-95	Neem seed powder at	1%	Defoliators and stem fly
		sowing + 3 spray of NSE		
		Thiodan 35EC	2ml/l water	Defoliators, stem fly and whitefly
		Metacide 50 EC	1ml/l	
		Hostathion 40 EC	1.25ml/l	
		Methomyl 12.5 L	3ml/l	
		Monocrotophos 36 EC	1.25ml/l	
		Fosmite 50 EC	1ml/l	
		Lindane 20 EC	2ml/l	
7.	2000-01(i)	Bt (Dipel)	1l/ha	Stem fly, Girdle beetle and whitefly
		Beauveria Bassiana (B.b)	1l/ha	
	(ii)	Carbosulfan 25 EC	0.8l/ha	Stem fly, Girdle beetle and whitefly
		Cartap hydrochloride	1kg/ha	
		Ethofenprox 10 EC	1l/ha	
		Profenophos+ cypermethrin 44 Ec	1l/ha	
		Chlorpyriphos+ Cypermethrin	1l/ha	
		Ethion 40+ cyper 5	1l/ha	
		Chlorpyriphos 20EC	1.5l/ha	
		Quinalphos 25 EC	1.5l/ha	
		Triazophos 40 EC	0.8l/ha	
	(iii)	Carbosulfan 25 DS	30g/kg seed	Seedling insect pest of soybean
		Thiamethoxam 70WS	3g/kg seed	

		Imidacloprid 70 WS	3g/kg seed	
		Chlorpyriphos 20 EC	4ml/kg seed	
		Thiamethoxam 25 WG	100g/ha (FS)	
		Imidacloprid 200 SC	100ml/ha (FS)	
		Phorate 10G	10kg/ha	
		Carbosulfan 3G	30 kg/ha	
	(iv)	Lufenuron 5EC	400 and 600ml/ha	Stem fly, whitefly and girdle beetle
		Difubenzuron 25 WP	300 and 400g/ha	
		Buprofezin 25 EC	200 and 400 ml/ha	
		Lambda-cyhalothrin 5EC	300ml/ha	
		Profenophos 50 EC	1500ml/ha	
8.	2001-02	Lufenuron 5EC	400, 500 and 600ml/ha	Stem fly, whitefly and girdle beetle
		Difubenzuron 25 WP	300, 350 and 400g/ha	
		Chlorpyriphos 20 EC	1500ml/ha	
9.	2002-03(i)	Lufenuron 5EC	400, 500 and 600ml/ha	Defoliators
		Difubenzuron 25 WP	300, 350 and 400g/ha	
		Chlorpyriphos 20 EC	1500ml/ha	
	(ii)	Triazophos 40 EC	0.8l/ha	Stem fly, girdle beetle, whitefly and defoliators
		Quinalphos 25 EC	1.5l/ha	
		Methoyl 40 P	1kg/ha	
		Ethion 50 EC	1.5l/ha	
		Ethofenprox 10 EC	1l/ha	
		Thiamethoxam 25 WG	100g/ha	
		Endosulfan 35 EC	1.5l/ha	
		Monocrotophos 36 SC	0.8l/ha	
10.	2003-04 (i)	Bt (Dipel)	1l/ha	Defoliators, stem fly, girdle beetle and whitefly
	(ii)	Chlorpyriphos 20EC	1.5l/ha	Stem fly, girdle beetle, defoliators and whitefly
		Triazophos 40 EC	0.8l/ha	
		Quinalphos 25 EC	1.5l/ha	
		Methoyl 40 SP	1kg/ha	
		Ethion 50 EC	1.5l/ha	
		Ethofenprox 10 EC	1l/ha	
		Thiamethoxam 25 WG	100g/ha	
		Endosulfan 35 EC	1.5l/ha	

		Monocrotophos 36 SC	0.8l/ha	
11.	2004-2005	Bt (Dipel)	1l/ha	Leaf tire, whitefly,
	(i)	Monocrotophos 36 SC	0.8l/ha	defoliator, stem fly
		Methoyl 40 SP	1kg/ha	and girdle beetle
		Ethofenprox 10 EC	1l/ha	
	(ii)	Chlorpyriphos 20EC	1.5l/ha	Stem fly, girdle beetle
		Triazophos 40 EC	0.8l/ha	defoliators and leaf tire
		Quinalphos 25 EC	1.5l/ha	
		Ethion 50 EC	1.5l/ha	
		Thiamethoxam 25 WG	100g/ha	
		Endosulfan 35 EC	1.5l/ha	
12.	2005-06	Bt (Dipel)	1l/ha	Defoliators, stem fly
		Monocrotophos 36 SC	0.8l/ha	and girdle beetle
		Methoyl 40 SP	1kg/ha	
		Thiamethoxam 25 WG	100g/ha	
		Ethofenprox 10 EC	1l/ha	
13.	2006-07	Indoxacarb 15 EC	0.3 and 0.15 l/ha	Defoliators, whitefly
		Diafenthiuron 50 WP	500g/ha	and pod borer
		Profenophos 50 EC	1.25 l/ha	
		Lambda-cyhalothrin 5EC	0.30l/ha	
		Emamectin benzoate 5SG	0.18Kg/ha	
		Triazophos 40 EC	0.8l/ha	
		Spinosad 45 SC	0.10 and 0.20l/ha	
		Thiamethoxam 25 WG	100g/ha	Defoliators, whitefly
		Thiamethoxam 70WG	3g/ha	and stem fly
		Thiamethoxam500FS	1,2,3 ga.i./ha	
		Bt.	1l/ha	Defoliators, girdle
		Monocrotophos 36SC	0.8l/ha	beetle and whitefly
		Methomyl 40 SP	1kg/ha	
		Ethofenprox 10 EC	1l/ha	
14.	2012-13	Rynaxypyre 20 Sc	@ 100 ml/ha	Defoliators, stem fly
		Indoxacarb 14.5 SL	@300 ml/ha	and girdle beetle
		Triazophose 40 EC	@ 800 ml/ha	
15.	2014-15	Rynaxypyre 20 Sc	100 ml/ha	Sucking pests and pod
		Indoxacarb 14.5 SL	300 ml/ha	borer
		Quinalphos 20 EC	1.5 l/ha	
		Imazathapyr 10 SL	1.0 l/ha	
		Quizalafop ethyl 5 EC	1.0 l/ha	

Plant Pathology 5

Low yield of soybean is generally attributed to several reasons, e.g. Socio-economic conditions, drought, flood, lack of inputs, diseases and pests. Soybean is mainly grown in the monsoon (rainy) season when high temperature and humid weather prevails making the crop more susceptible to disease and pest attack. Initially, the soybean was free of diseases in India. However, its continuous cultivation with simultaneous increase in area has led to increase in disease incidence. Losses due to various diseases are one of the major causes for reducing the productivity of the soybean in Uttarakhand. There are over 100 pathogens parasitizing soybean plants in different parts of the world of which 35 are economically important. In India, during the years 2007-08, 22 diseases were reported across the country, except for 9 diseases that were of wide occurrence, rests were limited to particular locations **(NRCS, 2011)**. Major diseases of soybean reported from different parts of India are Rhizoctonia aerial blight, Pod blight, Charcoal rot, Myrothecium leaf spot, Brown spot, Target leaf spot, Powdery mildew, Alternaria leaf spot, Curvularia leaf spot, Soybean rust, Bacterial pustule, Bacterial leaf blight and viral diseases such as Soybean mosaic virus, Soybean yellow mosaic virus and Leaf crinkle virus.

Plate 1. A field view of AICRP on Soybean Plant Pathology trials

The occurrence and severity of the diseases and resultant losses are dependent on the prevailing agro climatic conditions and varieties grown in an area. In Uttarakhand major diseases of soybean are seedling blight, bacterial pustules, pod blight, soybean mosaic (Soja Virus-1) yellow mosaic virus, rhizoctonia aerial blight and bud blight were observed from different areas. Amongst them the disease caused by RAB is economically more important because they cause heavy yield losses. Problems with germination and crop stand are related to seed decay, damping-off and seedling blights are often encountered in the field (Plate 1). Early planting, wet, poorly drained or compacted soils are especially prone to these diseases. Disease reduced shoot length, pod and seed formation, total number of seeds and seed weight. Rhizoctonia aerial blight develops most often during periods of high rainfall predominantly in Uttarakhand, Chhatisgarh, and Madhya Pradesh.

Mandate/ objectives of the Project

Aspects of Psychopathological areas being researched on priority with utmost emphasis on screening of germplasm/ accessions/entries to locate sources of resistance to be employed for breeding programme of varieties against major diseases, evaluation of need based fungicides, harnessing the role of fungal and bacterial antagonists, cultural operations etc. The ultimate aim is to develop IDM modules for management of diseases that are ecologically safe and harmonious to ecosystem. Besides these, the host, pathogen and plant factors affecting prevalence, incidence and severity of important fungal, bacterial, viral and nematode diseases are being worked out based on epidemiological information; predictive and forecasting modules are being developed. The Research work on soybean pathology at Pantnagar was started in mid-sixties with definite objectives in mind:

1. Survey and surveillance for soybean diseases
2. Screening of soybean trap nursery trial for important diseases that are endemic to the region
3. Evaluation of germplasm and breeding entries of soybean for their reaction to important diseases
    a. IVT
    b. AVT-I
    c. AVT-II
4. Performance of the previous year's resistant breeding entries
5. Development of economical and more effective IDM program for the management of economically important diseases over a larger area, with integration of fungicidal, biological and climatologically components

Soybean diseases, symptoms and management

Prevalence and Severity

Prevalence and severity of various important diseases of soybean growing areas and agro climatic zones I (low hills, sub tropical zones, foot hills) and zone II (mid-hill zone) covering important soybean growing districts of Uttarakhand during last fifty years from July to September. As can be seen in Table 1, the BLB, BP, RAB, PB, SMV and SYMV were found to be evenly spread in all the farmers' fields that were surveyed. The diseases like SMV, SYMV, BP, Fusarium wilt and RAB were appeared in 1st week of August to mid of August but BLB, Anthracnose pod blight and Charcoal rot were noticed in 1st week of September to mid of October. The first symptoms of SMV and SYMV were recorded on leaves in 2nd week of August in unsprayed field. The incidence of SMV ranged between 30 to 40 per cent on foliage while SYMV was observed in between 45 to 55 per cent on leaves (Figure 1 & Table 1).

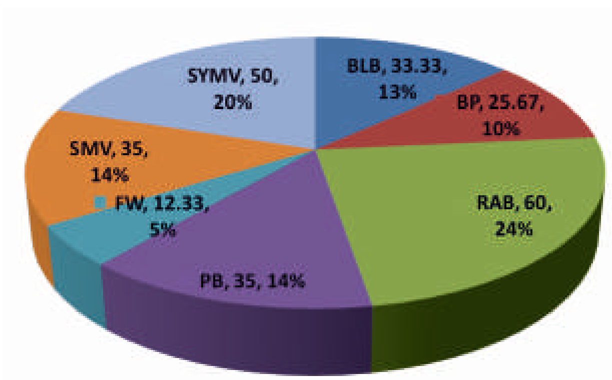


Figure 1. Distribution of soybean diseases in major districts of Uttarakhand

The RAB was found to be more prevalent and wide spread in all the soybean growing areas and its incidence was estimated maximum in susceptible cultivars which ranged from 15 to 60 per cent in Tarai region. Pantnagar was observed as the hot spot for RAB having maximum disease incidence and severity of 57.67 and 59.66 per cent which was significantly higher than other places of Uttarakhand. This disease is favoured by high temperature (>25ºC), high water table and relative humidity and these environmental conditions prevails in soybean growing areas in zone I of Uttarakhand (nine weeks after sowing), when the crop is at vulnerable stage for RAB. High temperature, cloudy conditions with high relative humidity are favourable for the development and spread of RAB. During last fifty years of survey report, RAB was observed to be a major problem in foot hill areas of Uttarakhand and Pantnagar has been considered as a hot spot of the disease. Not only now, it was found that the disease had gained attention since 1980's when its severity was high (AICRP, 1980). The disease like bacterial pustule, bacterial blight, and *Rhizoctonia* aerial blight were rapidly spread between September to October in unsprayed field. Pod blight was noticed in 3rd week of September and spreads rapidly in the month of October.

Table 1: Prevalence, incidence and period of occurrence of various diseases of soybean in Uttarakhand during *Kharif* season.

Sl. No.	Name of disease	Pathogen(s)	Disease incidence (%)	Period of its rapid spread
1	Bacterial Blight (BLB)	*Pseudomonas savastanoi* pv. *glycinea*	15-40	August – October
2	Bacterial Pustule (BP)	*Xanthomonas campestris* pv. *glycines*	10-40	September – October
3	Rhizoctonia Aerial Blight (RAB)	*Rhizoctonia solani*	15-60	August – October
4	Pod Blight (PB)	*Colletotrichum truncatum*	20-40	October
5	Fusarium wilt (FW)	*Fusarium sp.*	Trace	August
6	Soybean mosaic virus (SMV)	*Soja virus-1*	20-40	August – September
7	Soybean yellow mosaic virus (SYMV)	Mung bean yellow mosaic virus	40-55	August – September
8	Charcoal rot (CR)	*Macrophomina phaseolina*	Erratic	September October

Seed and Seedling Rots

It is the first and perhaps one of the most important problems in successful soybean production to achieve a proper emergence and stand in the field. One of the main reasons for poor seedling emergence in field is a large scale seed and seedling rots. The early season soybean diseases include those that cause seed decay, seedling blights and root rots of soybean (Plate 2). Disease symptoms of these early season soybean diseases may vary from seed decay to pre-emergence or post emergence damping off to wilt and death of established seedlings. The first and perhaps one of the most important problems in successful soybean production is to achieve a proper emergence and stand in the field (Plate 2). One of the main reasons for poor seedling emergence in field is a large scale seed and seedling rots. Under warm humid conditions the germinating seed is fully covered with variously coloured fluffy fungal growth which inhibits its germination or may kill the emerging seedling. Hence, right from the beginning this problem has been under study for determining its causes and evolving effective control measures. A large number of fungi like species of *Pythium, Phytophthora, Colletotrichum, Aspegillus, Fusarium, Macrophomina, Monilia etc.* and a few bacterial species of *Pseudomonas*, *Bacillus* etc. have been observed to be responsible for seed and seedling rots in soybean. These organisms are both, seed- and soil- borne in nature. *Fusarium*, *Pythium*, *Phytophthora* and *Rhizoctonia* are the most common of

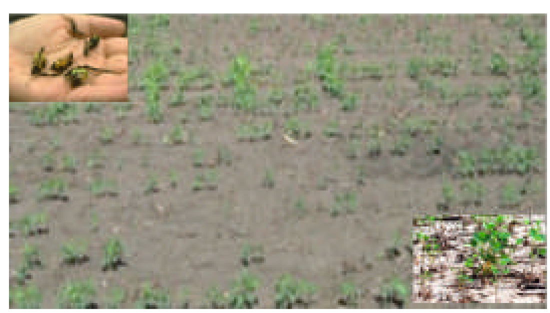


Plate 2. Field view of damage due to Seedling Rots

these early season pathogens.

The early season soybean diseases can be managed by soil solarization for a period of 30 days during May-June under Pantnagar conditions which has been found significant in reducing the seed and seedling rots. The seed treated with Thiram 4.5 g/kg or Thiram 75 W.P + Bavistin 25 S. D. (1:1, w/w) @ 3 g/kg seed effectively controlled these rots and significantly improved seedling emergence, crop stand and yield. Soybean seed treated with different fungicides and inoculated with *Rhizobium japonicum* planted at 0, 4, 24 and 48 h after treatment to observe the treatment effect on emergence, nodulation and yield exhibited significant increase in emergence and nodulation with Thiram, Bavistin, Difolatan and Dithane M-45. All fungicides used, enhanced the yield of soybean. Delay in planting of the fungicides treated and *Rhizobium* inoculated seeds, reduced the emergence and nodulation of soybean with the reduction depending on the fungicide used for seed treatment. Before sowing soybean seeds should be treated with fungicides, Thiram + Carbendazim (2:1 ratio) @ 3g/kg seeds or bioagents i.e. *Trichoderma harzianum* + *Pseudomonas fluorescens* (1:1 ratio) @ 10 g/kg seeds at least 12 hrs before planting of seeds for controlling seed and seedling rots and ensuing higher field emergence.

Rhizoctonia aerial blight (RAB)

Rhizoctonia aerial blight of soybean caused by *Rhizoctonia solani* Kuhn is a very common disease affecting most of the soybean cultivars in the warm humid 'Tarai' region of Uttarakhand and Uttar Pradesh. RAB was observed to be a major problem in foot hill areas of Uttarakhand. The symptoms of RAB were developed as leaf and pod spots, leaf blight, defoliation, stem and petiole lesions, web like mycelium and sclerotia produced on infected leaves (Plate 3a, b). The necrotic areas were smaller at initial stage and then covered entire leaflet. Lesions were reddish brown in colour, oval to linear in shape. The lesions initially appeared as water soaked at the base of the blade and petioles subsequently, spread in a fan shaped manner to the rest of the leaflet. Lesions later became necrotic and brown to tan with thin reddish brown margin which ultimately dries out. Web like mycelium and sclerotia was developed later on infected leaves (Plate 3a). RAB was observed to be initiated in the last week of August to the first week of September at CRC Pantnagar. Pantnagar was observed as the hot spot for RAB having maximum disease incidence and severity of 57.67 and 59.66 per cent. The results further warranted the need for better management of the disease in Pantnagar area.

Plate 3a. Symptoms and signs of Rhizoctonia aerial blight on leaves

Plate 3b. Field symptoms of Rhizoctonia aerial blight

By comparing the disease index of different cultivars for last six consecutive years, it was observed that per cent disease index of RAB on soybean varies in different blocks of Crop Research Centre, Pantnagar in different years. Among all the sixteen varieties tested PK-262, PK-472 were moderately resistant, variety JS-7244, JS-72-220, JS-7105, Bragg and Monetta were moderately susceptible while JS-7546, MACS-52, JS-93-05, Pb-1, KHSb-2, NRC-7, VLS-58, JS-335 and Shivalik were susceptible to Rhizoctonia aerial blight infection. Based on reaction, infection rate and AUDPC values of both the cultivars PK-472 (Disease index= 24.54%; r= 0.061 unit/day; AUDPC= 133.67) and PK-262 (Disease index= 26.71%; r= 0.044 unit/day; AUDPC= 147.81) exhibited moderate resistance to RAB and thus are most suited to Pantnagar condition. Therefore, these two cultivars are being used in crossing programme to develop high yielding soybean cultivars with partial resistance to RAB.

The disease development had three distinct phases i.e. establishment, progress and decline phases. The favorable time of RAB development was observed to be 35 SMW and after the 38 SMW the disease increased at a drastic rate and attained maximum disease at 42 SMW based on the presence of suitable environmental conditions for disease initiation and spread. The maximum progression was observed between R3 (Pod initiation) and R4 (Full pod) stage (60-74 days). The disease severity increased from 53 days at R1 (flowering) stage to 81 days when crop reached at maximum R6 (seed filling) stage and further to 95 days at R7 (physiological maturity) stage (Figure 2). The lowest disease severity of 3.20 per cent recorded on 53 days old plants while it was highest (52.02 %) on 95 days old plants. Among various environmental factors, maximum temperature, maximum relative humidity, rainfall and sunshine influenced the initiation and development of RAB. High temperature (>32ºC) and morning humidity (>88%) are required for initiation of RAB and after that minute reduction in the temperature and humidity don't have much effect on disease (Figure 3).

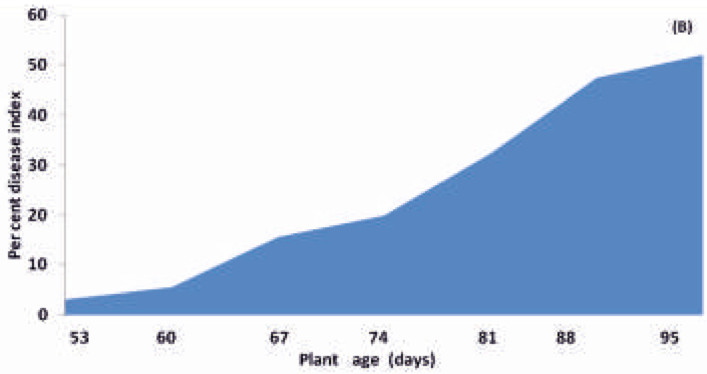


Figure 2: Disease progress curves of several years' pooled data of RAB disease index at given plant ages (R1-R2: 53 days; R3: 60days; R3 - R4: 67 days; R4-R5: 74days; R5: 81days; R5-R6: 88 days; R6- R7: 95 days)

It is evident from the disease progress data of the several years that the progress of disease intensity was observed slowly in the beginning of September and increased at a drastic rate in the last week of September (22nd to 29th September). The highest disease intensity was observed in cv. Pb-1and the least in JS-7105, PK-472 and PK- 262, which reaches at its maximum in the 2nd week of October. Thus these varieties are well suited to the conditions prevailing in Pantnagar keeping the disease pressure at its minimum. Pb-1 cultivar was not found suitalbe for this region as it is highly susceptible to Rhizoctonia aerial blight showing highest disease index and progress. The progress was slower in the beginning of September while it increased at a drastic rate in the last week of September i.e. from 22nd to 29th September after which the increase was again at a slower rate. The rise in infection rate in the initial stage of disease was slow in the 1st and 2nd week of September. This was followed by rapid progress of the disease due to favourable weather conditions and reaches maximum in most of the cultivars but declined later due to reduction in temperature and fall in relative humidity and decrease in the hours of bright sunshine (Figure 3).

The stepwise regression analysis was performed after pooling the all year's data to find out the relationship between weather parameters and disease index on different cultivars. The coefficient of determination was ranged between 0.78 to 0.94. It may further be noted that weather parameters altogether accounted for only 78 to 94 percent variation in the development of RAB. The maximum multiple coefficient of determination values between disease index and group of variables is 0.94 (PK-262) for pooled data. This clearly indicates 94 percent changes in disease index were affected by maximum temperature, morning RH, rainfall and sunshine collectively, whereas rest of the variation was due to unexplained (error variation) factors which might be genetic and/or the factors not included in the investigations. The results also revealed that almost similar trend was observed in the remaining varieties of the soybean. The observed and predicted values of RAB progression are depicted in Figure 4. In general, predicted values fluctuated around the original values. The high temperature (>32 ºC), RH morning (>88 %), rainfall (>14 mm) and sunshine (6.5 hrs) were most deciding factors for the development of RAB on all the varieties in developing the regression model during the mean values of several year data. The varieties JS-72-220, PK-262 and PK-472 were considered as moderately resistant to RAB whereas JS-7244, JS-7546, Bragg, Monetta, VLS-58 and JS-335 may have rate reducing components. It is also evident from the pooled data that the difference in successive observations followed the pattern of normal curve for all the years. Early attempts to predict RAB development relied heavily on the observations of the interactions between pathogens and environment favouring rapid disease development.

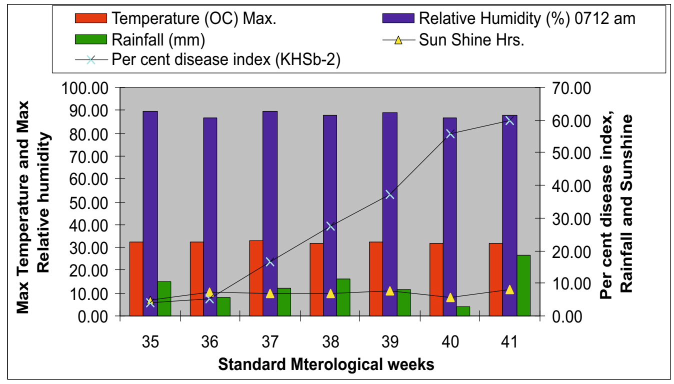


Figure 3. Pooled per cent disease index in relation to weather variables during disease period

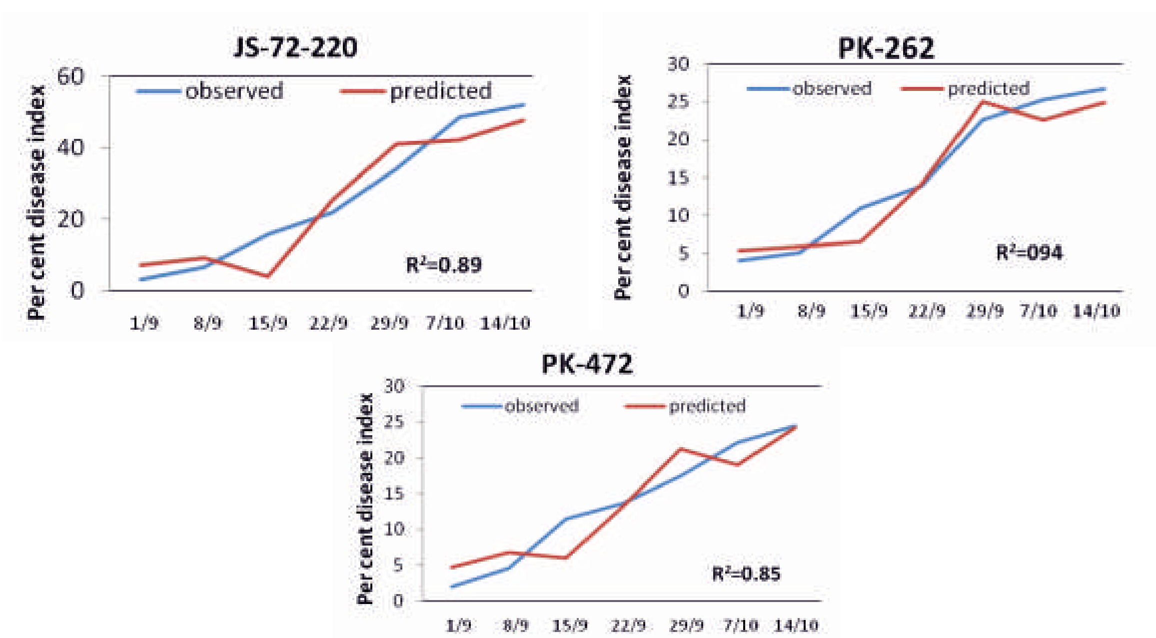


Figure 4: Observed and predicted per cent disease index by multiple regression method for RAB disease progression in moderately resistant cultivars of soybean

Depending upon the host pathogen relationship, the nature of damage caused and the method of disease management employed, different models have been proposed to predict yield losses. A crop yield loss per cent predicting models were developed based on linear and multiple regression equations with high R^2 (R^2=0.98 and 0.99) value in both the models (Linear regression and Multiple regression crop loss models) predict fitness of the model in predicting yield loss. The present models developed depicts the correlation with given PDI and expected yield. Model developed helps to calculate the yield with the given PDI. As fitting of the model is dependent on maximum R^2, it could be fitted anywhere at a particular PDI value. Further validation confirmed the model with low residual values of observed and predicted yield loss.

Management

1. Pyraclostrobin (0.1%), Pencycuron (0.1%) and Fluopyram (0.1%) were most effective in reducing RAB disease index while antagonist treatment with *T. harzianum, P. fluorescens* and *B. subtilis* were least effective in controlling *R. solani*.
2. Chemical control with Strobulin and Triazole group of fungicides were most effective against *R. solani* in field but its efficiency was slightly influenced by the prevailing environmental conditions.
3. Maximum yields were obtained from the plots receiving two sprays of Pyraclostrobin (29.30 q/ha), Fluopyram (29.21q/ha) and Pencycuron (29.10 q/ha) which was 43.56, 43.12 and 42.87 per cent more over the control.
4. Cost benefit ratio of the treatment Pencycuron (0.07:1) was superior followed by Hexaconazole (0.08:1), Pyraclostrobin (0.12:1) and Chlorothalonil (0.13:1) suggesting their economic feasibility as chemicals effective for management of Rhizoctonia aerial blight.
5. The maximum oil content was observed in Azoxystrobin (21.60%) and minimum in Myclobutanil (18.45 %) treated plots while highest protein content was recorded in Pyraclostrobin (37.95 %) and Myclobutanil (37.95 %). Strobulins have higher positive impact on the qualitative traits of the soybean seeds improving seed health by various mechanisms.
6. Out of the nine soybean seed samples harvested from the field treated with different fungicides, Myclobutanil was found to have 0.21ppm residue in the sample while Axozystrobin had 0.0071ppm residue while the other fungicides were found to have residue below the detection limit. All the residues were below the permissible minimum residue limit (MRL) set by the International Standards implicating their safe consumption.
7. Elicitor compounds including chemicals, hormones and bioagents increased the accumulation of defense compounds *viz*., H_2O_2, APX, POD, PPO, SOD and PAL, initiating a whole array of defense mechanisms thereby inducing induced systemic resistance (ISR).
8. All the elicitor biomolecules decreased the endogenous content of xylanase, laccase and cellulase to a greater extent, which have been reported as pathogenic determinants and assist pathogen attack. So reduction in their concentration strengthens the plant defense.
9. Different Integrated Disease Management (IDM) modules were tested against RAB in which combined use of cultural practices (deep summer ploughing), chemical method (seed treatment with carbendazim @2g/kg seed + foliar spray of carbendazim @0.05% at 30 DAS + P.E. soil application of herbicide i.e. pendimethalin @ 1.0 kg a.i. /ha) + Use of organic matter as vermicompost under biosuppression have been proved a better combination for reduction

of disease intensity of rhizoctonia aerial blight and to increase the yield of soybean.

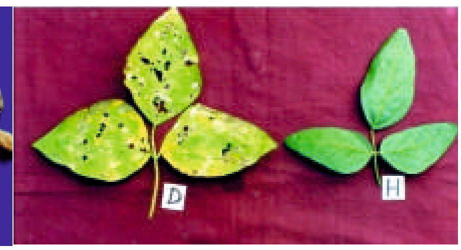
10. Sugarcane bagasse and Neem cake (De-oiled) amended soil extracts were found very effective against *Rhizoctonia solani*, causing aerial blight of soybean *in-vitro*.

11. Neem cake amended soil, inoculated with *Rhizoctonia solani* gave maximum percentage (91.47%) of seed germination and suppressed the seed and seedling rot caused by *R. solani* under green house conductions.

Pod Blight (Anthracnose)

It is caused by *Colletotrichum truncatum* or *Colletotrichum dematium* (Pers, ex Fr.) Grove var. *truncatum* (Schw.) Arx or *C. dematium* var. *truncata* (schw.) Andrus and Moore is a very serious problem in varieties that mature during rainy period. The infected seeds colonized by fungus may appear dirty with irregular brown areas or small uneven grey areas with black speck (Plate 4). The symptoms appear on stems, pods and leaf petioles as irregularly shaped brown blotches. The disease was severe, leaf rolling, premature defoliation and plant look like stunted. Pods may be shriveled and contain less seed or no seed. The most conspicuous effect of the disease is the production of shrivelled, diseased, poor quality grains which is worthless as a seed material. Seed rot, seedling decay, stem blackening, leaf spot, pod blackening and blight are the major symptoms. Young pods shrivel and do not form good seed. Number of acervuli develops in rings on pod surface, ultimately lead to blackening (Plate 4).

Infected shrivelled and healthy seeds



Diseased and healthy leaf

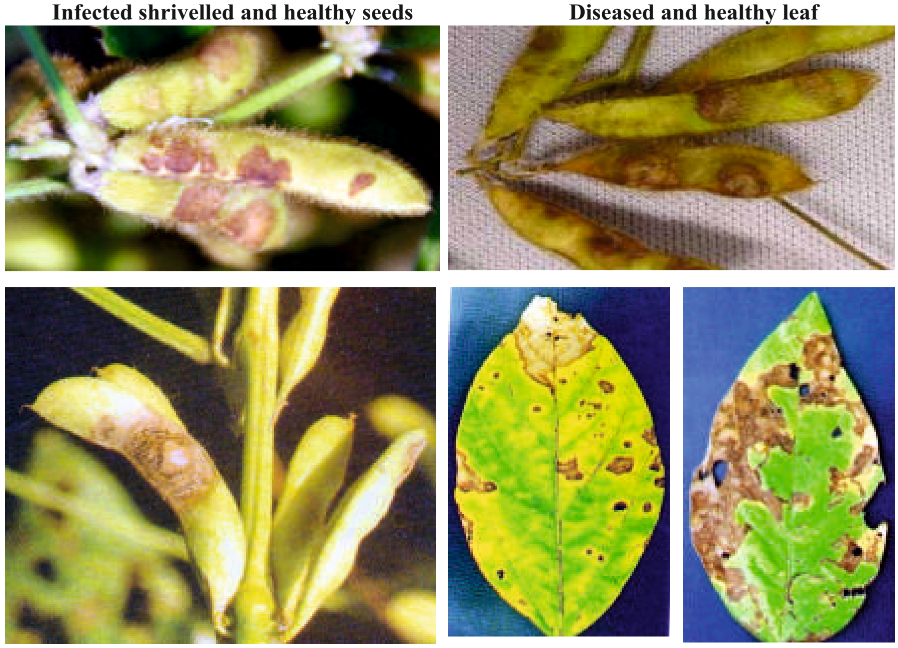


Plate 4. Acervuli development on pods and irregular spots on leaf (Anthracnose)

Management

1. The average reduction in seed yield, protein and fat to the tune of about 34, 13 and 3 percent, respectively in a susceptible cultivar (Shilajeet).

2. Among the fourteen varieties / cultivars screened against anthracnose, var. Kalitur has been identified as resistant and PK 1029 as moderately resistant.

3. Removal of plant debris, deep summer ploughing and sanitation practices found effective in reducing the pod blight.

4. Seed dressing with Thiram (3g) or Thiram (1.5g) + Carbendazim (1g) per kg seed is most effective against pod blight.

5. Six weekly foliar sprays of Zineb (2.5 kg/ha) starting at 30 days after planting significantly reduced the disease but effect on yield was non-significant.

6. Several newer fungicides have been evaluated against *C. dematium* var. *truncata in-vitro*, among them Tilt, Saaf, Bavistin and Benlate have been found to give complete inhibition (100 %) of mycelial growth of *C. dematium* var. *truncata in-vitro*.

7. Several bioagents have been tested against the *Colletotrichum dematium* var. *truncata* wherein *Trichoderma harzianum* has been found to give maximum inhibition (26 per cent) of mycelial growth of pathogen and was established a potent bioagent *in vitro*.

8. Crop rotation to non host crops is a proven strategy to reduce anthracnose inoculums in a field

Bacterial Pustule

Bacterial pustule disease caused by *Xanthomonas compestris* pv *glycines* and affects large number of soybean varieties. The disease reduces the yield up to 38 per cent as well as protein content in the grains. Most of the commonly grown soybean varieties are resistant to bacterial pustule disease. Detailed physiological studies on the causal bacterium have been completed. Optimum conditions for its *in-vitro* growth are Wakimoto's broth, at pH 6.8 and 30^{0}C temperature. The early symptoms consists of small, pale green spots with raised centers on leaves in the mid- to upper canopy (Plate 5). As the disease progresses, small brown-colored pustules form in the middle of the spots and the spots turn yellow. The spots may merge, forming large irregularly yellowing lesions. Bacterial pustule lesions are sometimes confused with the lesions caused by bacterial leaf blight (Plate 5). Bacterial leaf blight lesions appear water-soaked while the lesions of bacterial pustule do not. As in other bacterial diseases, if a soybean leaf with lesions due to bacterial pustule is cut and submerged in water, bacteria will stream out of the infected tissue.

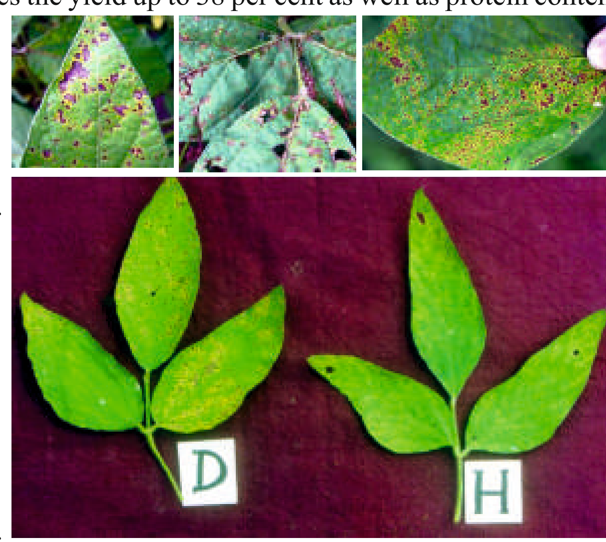


Plate 5. Bacterial pustule symptoms on soybean leaves, D= Diseased, H= Healthy leaves

Management

1. A coordinated chemical control field trial conducted for several years revealed that two high volume (1000 1/ha) foliar sprays, at 45^{th} and 55^{th} day after planting with a mixture of

Blitox-50 (1.5 kg/ha) + Agrimycin-100 (150 g/ha) or Streptocycline (150 g/ha) + Copper sulphate (1 kg/ha) are adequate for the effective control of the disease with consequent yield increase.

2. Two sprays of Copper oxychloride @ 0.2% + Streptocycline @ 0.01% at 45 and 55 DAS were also found effective against this disease.

Charcoal Rot

It is also called as dry root rot or dry weather wilt was one of the major constraint in soybean cultivation during 1975 to 2000 in UP and hilly areas of UP (now Uttarakhand). It is a major root inhabiting fungal problem responsible for losses up to 70 per cent in Uttarakhand (then part of UP) in 1980, resulting in poor seed quality and yield in hot dry weather. Charcoal rot is a soil borne root and stem disease of soybean that develops in the mid to late summer when plants are under stress, especially heat and drought stress. Infected plants may die prematurely and are often wilted and stunted (Plate 6). During 1975 spring season crop (Feb. –June) of most of the varieties were found showing the charcoal rot symptoms caused by *Rhizoctonia bataticola* (*Macrophomina phaseolina*) (Tassi) Goid. Screening of varieties under green house condition showed that the fungus can cause seed rot in all the varieties tested. the seed rotting in cultivars varied from 34 per cent to 100 per cent. In the stem inoculation screening technique conducted under green house conditions, Ankur, PK 73-94, PK 71-21, PK 71-39 and PK 72-4 showed only stem lesions unlike other varieties where seedling mortality was also recorded. The leaves turned yellow and wilted but remain attached. The tap root portion show light grey discolouration of epidermal and sub-epidermal tissues (Plate 6). After peeling off the skin of infected roots the black charcoal like powder with numerous microsclerotia and pycnidial fruiting bodies of *M. phaseolina* are visible. The fungus causes a reddish brown discolouration in the vascular tissue of the tap root and progresses upward (Plate 6).

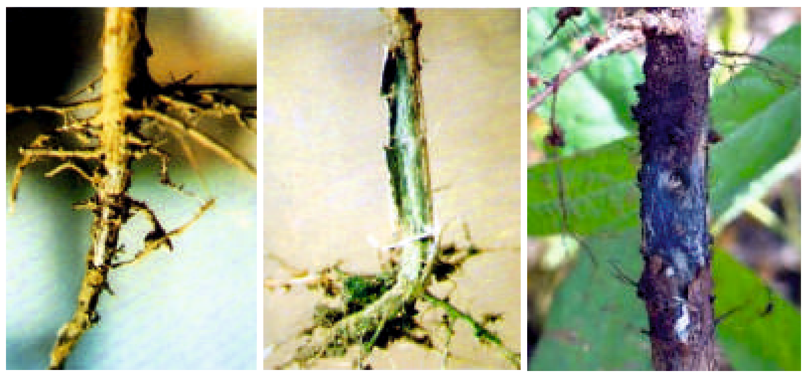


Plate 6. Discolouration of epidermal and fungal fruiting bodies on sub epidermal tissues of tap root

Management

1. Now-a-days, more emphasis is being given on biocontrol to combat plant diseases. Among bioagent tested, *Trichoderma harzianum* was found to be more effective as compared to *T. viride* and *Gliocladium virens*. Integration of Vitavax (0.1%) with *T. harzianum* (0.3 %) improves seedling emergence, plant population, number of branches per plant, number of buds/ plant, root nodulation, height of plant and increase in yield.

2. Use disease free healthy bold seeds

3. Removal of plant debris, deep summer ploughing and sanitation reduces the disease incidence

4. Seed dressing with Thiram (4.0 g/kg) or Thiram (1.5 g/ kg) + Carbendazim (1.5 g/kg) prior to sowing reduces seed borne inoculums and maintains good plant stand.

Soybean mosaic virus (SMV)

It is seed borne in nature and caused by Soja virus-1. The available germplasm received from coordinated cell were screened for its reaction against the SMV and resistant germplasm lines were identified. The identified resistant sources were utilized by the soybean breeder in making crosses and generating segregating progenies which were again evaluated for their reaction against SMV. Infected seeds may fail to germinate or may produce diseased seedlings. SMV can cause yield loss, affect seed quality, and reduce seed germination and nodulation. Yield reductions are generally low and infections late in the season cause little damage in Uttarakhand. Plants infected early in the season are stunted, with shortened petioles and internodes. Leaves are reduced in size, puckered and remain darker than the normal leaves. Dark green enations along the veins is a common feature (Plate 7). Plants infected when young tend to show more symptoms than plants infected when older. Affected leaflets curl down at the margins. The common aphid species are *Myzus persicae* and *Myzus convolvuli solani*. The virus is also transmitted through seeds and can remain viable in seeds for at least two years. Higher activity or populations of aphids favor virus transmission. Infected pods remain small, flat, deformed with few mottled seeds which are brown to black in colour (Plate 7).

Plate 7. Soybean mosaic caused by Soja virus-1

Management

1. Foliar sprays of Monocrotophos (0.1%) at 15-20 days interval to check the activity of aphids.
2. Roughing of infected plants in field
3. Use of soybean mosaic free seeds
4. Planting early in the season may be helpful in North Plain region.

Soybean Yellow Mosaic Virus (SYMV)

Soybean yellow mosaic virus was a major disease problem in this area when soybean project was started. The available germplasm were screened for its reaction against the SYMV and resistant germplasm lines were identified. The identified resistant sources were utilized by the soybean breeder in making crosses and generating segregating progenies which were again evaluated for their reaction against SYMV. Thus, the joint efforts of the soybean breeder and soybean pathologist resulted in the development

Plate 8. Soybean yellow mosaic disease of soybean. D, diseased and H, healthy

and release of the number of soybean varieties resistant to the SYMV. Soybean yellow mosaic disease caused by the Mungbean Yellow mosaic virus (MYMV) is the most important disease of soybeans in the northern plain zone of India. The disease has been very thoroughly studied in soybeans as well as in pulses. The only means of its spread is by a small white-fly (*Bemisia tabaci* Genn.) during July-August when the white fly population is high (Plate 8). It is not transmitted through seed. Both, the virus and the insect vector are common in case of yellow mosaic disease of soybean and other *Kharif* pulses like urd, moong, arhar, etc.

Management

1. Yield loss estimation studies indicated that depending on the soybean cultivar and age at the time of infection, the losses may vary from being negligible (by infection at 60 or more days) to as high as 80%.
2. The virus infection under green house conditions reduces the number of pods, number of seeds per pod, 1000 grain weight and yield; each one of which may be different in different soybean varieties. Highest yield loss of 93.2% was recorded in Kalitur and lowest loss of 42.4% was in Alankar.
3. The germplasm collection at Pantnagar was screened under green house conditions for its reaction to SYMV infection. Two resistant line E 721 and E 1448 and soybean cultivar UPSM 534 and a wild type soybean *Glycine formosana* as immune to this virus were identified. These sources are being utilized by the breeder to develop yellow mosaic resistant soybean varieties.
4. The spread of the disease in the field can be very effectively controlled by four sprays with Metasystox 25 E.C. @ 1 lit/1000 lit of water/ha on 20, 30, 40 and 50 days after planting.
5. Soil application of systemic insecticide granules in two split applications, at planting and 1 month later were tried to simplify the chemical control. Both, Phorate 10 G (25 kg/ha and 12.5 kg/ha) and Furadan 3 G (17.5 kg/ha) gave significant control of disease and increased the yield also.
6. Integrated Disease Management (IDM) module based on combined use of cultural practices i. e. barrier crop of maize on borders + use of chemicals i.e. seed treatment with Thiamethoxam 70ws @ 3g/kg seeds + spray of herbicide i.e. Imazethapyr 100 g a.i. /ha in soybean plots and on bunds at 25 DAS + vector management i.e. by use of sticky traps 15 DAS + spray of Quinalphos @ 2 ml/l of water at 30 DAS significantly reduced the white-fly population, disease intensity of soybean yellow mosaic and increased the yield of soybean.
7. Timely application of insecticides to control insect, also the vectors of viral diseases, recording the economic injury level and economic thresholds in a planned way provides a sound approach to crop management. Overall the effectiveness of the control practices should be compared to their cost taking into consideration the potential yield and crop value.

Bacterial Blight (BLB)

It can be seen on stem, petioles and pod but most conspicuous on leaves. Small, angular, translucent, water-soaked spots surrounded by a chlorotic halo appear on the leaves (Plate 9). The brown or black centers of these spots indicate that the tissue is dying. Typically these spots will enlarge and merge to form large, dead patches on the leaves. The centres soon dry out, turn reddish brown to black and are surrounded by a yellowish green halo. As the disease advances defoliation of leaves may occur. Large, black lesions develop on stems and petioles. BLB attacks all of the above-ground parts of soybean, but symptoms are typically seen on the mid-upper canopy of leaves and pods. Pod lesions are dark brown to black in colour, enlarge and coalesce to cover much of the pod. Seeds become infected and may eventually cover with a slimy bacterial growth. Seeds may shrivel and develop sunken or raised lesions or become slightly discolored. *Pseudomonas savastanoi* pv. *Glycinea*, the causal bacterium is motile, gram negative, rod-shaped with rounded ends, one to several polar flagella. The disease does not normally affect yield levels as it occurs early in the growth of soybeans and the crop is able to compensate the loss of photosynthetic area. The incidence of BLB have been observed from this area as 20 to 46 per cent depending on the environmental conditions

Plate 9. Bacterial blight symptoms on soybean leaves, D= Diseased, H= Healthy

Management

1. The available germplasm from GBPUA&T, Pantnagar centre and received from coordinated cell were screened for its reaction against the BLB and resistant germplasm lines were identified. The identified resistant sources were utilized by the soybean breeder in making crosses and generating segregating progenies which were again evaluated for their reaction against BLB.
2. Foliar spray of Cu-based fungicides (0.3%) + Streptocycline (0.01%) at the time of disease appearance is effective against bacterial blight
3. Usage of resistant cultivars in the proper environment is therefore an effective way of eliminating the impact of this pathogen.

Salient Achievements

1. Surveys for prevalence and severity of various important diseases of soybean in Uttarakhand were found to be evenly spread in all the farmers' fields. The RAB and SYMV incidence to be more severe (25-60 %) in all the soybean growing areas and BP, Collar rot, BLB, FW and Pod blight incidence were negligible in all the farmers fields that were surveyed. The incidence of BLB and SMV were observed in the range between 10 to 35 per cent on foliage. The disease is a constraint in the quality production of soybean in district Udam Singh Nagar of Uttarakhand. In general, the severity of disease varied from trace to severe.
2. Maximum trapping of bacterial pustule was observed on MACS-58 and JS 7244, while the maximum trapping of bacterial leaf blight was recorded on JS-93-05, whereas, maximum trapping of Anthracnose (Pod blight) was exhibited by NRC- 7 and JS-93-05 but the severe trapping of Rhizoctonia aerial blight was observed on Pb-1, MACS- 58 and also on JS-93-05. The SMV was appeared in severe form on JS-75-46, KHSb-2 and also on MACS-58 while the maximum pressure of SYMV was on JS-75-46 and Monetta variety of soybean. Most of the cultivars were recorded the lowest disease incidence to BP and BLB diseases of soybean. The cultivars, PK 472 and PK 262 were also recorded the lowest disease index to above said diseases of soybean.
3. After continuous screening of entries under Initial Varietal Trial, AVT-1 and AVT-2, several

entries were screened against major diseases such as Bacterial pustule, Bacterial leaf blight, Anthracnose, Rhizoctonia aerial blight, Soybean mosaic virus and soybean yellow mosaic virus whereas most of the entries showed resistant reaction and some of the cultivars were free from infection of BP and BLB. All the test entries were found susceptible to Rhizoctonia aerial blight.

4. Thirty entries which showed resistance (Absolute to Moderate level) in previous years of IVT, AVT-I and AVT-II were screened in hot spot conditions, in which all entries showed high resistance constantly from several years to Soybean yellow mosaic virus and were rated as resistant to Rhizoctonia aerial blight.

5. Several entries have been identified as resistant source to soybean mosaic virus

6. Soil application of FYM + plant population 1-2 m/ha and FYM + K_2O (60 kg/ha) + plant population and irrigation proved to be in best treatment for the management of premature drying problem of soybean.

7. Several promising cultivars seed were treated with Thiram 75 WP + Carbendazim 50 WP (2:1 ratio) @ 3 g/kg seeds followed by viable culture of *Bradyrhizobium japonicum* at 5g/kg seeds for controlling seedling rots and important foliar diseases. Maximum disease index were recorded on several foliar diseases i.e. bacterial pustule (MACS-58), Bacterial leaf blight (JS-93-05), Anthracnose pod blight (NRC 7), Rhizoctonia aerial blight (MACS-58, JS-93-05), Soybean mosaic virus (MACS-58), and Soybean yellow mosaic virus (JS-7546) of soybean. Most of the cultivars were free from infection of BP and BLB. The cultivars, PK 472 was recorded the lowest disease index to above said diseases of soybean.

8. Seed dressing fungicides and antagonist did not decrease or increase significantly the rhizospheric population density of soybean rhizobia and PSB at 50 % flowering stage over control. However, the yield was significantly higher in seed treated with thiamethoxam @ 3g/ kg seed.

9. For foliar disease and pod blight, two spray of carbendazim @ 0.05%, Mancozeb (0.25%), Copper oxychloride (0.3%), Thiophenate methyl (0.05%), Chlorothalonil (0.25%), Hexaconazole (0.1%), Propiconazole (0.1%), Pyraclostrobin (0.1%), Pencycuron (0.1%) and Fluopyram (0.1%) should be applied. First spray should be given as soon as disease appear and second spray after 15 days of first spray.

10. Chemical control with Strobulin and Triazole group of fungicides were most effective against *R. solani* in field but its efficiency was slightly influenced by the prevailing environmental conditions.

11. Charcoal rot of soybean can be effectively controlled by seed treatment with *Trichoderma harzianum* @ 0.4 + Vitavax 0.1 percent.

12. Improvement of soybean plant emergence and control of some of major foliar diseases can be effectively controlled by the use of seed treatment with carbendazim + Thiram (1: 2) @ 3g/ kg seed followed by foliar spray with *Trichoderma harzianum* and *Pseudomonas fluorescence* @ 0.30 percent.

13. Seed treatment with *Trichoderma harzianum* or *Pseudomonas fluorescence* @ 10g/ kg seed + soil treatment with Pant bioagent 3 mixed with FYM @ 500 g/quintal followed by two sprays of *Trichoderma harzianum* (0.30 %) reduced the severity of foliar diseases.

14. Integrated disease management (IDM) modules based on combined use of cultural practices, fungicides for fungal diseases, insecticide for virus disease and host resistance were evaluated against *Rhizoctonia* aerial blight and SYMV diseases

15. IDM module based on seed treatment with thiamethoxam + spray of Imazethapyr 100 g ai/ha in plot and bunds at 25 DAS + barrier crop of maize + yellow sticky traps 15 DAS + spray of quinalphos @ 2 ml/lit at 30-35 DAS reduced white fly population, yellow mosaic virus incidence and increased the yield (23.84 q/ha) of soybean.

16. IDM module based on deep summer ploughing + ST with carbendazim @ 2g/ kg seed + PE soil application of pendimethalin @ 1 kg ai/ha + vermicompost application to raise soil organic carbon up to 0.50% + foliar spray of carbendazim @ 0.05% at 30-35 DAS reduced disease index and intensity of RAB and increased yield (23.37 q/ha) of soybean.

Future thrust

1. Screening of germplasm / varieties / cultivars / land races of soybean against major diseases to identify the sources of resistance.

2. Development of economically and ecologically sustainable management techniques against major diseases of soybean occurring in different agro-climatic regions of the state.

3. Development of IDM modules for management of menacing diseases of soybean for the different regions of Uttarakhand.

4. Variability studies on pathogens causing major diseases of soybean in the state.

5. Development of forecasting module for major foliar diseases of soybean in Uttarakhand.

6. Studies on life cycle / disease cycle of menacing diseases of soybean in Uttarakhand.

7. Assessment of yield and nutrients losses due to major diseases of soybean in Uttarakhand.

8. To conduct the survey and surveillance for soybean diseases to identify the disease free areas for seed production.

Soybean has occupied a unique place in the world for providing high quality protein and edible oil without extra application of nitrogenous fertilizer. It fixes atmospheric di-nitrogen in symbiosis with *Rhizobium japonicum/Bradyrhizobium japonicum* to meet most of its nitrogen requirement. The effective symbiosis depends upon the compatibility of host plant with rhizobia for the formation of effective nodules and fixation of nitrogen for higher yield of soybean. To derive maximum benefit out of this association, it must be ascertained that sufficient number of nitrogen fixing bacteria are present in the soil, if not, then there is a need to inoculate the soybean seed with efficient strain of *Rhizobium japonicum* at sowing time. In 1966, at Pantnagar, it was found that the use of inoculants improved grain yield of soybean varieties and it was also reported that optimum rate of inoculant was 1.5 kg ha^{-1}, beyond which there was no extra benefit. Once it had been established that inoculation was necessary for improving the yields, an all out effort was made to work on various aspects of soybean *R. japonicum* symbiosis. Research work on soybean microbiology at Pantnagar was started in mid-sixties with definite objectives in mind.

A Field view of AICRP on Soybean Microbiology Trials

Mandate and Objectives

1. To study the performance of different *Rhizobium japonicum* strains on soybean varieties to select best suited for seed inoculation
2. To evaluate the performance of different composite cultures under Pantnagar conditions
3. To study the nitrate tolerance of rhizobial strains for nodulation in soybean
4. To study the influence of Arbuscular Mycorrhizal fungi (AMF), phosphorus solubilizing bacteria (PSB), plant growth promoting rhizobacteria (PGPR) and *B. japonicum* inoculation on nodulation, growth and yield of soybean
5. To screen IVT breeding lines for nodulation parameters with homologous soil rhizobia
6. To evaluate the rhizosphere competence/potentiality of AVT II entries of north plain zone for nodulation
7. To study the effect of integrated use of micro nutrients and *B. japonicum* on nodulation and yield of soybean

For successful nodulation and nitrogen fixation, the role of efficient strains can not be over looked. During last fifty years of research work on the selection of efficient rhizobial strains of soybean, several promising strains have been found and tested against different soybean varieties under varying soil conditions.

Survey for nodulation status of soybean in Kumaun, Garhwal, *Tarai*- Bhabar and Gangetic plain

The population of native rhizobia ranged from 76-92% in the soils of 61 sites where soybean was being grown and nodulation in soybean was found even at the height of 10000 ft. at Auli in Garhwal hills, indicating the adoption of soybean rhizobia at low temperature and pH conditions. Out of 31 samples collected from the *Tarai* and *Bhabar* plains 23 samples were found nodulated whereas poor to zero nodulation was recorded in the sandy to sandy loam soils of Bareilly, Badaun and Moradabad districts of Gangetic plain. The survey was also conducted in 1991 to evaluate the nodulation status in three districts namely Nainital, Almora and Pithoragrah of Kumaun division at different altitudes ranging from 1000–6500 ft. All 35 samples showed moderate to excellent nodulation in soybean without inoculation and without growing soybean previously indicating the presence of rhizobia in these soils.

Isolation and screening of *B. japonicum* strains from the soils of Kumaun, Garhwal and *Tarai*-Bhabar

A number of rhizobial strains were isolated from the nodules of soybean grown in various soils of Kumaon, Garhwal and Tarai-bhabhar. After isolation, the rhizobial strains were classified as efficient, moderately efficient and inefficient groups on the basis of increase in plant N content over uninoculated control at 45 DAS. The rhizobial strains S-2, S-6 and S-16 were found to be efficient as they gave 90.7%, 106.4%, and 104.2% increase in shoot N, respectively over uninoculated control.

Comparative studies on the performance of single and combined strains of *Bradyhizobium japonicum*

In an experiment conducted during spring season of 1971 with soybean variety 'Traverse' nodules were not found in uninoculated control. It is evident from Table 1 that nodulation was most rapid with E-188. Highly significant difference in the yield was recorded due to inoculation. The highest yield was recorded with 'Nitragin' followed by E-188.

Table 1: Influence of inoculation treatments on nodule number and nodule dry weight at 30 and 60 days after sowing and grain yield of soybean var. Traverse

Treatments	Nodule number per plant		Nodule dry weight (mg/pl)		Yield (Kg/ha)
	30 days	60 days	30 days	60 days	
Control	0.0	0.0	0.0	0.0	679
E-188 (lignical)	2.5	22.0	14.0	14.0	2134
E-188 (peat)	17.0	34.0	62.0	62.0	2537
FRS (sand)	2.0	5.0	5.0	10.0	996
Mixed IARI	0.3	4.0	4.0	1.5	956
SB-1	0.0	2.5	2.5	0.	1575
B-12S SB-16	2.3	8.0	8.0	14.1	1612
UPAU-2	0.5	3.6	3.6	2.	1012
Nitragin	5.1	33.0	33.0	21.0	2587

In another experiment conducted in *Kharif* 1971, only one strain SB-16 out of seven could produced significantly higher yield of soybean variety Bragg. During subsequent years the rhizobial inoculation experiments were conducted with different varieties. Single strain trials conducted during 1976 with three soybean varieties namely Bragg, Lee and PK 71-21 (Table 2) revealed that only PK 71-21 variety responded significantly better with respect to grain yield as compared to uninoculated control.

Table 2: Compatibility of single strains with different genotypes of soybean at 60 days

Treatments	Soybean varieties					
	Bragg		Lee		PK 71-21	
	Shoot dry weight (g/pl)	Bean yield (kg/ha)	Shoot dry weight (g/pl)	Bean yield (kg/ha)	Shoot dry weight (g/pl)	Bean yield (kg/ha)
Uninoculated	28.40	1822	33.50	2045	31.83	1895
SB-16	28.73	2044	29.07	1650	33.60	2339
USDA-110	31.40	1944	23.07	1783	33.97	2405
USDA-12	36.27	1695	31.47	1661	34.13	2183
C.D.	-	2.59	-	2.59	-	2.59

R. japonicum strains USDA-110, SB-1005 and SB-1020 proved promising with soybean variety Bragg in an inoculation trial during 1978. The soybean varieties PK 564 and Bragg were tested for nodulation with *B. japonicum* strains SB-120 and UASB 229. These strains showed better performance with Bragg while Parbhani strain with PK 564. The highest shoot dry weight was recorded by inoculation of SB-120 strain in PK 564 and Pusa 22 while strain UASB 229 gave highest shoot dry weight in Bragg. The grain yield was highest with inoculation of Parbhani, S-12 and UASB 229 strains in varieties PK 564, Pusa 22 and Bragg. This emphasizes the need to identify varieties which are more responsive to inoculation. In several trials, the testing of promising strains of rhizobia was done in 1998. Nine rhizobial strains namely Pant-1, Pant-2, Pant-3, Delhi-1, Delhi-2, Bj-1, Be-1, Rf-1 and Sehore-1 were tested for nodulation and plant growth parameters. Pant-3 strain showed highest number of nodules, nodule dry weight and grain yield closely followed by Pant-2, Pant-1 and Delhi-2 strains.

In 1999, three rhizobial strains *viz*., Pant-2, Delhli-2 and Bj-1 were tested alone and in mixture for nodulation parameters on soybean variety PK 416. The mixture of these three strains produced maximum number of nodules (102 nod./pl), nodule biomass, plant biomass and grain yield (4210 kg/ha). Individually, Pant -2 strain performed better than other strains. Pant -2 strain gave highest nodule dry weight (47.9 mg/pl) followed by the co-inoculation of Delhi-2 + Sehore-1 and Pant-2 + Bj-1 strains. Sehore-1 strain gave lowest nodule dry weight. The combination of Pant-2 + Bj-1strains produced highest grain yield of 3660 kg/ha followed by Pant -2 alone. Pant-2 strain was superior among all the strains on the basis of nodulation, plant biomass production and grain yield. The maximum number of nodules and N content in nodules were given by the strain Pant- 2 followed by local check and Indore-1 with soybean variety PS 1347 in the year 2012.

Evaluation of nitrate tolerant rhizobial strains

Application of nitrogen suppresses the symbiotic efficiency of rhizobial isolates. Considering it, work on the selection of nitrate tolerant strains was initiated during 1998-99 and various soybean rhizobial strains were screened for nitrate tolerance. The nodule formation by all the strains under study, except SB-315 decreased significantly with addition of 100 kg N/ha as urea. Maximum decrease of 36.02% was recorded with SB-102 and minimum in case of SB-315 but no significant change was found with strain SB-12. The studies revealed that application of 100 kg N/ha suppressed the nodulation i.e. reduced the *Rhizobium*- soybean symbiotic efficiency of different strains of *Rhizobium* but did not give any advantage in terms of grain yield over inoculation.

In 1999, the inoculation of SB-315 strain with 100 kg N/ha increased nodule number and nodule dry weight, plant biomass and grain yield over uninoculated control. The rhizobial strain SB-315 was found to be more nitrate tolerant than SB-327. In *Kharif* 2000, application of 100 kg urea N/ha basal dose significantly decreased nodule formation in soybean but application in split doses (50% basal + 50% at pod filling) enhanced nodulation (Table 3). Inoculation of rhizobial strains alone or with 100 kg N/ha improved nodulation over control. Maximum number of nodules, nodule dry weight and plant biomass was recorded with strain SB-315 when N was applied in split doses (50% basal + 50% at pod filling), however, highest grain yield was obtained with SB- 327.

Table 3: Evaluation of nitrate tolerant soybean rhizobia for nodulation and yield of soybean var. PK 416

S. No.	Treatments	At 50% flowering			Grain yield (kg/ha)
		Nodule no./plant	Nodule dry wt./plant (mg)	Plant dry weight (g)	
1.	Uninoculated control	32.3	180	19.0	2470
2.	*B. japonicum* SB-271	37.7	340	21.3	2940
3.	*B. japonicum* SB-315	36.7	357	22.7	2610
4.	100 kg N/ha	21.3	163	24.0	2573
5.	*B. japonicum* SB-271 + 100 kg N/ha	32.7	310	27.3	2704
6.	*B. japonicum* SB-315 + 100 kg N/ha	33.3	353	26.3	2419
7.	50 kg N/ha as basal + 50 kg N at pod filling stage	36.0	210	24.0	2678
8.	*B. japonicum* SB-271 + 50 kg N/ha as basal + 50 kg N at pod filling stage	36.3	397	26.7	3150
9.	*B. japonicum* SB-315 + 50 kg N/ha as basal + 50 kg N at pod filling stage	49.3	500	26.7	2466
	C.D. 5%	7.4	65.6	3.91	195

Screening of soybean germplasms for higher nodulation ability with native soil rhizobia

Breeding and development of new varieties programme is based on the various traits of the parents used. Nodulation i.e. ability to form effective symbiosis is one of the most important trait which could be used for the development of new varieties having improved symbiotic efficiency for harnessing the benefits of atmospheric nitrogen fixation for enhanced sustainable production in soybean. To address the issues and select the lines having greater symbiotic efficiency with rhizobia, the screening of soybean germplasms for nodulation was initiated in 1998. Thirty soybean germplasm lines were screened for nodulation parameters with native soil rhizobia at 50% flowering stage. A wide variation was observed among the soybean germplasms for nodulation with homologous native soil rhizobia. Five top ranking lines PK 1259, PK 1252, PK 1269, PK 1247, and PK 1245 produced 35 to 72 nodules per plant. Germplasm line PK 1259 produced small sized nodules. Since large size nodules are normally more effective in nitrogen fixation, therefore, it could be assumed that germplasm lines PK 1042, PK 1265 and PK 1261 were more effectively nodulated by native rhizobia. During the year 1999 to 2003, good nodulating germplasm lines were UPSL 20B, UPSL 19, UPSL 162, UPSL 117B, UPSL 85, UPSV 34, UPSV 19, UPSV 17, UPSV 45, UPSV 53, UPSL 73, UPSL 162, UPSV-35, UPSL 164, UPSL 94 and UPSV-19, while UPSL 77, UPSL 252, TG 573-28D and UPSV 72 were poorly nodulating.

In 2005 and 2006, maximum number of nodules per plant (24.7 nod./pl) and N uptake was recorded in PS 1397 and PS 1401 varieties followed by PS 1404 and PS 1406 while minimum in PS 1398, PS 1400 and PS 1029. In 2007 and 2008, maximum number of nodules (29.2 nod./pl) was recorded in Shilajeet followed by PK 416 while variety PK 262 showed minimum 20.7 nodules per plant. In 2009 and 2010, Germplasm line PS 1460 formed maximum nodules (30.4 nod/pl) followed by 1479 while minimum 1.5 nodules per plant was recorded in PS 1447.

Screening of IVT breeding lines for nodulation with native soil rhizobia

The screening of IVT breeding lines for nodulation with native soil rhizobia was done from 2012 to 2015 at 50% flowering stage. Forty IVT lines were tested in 2012 for nodulation parameters with homologous soil rhizobia. Maximum number of nodules (94 nod/pl) were recorded in the line with code no. 36. Other good nodulating lines were with code no. 11, 24, 27, 28 and 30, while minimum number of nodules (16 nod/pl) were observed in IVT line 23. In 2013, forty IVT lines were tested, maximum nodules (100 nod/pl) were shown by IVT line KBS 100-2012, other lines showing good nodulation (> 60 nod/pl) were DS 2961, KDS 722 and NRC 97 while AMS 1001 and RVS 2002-19 were poor nodulating. In 2014, thirty two IVT lines were tested with three checks, out of them good nodulating were RVS 2007-6, JS 20-96 and KBS 23-2014. Maximum nodules were shown by NRC 116 and minimum nodules by JS 20-87. In 2015, forty IVT lines were screened for nodulation with native soil bacteria. The nodulation varied greatly, maximum number of nodules (89 nod/pl) were shown by JS 20-116 while NRC 113 minimum. Other IVT lines showing better nodulation i.e. > 50 were DSb 30-2, MACS 1480, AMS 100-1, MACS 1491, JS 20-94, VLS 91, MAUS 710, NRC 118, PS 1572 KDS 775.

Rhizosphere competence/ potentiality of AVT II entries of north plain zone

Positive compatibility between host plant and inoculated bacterial strain is essential for good nodulation, N_2 fixation and yield of crop. Therefore, interaction between eight AVT II entries with four *B. japonicum* isolates was studied in 2009. Among AVT II entries, DBS 12 formed maximum nodules (11.73 nod./pl) while SL 744 minimum. *B. japonicum* isolate Indore -2 formed maximum and significantly more nodules than other isolates in AVT II entries SL 744, DBS 12, SL 752, NRC 76 and RKS 45 while Pant -1 performed better with JS 20 – 06 (Table 4).

In 2013, all the AVT II entries showed more number of nodules than check var. PS 1347 and Bragg. Maximum nodule number per plant, nodule dry weight, nodule N content were recorded in SL 958. Among AVT II entries, DS 2708 supported highest bacterial population (12.35×10^7 cfu/g soil) and dehydrogenase activity in the rhizosphere soil. However, the fungal and actinomycete populations were more in the rhizosphere soil of SL 958 and DS 2706, respectively (Table 5). In 2014, Three AVT II entries with three check varieties were tested for rhizosphere competnace/ potentiality. The check var. Bragg formed maximum number of nodules while only single nodule was formed in SL 688. Among AVT II entries, DS 2705 had shown maximum number of nodules and nodule dry weight per plant more than check var. PS 1347 and SL 688. The check varieties showed highest microbial population in their rhizosphere soils. The population of fluorescent pseudomonads was highest in the rhizosphere soil of AVT II entry DS 2705.

Table 4: Effect of *B. japonicum* isolates on nodule number on AVT II entries at 50% flowering

S. No.	AVT II Entries	*B. japonicum* Isolates					
		Uninoculated	Pant-1	Pant-2	Indore-1	Indore-2	Mean
1.	PS 1347 (check)	7.17	7.83	5.33	10.67	10.83	8.37
2.	SL 744	5.67	6.67	6.67	3.17	12.00	6.84
3.	Ps 1437	9.33	7.83	7.17	8.00	8.83	8.23
4.	DS 2410	10.67	6.33	8.33	10.33	10.17	9.17
5.	DBS 12	8.33	7.83	7.17	10.50	24.83	11.73
6.	NRC 77	14.17	12.67	11.83	2.33	8.17	9.83
7.	JS 20-06	13.50	13.67	8.50	10.83	10.50	11.40
8.	SL 752	11.50	8.33	3.67	11.17	20.83	11.10
9.	JS 20-09	13.67	9.33	7.83	3.00	7.50	8.27
10.	NRC 76	13.00	11.50	9.00	6.33	18.33	11.63
11.	RKS 45	9.95	8.92	7.47	7.19	14.30	9.57
12.	Mean	10.63	9.17	7.54	7.59	13.30	
	C.D. = 0.05	Entry 1.25		Isolate 0.84		Interaction 2.79	

Table 5: Rhizosphere competence of AVT II entries of soybean for nodulation, microbial population and dehydrogenase activity at 50% flowering

AVT II Entries	Nodule No./plant	Nodule dry weight (mg/pl)	Nodule N content (%)	Microbial population			DHA (pico Katal/g soil)
				Bacteria ($\times 10^8$ cfu/g soil)	Fungi ($\times 10^5$ cfu/g soil)	Actinomycetes ($\times 10^6$ cfu/g soil)	
SL 958	87	350	4.20	1.07	12.84	4.33	430.66
DS 2706	47	300	3.78	1.02	3.79	5.03	559.22
DS 2708	40	255	3.64	1.23	3.39	3.62	690.99
Bragg (check)	22	140	3.65	3.46	4.27	9.70	642.07
PS 1347 (check)	24	80	3.45	3.27	7.28	10.72	388.99

In 2015, among six AVT II entries of soybean, SL 955 gave maximum nodule number (56 nod/pl) and leghaemoglobin content, significantly more than all other entries except 3102 while PS 1550 was poor in nodule formation and dehydrogenase activity (Table 6). PS 1556 showed highest nodule dry weight, dehydrogenase activity, PSB and fluorescent pseudomonads population in the rhizosphere soil.

Response of different varieties to inoculated rhizobial strain

Different soybean varieties were tested for nodulation parameters (*Kharif,* 1998) with *Rhizobium* strain USDA-110 so that, high nitrogen fixing traits could be used for further breeding programme. The varieties namely PK 1169, Bragg, SL 443 were on par regarding nodule number. However, Bragg gave highest nodule dry weight (122 mg/pl) followed by JS (SH) 91-16, PK 1169, SL 444, PK 1180 and SL 443. In 2000, variety PK 1042 formed maximum number of nodules and highest grain yield due to inoculation with rhizobial strain USDA 110.

Table 6: Rhizosphere competence of AVT II entries of soybean for nodulation, microbial population, dehydrogenase activity and leghaemoglobin content at 50% flowering

AVT II Entries	Nodule No./p	Nodule dry weight (mg/pl)	Microbial population		Dehydrogenase activity (µg/g soil/h)	Leghaemo-globin content in nodules (mg/g)	AMF root colonization (%)
			PSB ($\times 10^5$ cfu/ g soil)	Fluorescent pseudomonad ($\times 10^5$ cfu/g soil)			
SL 955	56	18	4.55	4.22	11.80	1.12	60.80
SL 983	27	14	2.88	5.99	11.10	0.93	74.53
SL 1028	34	16	5.33	4.11	11.10	1.05	62.40
PS 1550	25	20	5.66	4.33	9.57	0.99	56.27
PS 1556	36	24	8.22	7.22	11.93	0.96	57.87
DS 3102	42	22	4.77	6.76	10.30	1.01	64.27
PS 1092 Check	31	12	5.55	2.44	10.97	1.10	65.47
SL 688 Check	51	22	5.88	4.33	11.50	0.99	60.27
PS 1347 Check	23	19	3.66	3.11	10.27	1.12	59.47
C.D.(5%)	10	ns	ns	2.33	ns	ns	ns

Carrier based composite cultures and evolution

Earlier work, between 1966 and 1970 on the inoculants had been mostly done on the response, inoculation rates and other aspects of imported soybean inoculants like 'Nitragin'. In order to initiate and encourage indigenous production and use of inoculants, research work on suitable strains, carriers, amendments, stickers and other aspects of production technology was started in late sixties and culmination of these efforts was the setting up of a Pilot Plant in 1973-74 for legume inoculants production and development under the Department of Soil Science, Pantnagar. This plant has done pioneering work in popularizing soybean inoculants among the Indian farmers.

Besides the selection of suitable strains of *R. japonicum* for inoculants production, the basic problem that had been faced was the availability of suitable carrier for rhizobia which could prove as good as American peat because the shelf- life of agar based cultures which were produced during 1970 – 71 was very short, work on the several carriers was started simultaneously. On the basis of shelf- life, availability and ease of operation, lignite alone or with certain amendments like FYM, poultry manure and legume meal had proved a very good substitute of American peat. As a result, lignite even now is being used as a carrier in large number of indigenous inoculants. In an experiment conducted in *Kharif* 1976, the performance of low grade coal as a carrier was studied. The yield in case of low grade coal based Pantnagar and JNKVV cultures did not differ significantly from that of uninoculated control. Sterilized carrier is supposed to increase shelf-life of inoculants. However, studies on the survival of *R. japonicum* on sterilized and unsterilized lignite have revealed that death rate and cell number of rhizobia during two months of storage at room temperate was almost same (Table 7). Inoculation with unsterilized lignite based rhizobial culture gave two times more nodule number and 50% more nodular tissue than sterilized lignite based rhizobial culture. It indicated that carrier like lignite, which is mined from a considerable depth, need not be sterilized as it is likely to have low microbial contaminants. But carriers like FYM, soil and pressmud may be sterilized before the use because of heavy contamination. Research and development work at Pilot Plant for legume inoculants have shown that coconut shell powder, vermiculite and charcoal can also be used as carriers. Various trials on the composite cultures in previous years have shown that composite cultures performed better than single strain inoculants. This is understandable because rhizobial strains differ in their adaptability, infectivity, effectivity and host specificity. Therefore, a combination of more than one strain has better chance of infecting and nodulating different host varieties under different agro-climatic conditions.

Table 7: Survival of *R. japonicum* (strain USDA-110) in sterilized and unsterilized lignite at room temperature

Observations	Days of observations			
	0	24	42	64
Sterilized carrier				
pH	6.9	7.0	7.0	7.0
Moisture (%)	34.8	31.2	30.5	21.1
Cell number ($\times 10^6$/g)	800.0	70.5	0.85	0.005
Unsterilized carrier				
pH	6.5	6.9	6.9	6.9
Moisture (%)	34.3	30.5	30.0	17.9
Cell number ($\times 10^6$/g)	455.0	37.5	1.2	0.590

An experiment conducted during *Kharif* 1975, showed that inoculation of soybean variety Ankur with GBPUAT, Banglore 1, JNKVV 2 and JNKVV 3 cultures brought significant increase in bean yield over the uninoculated control (Table 8). But the trial conducted during 1976 with different composite cultures obtained from various sources could not give any significant increase in bean yield of variety Bragg. Experiments conducted during later years also revealed a similar pattern, although the inoculation with composite cultures resulted in higher yields.

Table 8: Performance of different composite cultures of *Rhizobium japonicum* on Ankur var. of soybean

Treatments	Nodule number per plant		Bean yield (Kg/ha)
	30 days	60 days	
Uninoculated Control	31	178	2012
Bangalore-1	33	121	2599
Bangalore-2	24	169	1994
JNKVV-1	33	137	2123
JNKVV-2	29	147	2580
JNKVV-3	31	151	2562
IARI-1	31	104	1957
IARI-2	31	195	2161
IARI-3	27	203	2129
GBPUAT	32	200	2655
C.D. 5%	-	-	3.12

The performance of four inoculants *viz*., Pantnagar, IARI-1, Bangalore and Local was studied in 1991 on soybean varieties PK 327 and PK 416. The Bangalore inoculant significantly increased nodule number and nodule dry weight at 60 days in PK 416 variety but no significant increase was recorded in PK 327, the local inoculant performed poorly with both the varieties. The response was more pronounced in terms of plant dry weight. Pantnagar inoculant supported highest plant dry weight in both PK 327 and PK 416 varieties. IARI-1 and Pantnagar inoculants significantly increased grain yield of both the varieties. In 1992, the evaluation of selected *B. japonicum* inoculants showed that Pantnagar inoculant gave maximum number of nodules per plant in soybean variety PK 327 while Bangalore and local inoculants in PK 416.

Inoculation rates, methods, amendments, stickers and nodulation problem in soils

In the experiments conducted during late sixties, it has been found that 1.5 kg. of inoculant per hectare was the optimum dose, but no such information was available on indigenous inoculants specially under adverse soil conditions. Large scale failure of nodulation was observed in the soils of Bareilly and Badaun during the years 1974-75. These soils were sandy loam with a pH of 7.3 to 7.8 and organic matter content 0.8 to 1.02%. Native varieties like Type 49, Kalitur and Type 1 nodulated well in these soils but exotic varieties failed to nodulate.

In a pot experiment (1986), the performance of three strains of *R. japonicum* in four soils namely Haldi loam, Haldwani sandy loam, Bareilly sandy loam and Ranichauri clay loam of different climatic conditions revealed that the infection of roots by inoculated *R. japonicum* strains, measured through serological as well as antibiotic resistance techniques varied significantly. Strain S-12 performed better in all the soils than other strains by forming 70% nodules where as TAL-94 formed 76.7% nodules in Ranichauri clay loam soil. SB -31 strain seemed to be least effective but showed higher N_2ase activity in Ranichauri clay loam and Bareilly sandy loam soils in comparison to uninoculated control. In competition with native rhizobia, strain S-12 and SB-31 formed more nodules than TAL-94. This had clearly indicated that a rhizobial strain must be infective, competitive and efficient in nitrogen fixation. Strain S-12 and SB-31 recorded higher plant biomass in Pantnagar soil over TAL-94. Strain S-12 gave highest grain yield in Pantnagar soil followed by TAL-94 and SB-31 strains.

In an experiment conducted during *Kharif* 1975, nodulation of soybean variety Bragg was very poor in uninoculated control and at normal rate of inoculum. Nodulation was maximum with ten times of recommended level of Pantnagar culture indicating that soil was lacking native *R. japonicum* strains (Table 9). Mulching with wheat straw or pelleting the seed with Talc and inoculum also helped in nodulation. In a similar experiment done in dry and hot soils of Bilwa (Bareilly) in 1977, indicated that pelleting is a good practice for such soils. The experiment was again repeated at the same location with some additional treatments gave similar results.

Soil temperature plays an important role in the success and failure of nodulation. In an experiment with nine strains of *R. japonicum* tested against four growth temperatures *viz*., 28, 35, 40 and 45ºC, it was observed that higher temperatures completely inhibited nodulation. Dry matter accumulation was also significantly affected by temperature and maximum accumulation was obtained at 28ºC.

The size of carrier particles plays an important role in controlling the moisture and number of rhizobial cells in the inoculants. The particle size of 100 mesh showed highest moisture retention and shelf life of inoculant after 105 days at 30% moisture. The loss of moisture (21.3%) increased with increase in the particle size, 30 mesh size of particles showed 18.8% moisture.

Table 9: Nodulation problem in soil of Bareilly U.P. in soybean Bragg.

S. No.	Treatments	Nodule no. per plant	Leghaemoglobin content in fresh nodule (µg/g)
1.	Uninoculated control	1	-
2.	Recommended rate of Pantnagar culture	2	-
3.	Ten times of recommended rate of Pantnagar culture	55	418
4.	Imported granular inoculums	10	275
5.	Imported Nitragin culture	18	315
6.	210 kg N/ha	0	-
7.	Normal rate of inoculums + mulching the soil with wheat straw	35	375
8.	Pelleting seed with Talc + inoculums	30	351
9.	Normal rate of inoculums + micronutrients	10	187

In an experiment conducted to study the effect of method of inoculation, it was observed that drilling near one week old plants was better in case of nodule number but nodule and shoot dry weight were highest with seed inoculation. Drilling method gave highest grain yield, however, both the methods did not differ significantly with each other. Seed inoculation is more economical, needs 500g inoculant /ha than drill method which needs 15-20 kg of inoculant along with the additional cost of labour.

Evaluation of commercially available *Rhizobium* inoculants

Among seven inoculants tested during *Kharif* 2001, Pantnagar inoculant resulted in maximum increase (25.8%) in nodules number over uninoculated control followed by IARI inoculant. Mixed inoculant of Pant-1, Delhi-2 and Bj-1 strains performed significantly better than Anmol and Nitragin by synthesizing maximum nodule number, nodule dry weight and plant dry weight and 5–19.2% more grain yield. Lignite or wood charcoal amended with organic materials can serve as better carrier for rhizobia. The inoculant should have 40% moisture content and it should be stored preferably below 15^0 C.

The performance of six commercially available and one mixed inoculant (mixture of Pant-2, Delhi-2 and Bj-1 strains) on soybean variety PK 416 was studied in *Kharif* 2002. All the inoculants performed better compared to uninoculated control, but significant increases in nodule number was found with mixed, KRIBHCO, NAFED and IARI inoculants. The mixed inoculant gave highest nodule number, nodule dry weight and grain yield (2367 kg/ha) followed by IARI inoculant.

Effect of fungicides and bioagents along with inoculants

A field experiment conducted during spring 1975 with three soybean varieties (Adelphia, Hark and Harrsoy), three levels of fungicide thiram (0, 0.2 and 0.4%) and three levels of inoculum (0, normal and 10 times the normal rate) revealed that seed without fungicide recorded higher, though not significant yield. The experiment conducted with antifungal agents in *Kharif* 1984 showed that thiram and PCNB in mixed cultures gave about 50% more nodules.

In an another experiment in 2009, treatment with thiram @ 3 g/ kg seed gave maximum nodule number while vitavax resulted in minimum nodule number. Carboxin (2 g/ kg) gave highest grain yield (1446 kg/ ha) showing 16.2% increase over control. Total microbial population in soil reduced with increase in the concentration of fungicides. However, bio-agent *Pseudomonas* showed positive effect on the number of PSB and *B. japonicum* in soil. The fungicide carbendazim (0.5%) showed maximum decline in the number of *B. japonicum* while PSB number declined with 0.4% concentration.

Effect of co-inoculation of *Rhizobium* with other beneficial microorganisms in soybean

Rhizosphere of various plants is inhabited by various beneficial as well as hamful microorganisms. The associations between the rhizospheric microorganisms may prove either synergistic, harmful or neutral to the growth of plants. Various microorganisms in the rhizosphere effect the symbiotic efficiency of *Rhizobium* through number of means such as improving P availability, enhanced micronutrient access, synthesis of plant growth promoting substances, inhibiting the growth of various disease causing microbes, imparting tolerance to varius biotic and biotic stress conditions etc. To find out the interaction effect of *Rhizobium* with other beneficial microbes on nodulation, growth and yield of soybean the experiments were undertaken over the years.

A field experiment conducted in 1982 to study the comparative effectiveness of *R. japonicum* and *Azospirillum brasilense* in soybean revealed that grain yield rose by 13 and 27% over uninoculaed control due to inoculation of live cells of *R. japonicum* alone and *R. japonicum* + *Azospirillum brasilense,* respectively, indicating a synergistic effect of about 13% due to incorporation of both the microorganisms together.

Phosphorus is an important element involved in the ATP generation, nodule formation, nitrogen fixation and plant growth. Arbuscular mycorrhizal fungi (AMF) and phosphate solubilizing bacteria (PSB) solubilize, translocate P from non-rhizospheric soil and make it available to plant. In addition to P translocation, AM-fungi also provide various micronutrients and water from the deeper zone of soil and imparts tolerance to plants to fight with various biotic and abiotic stress(es). Therefore, effect of inoculation of AMF and PSB with different phosphorus levels on nodulation and yield of soybean was evaluated through various experiments during 1989 and onwards, and it was found that phosphorus application @ 30 and 60 kg P_2O_5 / ha as SSP showed positive influence on the nodule number, nodule dry weight and plant biomass. However, co-inoculation of PSB and *R. japonicum* was superior than 30 kg P_2O_5/ha and the effect was more pronounced with rock phosphate.

In 1998, the application of 60 kg P_2O_5/ ha as SSP supported synthesis of maximum nodules and plant biomass equivalent to the inoculation of PSM-2 or PSM-3 with rock phosphate. The grain yield significantly increased with SSP, rock phosphate + *Pseudomonas striata*, PSM-2 or PSM-3 with rock phosphate. This shows that the use of suitable PSM strains increased availability of P from a cheaper source like rock phosphate. In another experiments conducted during 1999, 2000 and 2002, it was found that increased dose of SSP from 30 kg $P_2O_{5/}$ ha to 60 kg/ P_2O_5 ha increased nodulation, plant biomass and grain yield of soybean (Table 10). The combination of FYM @ 1 or 2 t/ha + 60 kg $P_2O_{5/}$ ha + PSM + *Rhizobium* gave maximum number of nodules, nodule dry weight, plant dry weight and grain yield (3740 kg/ ha). Results suggested that FYM application with suitable strain of PSM enhance P availability vis-à-vis symbiotic efficiency of *Rhizobium*-soybean system for nitrogen fixation and grain production.

During 1991, dual inoculation of VAM-fungi and *B. japonicum* recorded highest (22.7 nod/pl) nodule number and nodule dry weight. Application of 30 and 60 kg P_2O_5/ha along with VAM fungi and *B. japonicum* inoculation gave significantly higher plant dry weight and grain yield than control. The results indicated synergistic effect of inoculation either of P-solubilizer or VAM with *R. japonicum*. In

Table 10: Effect of phosphate solubilizing microorganisms in combination with organic manure on soybean variety PK 416 at different levels of phosphorus

S. No.	Treatments	Nodule no./plant	Nodule dry wt./plant (mg)	Plant dry weight (g)	Grain yield (kg/ha)
1.	FYM 1t/ha + 60 kg P_2O_5/ha as SSP	26.4	294	28.5	3060
2.	FYM 1t/ha + 30 kg P_2O_5/ha as SSP	25.3	232	21.1	2630
3.	FYM 1t/ha	21.2	224	20.8	2910
4.	(1) + PSM-2	32.1	268	33.0	3200
5.	(2) + PSM-2	22.2	243	29.6	2890
6.	(3) + PSM-2	20.4	236	25.2	2960
7.	FYM 2t/ha + 60 kg P_2O_5/ha as SSP	36.9	251	34.5	2850
8.	FYM 2t/ha + 30 kg P_2O_5/ha as SSP	31.5	239	33.5	2940
9.	FYM 1t/ha	26.3	234	30.7	32.00
10.	(4) + PSM-2	43.7	315	38.5	3740
11.	(5) + PSM-2	27.2	247	34.1	3330
12.	(6) + PSM-2	23.1	245	30.8	3520
13.	Uninoculated	22.1	196	27.5	3550
	C.D. 5%	4.35	5.0	3.6	63.7

an another study, dual inoculation of PSB and *B. japonicum* showed maximum number of nodules followed by 60 kg P_2O_5/ ha along with VAM and *B. japonicum*. Addition of phosphorus through rock phosphate or SSP significantly increased nodule, plant dry weight and grain yield (2113 kg/ha).

In 2004, *B. japonicum* inoculation alone significantly increased nodulation and 14% grain yield of soybean over uninoculated control (Table 11). Co-inoculation of AM-fungi either with *B. japonicum* or PSB along with 40 kg P_2O_5/ ha synthesized more nodule number, nodule dry weight, microbial biomass carbon, AMF root colonization and highest N and P content in plant than alone application of 40 kg P_2O_5/ha.

Plant growth promoting rhizobacteria are known to stimulate plant growth by secreting growth promoting substances such as gibberellins, IAA, auxins etc. and increasing supply of plant nutrients. Certain PGPR also act as biocontrol agents restricting the competition in the rhizosphere with the disease causing microbes and providing opportunity to the beneficial microbes for access of the limited carbon substrates. Therefore, a study was conducted to evaluate the effect of dual inoculation of PGPR and *B. japonicum* on the nodulation and yield of soybean var. PS 1347 during 2003, 2005 and 2006. It was observed that dual inoculation of *B. japonicum* with PGPR Pv, Kb, and RP-24 produced significantly more nodule number than uninoculated control (Table 12). Dual inoculation of *B. japonicum* and PGPR RP 7 or RP 24 resulted in more nodules per plant and grain yield than control and was better than *B. japonicum* alone. However, combined inoculation of *B. japonicum* + PGPR + PSB showed maximum nodulation, plant dry weight, grain yield and plant N content.

The interactive effect of AM-fungi and PGPR were evaluated in a pot trial in 2012 with soybean variety PS 1347. AMF alone inoculation recorded maximum nodule number per plant (Plate 1) followed by dual inoculation of *Paenibacillus polymyxa* and AMF (Plate 3). Different PGPR varied in their effect on growth of soybean cv. PS 1347 (Plate 2). The treatments with AMF alone and co-inoculation with PGPR showed

Table 11: Effect of AM, PSB and *B. japonicum* inoculation on nodulation and yield of soybean var. PK 416

S. No.	Treatments	Nod. no./pl	Nod. dry wt (mg/pl)	Plant dry wt (g/pl)	MBCAM (mg/kg soil)	Infection (%)	Grain yield (kg/ha)
1.	Uninoculated control	10.8	121.50	16.69	242.15	65.50	2253.0
2.	*B. japonicum* alone	17.4	191.50	19.37	270.80	69.15	2446.0
3.	AMI alone	20.0	157.00	16.77	307.15	75.70	2538.5
4.	PSB alone	15.0	156.50	17.40	254.40	67.50	2650.5
5.	2 + 3	23.6	194.50	22.44	257.20	72.50	2369.0
6.	2 + 4	18.9	186.00	22.09	269.25	70.50	2777.5
7.	3 + 4	20.1	186.50	17.87	251.95	72.85	2333.5
8.	2 + SSP @ 60 kg P_2O_5/ha	23.0	201.00	16.39	262.05	70.85	2719.5
9.	2 + SSP @ 40 kg P_2O_5/ha	17.9	163.00	20.69	268.65	75.50	2403.0
10.	3 + SSP @ 40 kg P_2O_5/ha	19.2	164.00	17.77	302.25	75.85	2401.5
11.	4 + SSP @ 40 kg P_2O_5/ha	17.2	179.00	16.95	278.90	71.30	2773.5
12.	5 + SSP @ 40 kg P_2O_5/ha	17.7	192.50	20.70	280.75	78.30	2507.5
13.	6 + SSP @ 40 kg P_2O_5/ha	17.5	162.50	21.44	288.60	71.65	2607.5
14.	7 + SSP @ 40 kg P_2O_5/ha	21.3	201.50	19.80	295.20	78.00	2576.5
15.	SSP @ 40 kg P_2O_5/ha	17.8	173.50	17.00	250.35	67.15	2491.5
16.	SSP @ 60 kg P_2O_5/ha	24.0	149.50	21.07	260.15	67.35	2503.0
17.	C.D. 0.05)	4.6	37.95	4.53	29.70	6.30	NS

significantly more nodules, nodule biomass and AMF root colonization than uninoculated control. In 2013, the inoculation of AMF and PGPR improved nodulation in soybean (Plate 4). Maximum nodules (275 nod/pl), nodule dry weight, N content in nodule and root colonization of AM-fungi were recorded with combined inoculation of *Acinetobacter calcoaceticus* (BK 5) + *Paenibacillus polymyxa* (HKA 15) + *Burkholderia arboris* (MRS 2) + Arbuscular mycorrhizal fungi (AMF).

In 2014 also, the inoculation of AMF with PGPR significantly increased nodulation in soybean compared with co-inoculation of PGPR. Co-inoculation of AMF + *B. arboris* gave maximum number of nodules and significantly higher grain yield of 1660.49 kg/ha than alone inoculation of *P. polymyxa* and uninoculated control.

Combined inoculation of *P. polymyxa* + *B. arboris* + AMF significantly enhanced root colonization of AM fungi. In 2015, AMF alone inoculation recorded maximum nodule number per plant but highest nodule dry weight, leghaemoglobin content, root colonization of AM fungi, N & P content in grain and grain yield.

Effect of *B. japonicum* inoculation with micronutrients

Micronutrients play a very pivotal role on growth of micro as well as macrosymbiont and their symbiotic efficiency for nitrogen fixation. The experiment was conducted for three years from *Kharif* 2006 to 2008 to study the effect of *B. japonicum* inoculation and micronutrients application on nodulation, growth and yield of soybean variety PS 1347 (Table 13). The application of 5 kg Zn/ ha alone and with *B. japonicum* significantly increased nodulation in soybean than *B. japonicum* alone. The zinc performed better than Mo and B for nodule number and plant dry weight. However, inoculation of *B. japonicum* with 5 kg Zn/ ha + 5 kg B/ ha+ 4 g Mo/ kg seed gave maximum nodule number, nodule dry weight, plant dry weight and grain yield.

Table 12: Co- inoculation effect of *B. japonicum* and PGPR on nodulation and yield of soybean var. PS 1347

S. No.	Treatments	Nod. no./pl	Nod. dry wt (mg/pl)	Plant dry wt(g/pl)	Plant N (%)	Grain yield (kg/ha)
1.	Uninoculated control	10.65	156.00	19.50	1.21	2167.50
2.	*B. japonicum* alone	21.05	246.50	29.70	1.67	2480.50
3.	*B. japonicum* + PF I	21.00	250.50	27.30	1.43	2560.50
4.	*B. japonicum* + PF IV	19.50	243.50	30.60	1.33	2506.50
5.	*B. japonicum* + Pv	16.05	260.00	29.50	1.50	2549.00
6.	*B. japonicum* + Bc	18.25	257.50	24.80	1.46	2437.00
7.	*B. japonicum* + Kb	18.50	290.00	33.15	1.55	2464.00
8.	*B. japonicum* + RP 7	23.30	279.00	24.25	1.57	2344.50
9.	*B. japonicum* + RP 24	21.65	303.50	30.25	1.21	2352.50
10.	PF I	18.95	233.00	30.10	1.41	2713.00
11.	PF IV	19.35	230.50	29.35	1.43	2634.00
12.	*Proteus*	20.10	268.00	29.95	1.31	2657.00
13.	*Bacillus*	15.30	253.00	25.85	1.27	2568.00
14.	*Klebsiella*	18.85	190.50	24.65	1.37	2506.50
15.	RP 7	18.15	239.50	28.60	1.28	2575.50
16.	RP 24	14.40	233.00	23.40	1.21	2460.00
	C.D. (0.05)	3.30	44.20	3.10	NS	NS

Table 13: Effect of integrated use of micronutrients and *B. japonicum* inoculation on nodulation and yield of soybean var. PS 1347

S. No.	Treatments	Nod. no./pl	Nod. dry wt (mg/pl)	Plant dry wt(g/pl)	Grain yield (kg/ha)
1.	Uninoculated control	13.1	106.7	12.9	2307.7
2.	*B. japonicum*	23.1	115.0	20.3	2484.3
3.	Local check	22.3	132.3	18.4	2583.3
4.	*B. japonicum* + Boron (Brax) @ 5 kg/ha	22.0	127.0	17.5	2663.0
5.	*B. japonicum* + Zinc (Zinc sulfate) @ 5 kg/ha	22.0	146.0	21.3	2775.3
6.	*B. japonicum* + Mo (sodium molybdate)@ 4 g/kg seed	19.5	123.3	20.1	2604.7
7.	Boron (Brax) @ 5 kg/ha	21.1	108.7	18.2	2542.3
8.	Zinc (Zinc sulfate) @ 5 kg/ha	24.4	150.3	22.7	2697.3
9.	Mo (sodium molybdate) @ 4 g/kg seed	20.6	137.3	18.9	2592.3
10.	*B. japonicum* + 7 + 8 + 9	25.0	161.7	23.2	2785.7
	C.D. (0.05)	4.6	26.2	4.8	NS

Salient achivements

1. Seed treatment of soybean with *Bradyrhizobium japonicum* at sowing time increased nodulation and yield of soybean especially in soils where soybean is being taken first time.

2. Combined inoculation of *B. japonicum* either with PSB or AM-fungi enhanced soybean yield.
3. Application of 40 kg P_2O_5/ha along with dual inoculation of *B. japonicum* either with PSB or AM-fungi is more beneficial.
4. Dual inoculation of *B. japonicum* with PGPR is more beneficial than their alone inoculation.
5. Inoculation of *B. japonicum* with micronutrients i.e. zinc @ 5 kg zinc sulfate/ha + B @5 kg borax/ha + Mo @ 4 g sodium molybdate /kg increased nodulation and yield of soybean.

Future thrust

1. Selection of promising multi-trait soybean rhizobial strains for wider range of soybean varieties.
2. Evaluation of rhizosphere competence/potentiality of AVT II entries of soybean for incorporation in breeding program for harnessing the microbes potential.
3. Isolation and screening of rhizobacteria capable of producing ACC deaminase antioxidant potential and phytohormones for developing inoculants to mitigate abiotic stress in soybean.

Plate 2: Effect of *Acinetobacter calcoaceticus* (BK-5), *Paenibacillus polymyxa* (HKA-15) and *Burkholderia arboris* (MRS- 2) on the growth of soybean var. PS 1347

Plate 3: Effect of AM fungi and *P. polymyxa* on the growth of soybean.

Plate 4: Effect of *Burkholderia arboris* (MRS 2) and AM fungi on the growth of soybean.

Plate 1: Effect of AM fungi inoculation on growth of soybean var. PS 1347.

Theses Submitted for Post Graduate Degree

M. Sc. Ag. Theses

Sl. No.	Title of thesis	Name of student	Year of Submission	Name of Advisor
	Genetics & Plant Breeding			
1.	Extant of natural crossing in soybean	Arun Kr. Saha	-	Dr. B.B. Singh
2.	Inter varietal competition in soybean	Ram Kishore	1970	Dr. B.B. Singh
3.	The extant and nature of heterosis for yield and other quantitative characters in soybean	D. N. Choudhury	1971	Dr. B.B. Singh
4.	Genetic and cytological studies on male sterile mutant in soybean	A. B. Patil	1974	Dr. B.B. Singh
5.	Inheritance of some quantitative characters in an interspecific cross in soybean	K. C. Bhardwaj	1974	Dr. B.B. Singh
6.	Studies on genetic divergence and phenotypic stability in soybean	D. N. Chaudhury	1975	Dr. B.B. Singh
7.	Inheritance of resistance to YMV in soybean	A. S. Malik	1976	Dr. B.B. Singh
8.	Relationship of seed vigor with yield and yield components in soybean	R. P. S. Rana	1977	Dr. B.B. Singh
9.	Genetic and cytological studies on induced male sterility mutants in soybean	A. N. Jha	1977	Dr. B.B. Singh
10.	Evaluation of induced quantitative mutants and characters association analysis in soybean	A. K. Dwivedi	1979	Dr. M.P. Pandey
11.	Genetic study of seed impermeability in soybean	Jai Prakash Shahi	1980	Dr. P.S. Bhatnagar
12.	Genetic divergence and path coefficient analysis in new breeding lines in soybean	Kamendra Singh	1983	Dr. H.H. Ram
13.	Soybean cultivar identification by use of electrophoretic pattern of seed proteins	Hari Kumar	1988	Dr. H.H. Ram
14.	Stability analysis in the elite lines of soybean	N.S. Dhaka	1988	Dr. H.H. Ram
15.	Genetic variability and interrelationship in M5 progenies of soybean	Omleir	1989	Dr. H.H. Ram
16.	Growth stages and yield components in determinate Vs indeterminate soybean	P.K. Bhattacharya	1990	Dr. H.H. Ram
17.	Visual selection and index selection in soybean	P.T. Dao	1991	Dr. H.H. Ram
18.	Extant of genetic variability and classificatory analysis in advance of breeding lines of soybean	Sanjoy Chauhan	1996	Dr. Puspendra

19.	Studies on genetic diversity in the indigenous and exotic germplasm lines of soybean	Saurabh Shukla	1996	Dr. Kamendra Singh
20.	Effectiveness of early generation selection in interspecific crosses of soybean	Praveen Siddhu	1997	Dr. Puspendra
21.	Stability analysis in soybean over difference plant diversity	Dhanpat Kumar	1998	Dr. Kamendra Singh
22.	Estimation of variability, correlation and path coefficient for seed yield and its component in soybean	Mukesh Kumar	2000	Dr. Kamendra Singh
23.	Genetic variability and correlation studies for flower production, abscission rate, yield and yield components in soybean	Charan Singh	2000	Dr. Puspendra
24.	Gama rays, ethyl methyl sulfonate and diethyl sulfonate induced variation for yield and yield contributing traits in soybean	Saswat Kumar	2001	Dr. Puspendra
25.	Genetic divergence, correlation and path coefficient analysis for seed yield, its component and quality traits in soybean	Rahul Dev Pandey	2001	Dr. Kamendra Singh
26.	Studies on metroglyph components in mechanical diallele mixture in soybean	Arun K. Agnihotri	2002	Dr. Puspendra
27.	Studies on genetic variability and correlation and seed longevity and its components in soybean	Shilpi Tiwari	2002	Dr. B.V. Singh
28.	Studies on residual heterosis and transgressive segregation for yield and its components in soybean	Jai Prakash Aditya	2003	Dr. Puspendra
29.	Studies on genetic divergence on Indian varieties of soybean	Bhawana Sharma	2003	Dr. B.V. Singh
30.	Residual heterosis and transgressive segregation studies for yield and its components in soybean	Anuradha Bhartiya	2004	Dr. Kamendra Singh
31.	Transgressive segregation and residual heterosis in soybean	Preeti Massey	2005	Dr. B.V. Singh
32.	Estimation of genetic diversity and characters association for seed yield and its components in elite lines of soybean	Narendra Singh	2005	Dr. Kamendra Singh
33.	Morphological characterization and genetic divergence studies in released varieties of soybean in India	Alpana	2005	Dr. Puspendra
34.	Hydration treatment and its effect on generation of and other yield components in F3 generation of Birsa-Soya /Ds-71-05 crosses of soybean	Sunita Pandey	2006	Dr. Puspendra

35.	Genetic divergence and correlation studies during winter and rainy season for yield and its components in soybean	Kamal Pandey	2006	Dr. Kamendra Singh
36.	Genetic divergence studies in Virginia germplasm of soybean	Hema Pandey	2006	Dr. B.V. Singh
37.	Heterosis correlation and variability studies for yield and its components in soybean	Mamta Arya	2007	Dr. Kamendra Singh
38.	Studies on genetic variability and photosensitivity in advance breeding lines of soybean	Kalian Singh	2009	Dr. Kamendra Singh
39.	Studies on genetic divergence and character association in elite lines of soybean	Kuldeep Singh	2010	Dr. Kamendra Singh
40.	Heterosis and path coefficient analysis in soybean [*Glycine max* (L.) Merrill]	Samant Pooja	2010	Dr. Kamendra Singh
41.	Genetic divergence and path coefficient analysis in soybean [*Glycine max* (L.) Merrill]	Hitesh Pandey	2012	Dr. Kamendra Singh
42.	Studies on Genetic Parameters for quantitative and qualitative traits in soybean [*Glycine max* (L.) Merrill]	Kunduru Bharath	2016 .	Dr. Kamendra Singh
43.	Studies on genetics diversity and correlation of quantitative and qualitative traits in soybean [*Glycine max* (L.) Merrill]	Tanuj Upreti	2017	Dr. P.S. Shukla
	Agronomy			
1.	Effect of inorganic and organic sources of nutrients on growth and quality of soybean [*Glycine max* (L.) Merrill]	Hemant Singh Manral	1998	Dr S.C. Saxena
2.	Response of soybean [*Glycine max* (L.) Merrill] + maize (Zea mays L.) intercropping to phosphorus nutrition under *Tarai* condition.	Ashok Kumar Dey	2000	Dr S.C. Saxena
3.	Yield dynamic studies on plant population with respect to different varieties of soybean [*Glycine max* (L.) Merrill]	Deepti	2002	Dr S.C. Saxena
4.	Intergrated weed management in soybean [*Glycine max* (L.) Merrill]	Akanksha Gupta	2004	Dr S.C. Saxena
5.	Nutrient management in soybean [*Glycine max* (L.) Merrill].	Rajnish Singh	2005	Dr S.C. Saxena
6.	Evaluation of new herbicide molecules in soybean [*Glycine max* (L.) Merrill]	Vishal Kumar	2009	Dr S.C. Saxena
7.	Optimization of nutritional levels for newly released soybean [*Glycine max* (L.) Merrill] varieties under *Tarai* condition of Uttarakhand	Ashok K. Joshi	2011	Dr S.C. Saxena

8.	Effect of seed rate , spacing and its economics of new released soybean varieties under Uttarakhand	Mukta Joshi	2012	Dr S.C. Saxena
9.	Bio-efficacy of Flauzifop-P-Butyl 12.5% and Fomesafen 12.5% alone and in combination for total weed control in soybean	Nazim Hamid Mir	2013	Dr Dheer Singh
10.	Integrated weed management in soybean	Satendra P. Singh	2013	Dr S.C. Saxena
11.	Impact of herbicides and mulch on weed and productivity of soybean under *Tarai* condition of Uttarakhand.	Debarati Datta	2016	Dr S.C. Saxena
	Entomology			
1.	Incidence of insects associated with soybean in different plant spacing and intercropping system	Sathish Kumar	1981	Dr. A. K. Bhattacharya
2.	Susceptibility of soybean germplasm to cigarette beetle *Lesioderma cerrieone*(Fab)	S.K. Sachan	1983	Dr. G.C. Sachan
3.	Susceptibility of soybean germplasm to *Melanogromyza sojae* (Zehnter)	Rehman	1985	Dr. M.S. Khalsa
4.	Efficacy of various insecticides against major insect-pests of soybean [*Glycine max* (L) Merril]	A.K. Singh	1986	Dr .V. K. Sharma
5.	Relative susceptibility of soybean varieties and soya products to *Lasioderma semicorne* (Fabricius) and developmental behavior of *Tribolium castaneum* on soya products	Sanjay Sharma	1993	Dr. A. K. Bhattacharya
6.	Efficacy of various insecticides against major insect pests of soybean [*Glycine max* (L.) Merrill]	Arun Kumar Singh	1996	Dr. Shri Ram
7.	Efficacy of neem based products in comparison to triazophos against major pest of soybean	Arbind Kumar	1997	Dr. Shri Ram
8.	Comparison of newer and traditional methods to control the insect pests of soybean	Abebe Megersa	1999	Dr. Shri Ram
9.	Efficacy of different management strategies to control lepidopterous defoliators associated with soybean	Raj Kumar	2000	Dr. Shri Ram
10.	Evaluation of bio-rational pesticide against major insect-pest of soybean	J.P. Purwar	2001	Dr. Shri Ram
11.	Field efficacy of cow urine in comparison to chemical and bio-pesticide against major insect-pests of soybean	Garima Mangalik	2002	Dr. Shri Ram
12.	Effectiveness of cow urine and its decoctions against major insect-pests of soybean	Poonam Chialna	2003	Dr. Shri Ram

13.	Comparison of newer and traditional methods to control the insect pest of soybean	Rohit Malik	2004	Dr. Shri Ram
14.	Field efficacy of cow urine and its decoctions as well as it's mixtures with triazophos against the insect pest of soybean.	B. Mallangouda	2005	Dr. Shri Ram
15.	Comparative study and compatibility of neem seed kernel extract with biopesticides and its efficacy with different additives against major insect pests of soybean	Rachna Pandey	2006	Dr. Shri Ram
16.	Efficacy of some insecticides against major insect pests of soybean and their impact on natural enemies	K.K. Panda	2007	Dr. Shri Ram
17.	Comparative efficacy of some newer insecticides and *Bacillus thuringiensis* var. *Kurstaki* against major insect pests of soybean and their impact on natural enemies	V.V. Nisal	2007	Dr. R.S.Bisht
18.	Efficacy of some novel insecticides on major insect pest of soybean and their impact on natural enemies	Pooja Gangwar	2010	Dr. Neeta Gaur
19.	Evaluation of some germplasm and novel insecticides against insect pests of soybean	Hemlata Martoliya	2011	Dr. Neeta Gaur
20.	Comparative efficacy of some insecticides against insect pests of soybean under field condition.	Divyajyoti Pokhriyal	2011	Dr. Neeta Gaur
21.	Bioefficacy of some neonicotinoid organophosphates and pyrethroids against insect pests of soybean	Akanksha Chand	2012	Dr .Neeta Gaur
22.	Population dynamics, relative resistance in soybean germplasm aginst whitefly (*Bemisia tabaci*) in field and pulse beetle (*Callosobruchus chinensis*, Bruchidae Coleoptera) infestation under storage conditions.	Kalpana Bisht	2013	Dr. A. K. Karnatak
23.	Screening of some soybean germplasm against Pulse beetle ,*Callosobruchus chinensis* (Linnaeus)	Asha Vishwakarma	2013	Dr. Neeta Gaur
24.	Bioefficacy of emamectin benzoate, indoxacarb and chlorantraniliprole against major insect pest of soybean and their effect on natural enemies.	Sandeep Kaintura	2014	Dr. A. K. Karnatak
25.	Seasonal incidence of major insect pests and their natural enemies on soybean and bioefficacy studies of some novel insecticides against them.	Kiran Negi	2014	Dr. Neeta Gaur

26.	Laboratory studies on antibiosis and antixenotic effect on soybean [*Glycine max* (L.) Merrill] germplasm against *Spodoptera litura* (Fabricius) and *Spilarctia obliqua* (Walker)	Priyanka Kohli	Persuing	Dr. Neeta Gaur
27.	Screening of germplasm lines and management of whitefly (*Bemisia tabaci*) in soybean [*Glycine max* (L.) Merrill]	Deepshikha Karayat	Persuing	Dr. Neeta Gaur
	Plant Pathology			
1.	Studies on the seed-borne microflora of soybean seed produced in the *Tarai*.	O.V. Singh	1970	Dr. Y.L. Nene
2.	Studies on the ring spot disease of soybean.	S.P. Singh.	1971	Dr. Y.L. Nene
3.	Physiological and pathological studies with *Colletotrichum truncatum* causing pod blight disease in soybean.	R.K. Malhotra	1971	Dr. C. Chaturvedi
4.	Soybean rust: Symptoms, etiology and chemical control.	K.P. Singh	1973	Dr. P.N. Thapliyal
5.	*Rhizoctonia* aerial blight of soybean symptoms, etiology and chemical control.	H.S. Verma	1973	Dr. P.N. Thapliyal
6.	Chemical control of anthracnose (pod blight) of soybean caused by *Collectotrichum dematium* (Pres. Ex Fr. Grover var. truncate (Schw) Arx.	N.N. Choudhary	1977	Dr. P.N. Thapliyal
7.	Uptake and translocation of five systemic fungicides in soybeans and their *in vitro* effectivity against *Macrophomina phaseolina*.	P.S. Chauhan	1978	Dr. P.N. Thapliyal
8.	A new mild strain of soybean mosaic virus and its effect on yield.	H.M. Singhavi	1979	Dr. S.P.S. Beniwal
9.	Factors affecting seed and seedling rot diseases of soybean [*Glycine max* (L.) Merrill]	K.D. Agarwal	1983	Dr. R.S. Singh
10.	Studies on compatibility between seed treatment fungicides and *Rhizobium* inoculum in soybean.	S.P. Singh	1984	Dr. V.K. Agarwal
11.	Effect of some agrochemicals and the interactions on the growth of *Rhizoctonia solani* Kuhn, incitant of aerial blight of soybean, *in vitro*.	J.P. Rai	1993	Dr. K.S. Dubey
12.	Fungicidal seed treatment studies on soybean cultivars.	V.K. Dhinwa	1995	Dr. P.N. Thapliyal
13.	Studies on a new blight disease of soybean cultivar VLS-2 in Tarai region of U.P.	R.K. Poddar	1995	Dr. P.N. Thapliyal
14.	Studies on certain aspects of anthracnose of soybean caused by *Colletotrichum dematium* var. *runcate* (Schoo)Andrus & Moone	Bijendra Kumar	2001	Dr. K.S. Dubey

15.	Arial blight of soybean (*Rhizoctonia solani*): cultural characters of the pathogen and disease management.	Ruchi Agarwal	2001	Dr. P. Kumar
16.	Studies on genetic identity and seed health testing in soybean [*Glycine max* (L.) Merri.]	Motilal R. Lamani	2001	Dr. K P Singh
17.	Variation in isolates of *Colletotrichum dematium* var. *trancata* the causal organism of soybean pod blight.	Sachin Tomer	2002	Dr. P. Kumar
18.	Studies on seed borne nature of *Colletotrichum truncate* (Sch.) Andrus and W.P. Moore, the cause of anthracnose of soybean [*Glycine max* (L.) Menill] and its management.	Neelam Singh Baliyan	2003	Dr. Karuna Vishunavat
19.	Studies on some aspects of bacterial blight of soybean caused by *Pseudomonas savastanoi* pv. *Glycinea*.	Neetu Rani	2003	Dr. P. Kumar
20.	Studies on seed borne nature of charcoal rot of soybean (*Macrophomina phaseolina* (Tassi Goid), its transmission and management through seed treatment.	Vinod Arya	2003	Dr. Karuna Vishunavat
21.	Studies on *Rhizoctonia solani* Kuhn, the Incitant of aerial blight of Soybean with special reference to variability among the isolates.	Lalan Sharma	2006	Dr. S.N Vishwakarma
22.	Studies on certain aspects of aerial blight of Soybean caused by *Rhizoctonia solani* Kuhn.	Shailesh Pandey	2006	Dr. K.S. Dubey
23.	Chemicals, botanicals and bio-agents against *Fusarium oxysporum* the cause at seed rot of soybean	Priyanka Mehta	2007	Dr. Karuna Vishunavat .
24.	Studies on certain aspects of anthracnose of soybean caused by *Colletotrichum dematium* var. *truncate* (Schw.) Andrus and Moore”	Rekha	2008	Dr. K.S. Dubey
25.	Studies on Symptomatology, Etiology & Management of Aerial blight of Soybean	Rajendra Upreti	2010	Dr. K.S. Dubey
26.	Cultural and physiological aspects of *Rhizoctonia solani*, the causal organism of aerial blight at soybean	Archana Negi	2011	Dr. Vishwanath
27.	Anthracnose of soybean symptomology etiology and management	Meenakshi Rana	2012	Dr. K.S. Dubey
28.	Drechslera blight of Soyabean Symptomology, Etiology and management	Kalpna Gairolo	2013	Dr. K.S. Dubey
	Microbiology			
1.	Influence of PSB and VA mycorrhizal inoculation on soybean–*Rhizobium* symbiosis	Mahendra Singh	2005	Dr. Narendra Kumar

2.	Interactive effect of *B. japonicum* and PGPR on *Glycine max* - *B. japonicum* symbiosis and soil properties	Shalini Dwivedi	2006	Dr. Narendra Kumar
3.	Symbiotic efficiency of native soil bradyrhizobia in soybean genotypes.	Babita Bhatt	2008	Dr. Narendra Kumar
4.	Influence of fungicides and bio-agents on nodulation, growth, nutrient uptake by soybean grown on Mollisols	Gaurav Mishra	2010	Dr. Narendra Kumar
	Ph.D Theses **Genetics and Plant Breesing**			
1.	Studies on heterosis combining ability…in soybean	V.S. Chauhan	1976	Dr. B.B. Singh
2.	Studies on radiation stimulation and induction of genetic variability by physical and chemical mutagen in soybean	H.D. Upadhaya	1980	Dr. K.P.S. Chauhan
3.	Studies of induced variability quantitative characters in soybean	Jeet Singh Sandhu	1984	Dr. P. S. Bhatnagar
4.	Genetics of seed quality in soybean	Virendra D. Verma	1985	Dr. H.H. Ram
5.	Genetics of quantitative traits and selection for yield and other characters in soybean	Pushpendra	1985	Dr. H.H. Ram
6.	Selecting parental cultivars and crosses and visual selection for seed yield in early generation in soybean	Kamendra Singh	1987	Dr. H.H. Ram
7.	Stability analysis in soybean	Rajat Saxena	1987	Dr. P.S. Bhatnagar
8.	Studies on induced polygenic mutations in M3 and M4 generations of soybean	S.K. Chaturvedi	1988	Dr. H.H. Ram
9.	Genetics of vegetative and reproductive and their importance in inbreeding soybean	N.N. Pathak	1988	Dr. H.H. Ram
10.	Genetics and screening methods of seed longevity in soybean	P.T. Dao	1995	Dr. H.H. Ram
11.	Elucidating the genetics and physiology of seed longevity in soybean	Puspak Mani Bhardwaj	2009	Dr. Pushpendra
12.	Studies on inheritance of major quantitative traits in soybean	Rajneesh Kr. Singh	2009	Dr. Pushpendra
13.	Stability analysis for various quantitative characters and assessment of molecular diversity in soybean [*Glycine max* (L.) Merrill]	Gunjan Tiwari	2013	Dr. Kamendra Singh
14.	Stability analysis for yield and quality traits and assessment of diversity using SSR molecular marker in soybean [*Glycine max* (L.) Merrill]	Ms. Aneeta Yadav	2014	Dr. Kamendra Singh

15.	Genetic analysis for yield and its components in early generation and assessment of molecular diversity in soybean [*Glycine max* (L.) Merrill]	Nagma Kousar	2014	Dr. Kamendra Singh
16.	Studies on heterosis, transgrassive segregation selection index and determination of parental molecular diversity in soybean [*Glycine max* (L.) Merrill]	Minakshi Joshi	2015	Dr. Kamendra Singh
17.	Studies on seed longevity with packaging materials, genetic variability and molecular diversity of soybean [*Glycine max* (L.) Merrill]	Smt Vandana Bhakuni	2017	Dr. P.S. Shukla
18.	Effectiveness of early generation selection based on F2 heritobility in soybean [*Glycine max* (L.) Merrill]	Minakshi Bisht	Perusing	Dr. Kamendra Singh
19.	Studies on seed longevity based on biochemical, genetical and molecular in soybean [*Glycine max* (L.) Merrill]	Kumar Nishant Chourasia	Perusing	Dr. Kamendra Singh
20.	Morphological and molecular genetic diversity study in soybean germplasm.	Narendra Singh Dhaka	Perusing	Dr. Kamendra Singh
21.	Morphological and molecular genetic diversity and seed longevity studies in soybean germplasm	Mr. Anil Bairwa	Perusing	Dr. P.S. Shukla
	Agronomy			
1.	Evaluation of diclosulam and hayloxyfop for weed control in soybean [*Glycine max* (L.) Merrill]	Rakesh Chandra Nainwal	2010	Dr S.C. Saxena
	Entomology			
1.	Effect of manual and insect defoliation on the yield of soybean	Shri Ram	1987	Dr. A. K. Bhattacharya
2.	Efficacy of insect growth regulators against major defoliators of soybean	Kuldeep Sharma	2003	Dr. Shri Ram
3.	Seasonal incidence and screening of soybean cultivars and efficacy of chlorantraniliprole 18.5 SC against major insect pests.	Vaibhav Mathur	2013	Dr. R.S. Bisht
4.	Studies on entomopathogenic fungi against major lepidopteran insect pests from soybean growing areas of Kumaun Uttarakhand	Mona Joshi	2014	Dr. Neeta Gaur
5.	Screening of soybean genotype against major lepidopteran pests through morphological,bio-chemical and molecular basis.	Anchala Nautiyal	2015	Dr. Neeta Gaur

6.	Studies on transmission of yellow mosaic virus and management of its vector whitefly [*Bemisia tabaci* (Gennadius)] in soybean [*Glycine max* (L.) Merrill]	Swathi Mogalapu	Persuing	Dr. Neeta Gaur
7.	Survey and identification of gut micro organisms of *Spodoptera litura* (Fabricius) [Noctuidae: Lepidoptera] on soybean [*Glycine max* (L.) (Merrill.)]	Rukesh Pramod	Persuing	Dr. Neeta Gaur
	Plant Pathology			
1.	Studies on Bayleton and Baytan: *In vitro* stability, systemicity and response in soybean [*Glycine max* (L.) Merrill]	S.R. Gautam	1981	Dr. P.N. Thapliyal
2.	Physiological and pathological studies on *Rhizoctonia solani* Kuhn causing aerial blight of soybean.	K.S. Dubey	1988	Dr. P.N. Thapliyal
3.	Integrated Management of seed and seedling rot problems in soybean	Uma Kumari	1995	Dr. P.N. Thapaliyal
4.	Biological control of seed and seedling rot complex of Soybean.	R. Pant	1998	Dr. A.N. Mukhopadhyay
5.	Pod blight of soybean: variability in causal fungus *Colleto*trichum *truncatum* (Schw) Andrus and Moore and disease management.	G. P. Jastap	1999	Dr. P.N. Thapaliyal
6.	Integrated management of charcoal Rot caused by *Macrophomina phaseolina* (Tassi) Goid. of soybean.	Ajit Saxena	2001	Dr. H.S. Chawla
7.	Studies on cultural and physiological characteristics of *Rhizoctonia solani* Kuhn and management of the aerial blight of soybean	Anjana Ray,	2006	Dr. P. Kumar
8.	Compatibility and interaction effects of pesticides, antagonists, biofertilizers and botanicals on *Rhizocotonia solani* (Kuhn) causing aerial blight of soybean.	Akoijam Ratankumar Singh	2011	Dr. K.S. Dubey
9.	Epidemiology and management of Rhizoctonia aerial blight of soybean [*Glycine max* (L.) Merril]	Mamta Mathpal	2016	Dr. K P Singh
	Microbiology			
1.	Organic wastes recycling through composting and their nutrient potential in soybean [*Glycine max* (L.) Merril]	Amit Mishra	2005	Dr. Narendra Kumar
2.	Effect of manures, fertilizers and micronutrients on nodulation, growth and yield of soybean [*Glycine max* (L.) Merril]	Mahendra Singh	2008	Dr. Narendr.a Kumar
3.	Effect of nutrient management and post emergence herbicides on *Glycine max* – *Rhizobium* symbiosis and soil properties	Shrila Das	2011	Dr. Narendra Kumar

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1. **Singh, B.B.; Singh, K. and Pushpendra 1979**. Induced cytoplasmic male sterility in soybean. *Soybean Genetic News l.*, **6**: 39-41.
2. **Ram, H.H.; Pushpendra; Singh, K. and Verma, V.D. 1981**. Breeding soybean varieties for the Northern India. *Soybean Genetics News l.*, **8**: 74-78.
3. **Ram, H.H.; Verma, V.D.; Singh, K. and Pushpendra 1981**. Pod setting under standard crossing procedure in soybean. *Soybean Genetic News l.,* **8**: 78-79.
4. **Ram, H.H.; Pushpendra; Verma, V.D. and Singh, K. 1982**. Note on effect of selection for quantitative traits in M3 progenies of soybean. *Indian J. Agric. Sci.,* 52(**6**): 404-405.
5. **Ram, H.H.; Verma, V.D.; Singh, K. and Pushpendra, 1982**. New breeding lines of soybean developed at Pantnagar. *Soybean Genetic News l.,* **9**: 39-42.
6. **Ram, H.H.; Verma, V.D.; Pushpendra and Singh, K. 1982**. Extent of selfing during crossing in soybean. *Soybean Genetic News l.,* **9**: 42-43.
7. **Ram, H.H.; Singh, K.; Pushpendra and Verma, V.D. 1982**. Screening for photo period insensitivity under natural conditions in soybean. *Soybean Genetic News l.,* **9**: 43-44.
8. **Singh, K. and Ram, H.H. 1983**. Dry matter yield and branching ability as selection parameters in soybean. *Soybean Genetic News l.,* **10**: 13-15.
9. **Ram, H.H.; Singh, K.; Pushpendra and Verma, V.D. 1984**. Breeding for resistance to yellow mosaic virus through inter specific hybridization in soybean. *Soybean Genetic News l.,* **11**: 46-48.
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12. **Singh, K. and Ram, H.H. 1985**. Genetic divergence in soybean *Indian J. Genetics*, **45**: 531-538.
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14. **Singh, K. and Ram, H.H. 1989**. Visual selection for seed yield in F_2, F_3 and F_4 generations in soybean in the subtropics. In: Proc. World Soybean Research Conference IV, 5-9, March. Boenos Aires, Argentina 962-968.
15. **Ram, H. H.; Singh, K. and Pushpendra 1992**. Genetic divergence in the elite germplasm of soybean. *Narendra Dev. J. Agric. Res.,* 7 (**1**): 156:163.
16. **Chauhan, S.; Pushpendra and Singh, K. 1998**. Meterogliph and index score analysis in advance breeding lines of soybean. *Soybean Genetic News l.,* **25**: 77-79.
17. **Shukla, S.; Singh, K. and Pushpendra 1998.** Correlation and path coefficient analysis of yield and its components in soybean {*Glycine max.* (L.) Merrill}. *Soybean Genetic News l.,* **25**: 67-70.

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24. **Praveen, S.; Pushpendra; K. Singh, B. V. Singh and Gupta, M. K. 2007.** Early generation selection for pods / plant and dry matter yield in inter specific crosses of soybean. *Soybean Research,* **5** (1): 1-7.

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26. **Sharma, B.; Singh, B.V.; Singh, K.; Pushpendra and Gupta, M.K. 2007**. Selection criteria for improvement of grain yield in Soybean [*Glycine max* (L.) Merrill]. *Pantnagar Journal of Research,* **5*(1*)**: 43-44.

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28. **Pandey, S.; Pushpendra; Singh, B.V.; Singh, K. and Gupta, M.K 2008**. Effect of hydration treatment on germination and yield components in F_3 generation of black and yellow seeded soybean (*Glycine max* (L) merrill*). Pantnagar Journal of Research,* **6**(1): 36-41.

29. **Pandey, K.; Singh, K.; Singh B. V.; Pushpendra; Gupta, M.K. and Yadav N. S. 2008**. Character association and path coefficient analysis in advance breeding lines of soybean (G. *max* (L) Merrill). *Soybean Research,* **6**:15-20.

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Soybean workers at Pantnagar since 1967

Genetics and Plant Breeding

Sl. No.	Name	Period
1	Dr. P. S. Bhatnagar	Up to 1968
2	Dr. B. B. Singh	1969-1978
3	Dr. Hari Har Ram	1979-1992
4	Dr. Pushpendra	1975 - continue
5	Dr. Kamendra Singh	1975 - continue
6	Dr. V. D. Verma	1978-1986
7	Dr. B. V. Singh	1999-2007
8	Dr. P. S. Shukla	2012 - continue
	Technical staff	
1	Mr. R.P.S. Pundir	1969-1970
2	Dr. B. D. Singh	1969-1974
3	Dr. S. C. Gupta	1969-1972
4	Sri V. S. Serohi	1974-1975
5	Dr. M. K. Gupta	1992 - continue
6	Dr. R. K. Sinha	2011 - 2015
	Agronomy	
1.	Dr. M. C. Saxena	1967-1976
2.	Dr. J. N. Singh	1976-1982
3.	Dr. A. S. Chandel	1982-2005
4.	Dr. S. C. Saxena	1977-Continue
5.	Dr. Ajay Kumar	2016-Continue
6.	Sri Ram Prakash	2002-2011
7.	Mr.Sushil Kumar	1995-2006
8.	Dr. Dalchand	2011-Continue
	Microbiology	
1	Dr. K.V.B.R. Tilak	1967-1977
2.	Dr. R.P. Pareek	1977-1980
3.	Dr. L.M. Pant	1980-2000
4.	Dr. Ramesh Chandra	2000-2002
5.	Dr. Narendra Kumar	2002- continuing
6.	Dr. K.P. Raverkar	2013- continuing
7.	Mr. A.K. Katiyar	
8.	Mr. C. L. Sharma	1995-2016
9.	Mr. Sushil Kumar	2016- continuing

	Plant Pathology	
1.	Dr. P N Thapliyal	1968-1998
2.	Dr. K S Dubey	1983-1995; 2004-2015
3.	Dr. Y P S Rathi	1999-2003
4.	Dr. Pradeep Kumar	1999-2003
5.	Dr. S N Vishawakrma	2004-2007
6.	Dr. Vishwanath	2008-2010
7.	Dr. K P Singh	2013- Continuing
8.	Mr. H K Bhadula	1968-1982
9.	Mr. R B Sachan	1996-Continuing
	Entomology	
1.	Dr. Y,S,Krishnan	1969-71
2.	Dr. J.F.S.Chandra	1969-70 (left in 1969)
3.	Mr. R.R.P.Chaudhary	1969-1976
4.	Mr. Mahavir Singh	1969-1970
5.	Dr. A.K. Bhattacharya	1971-1997
6.	Dr. Y.S Rathore	1973
7.	Dr. R.R.S. Rathore	1973-1974
8.	Mr. Shri Ram	1975-2007
9.	Mr. Raj Kumar	1995-2004
10.	Dr Neeta Gaur	2006 to continuing
11.	Mr. Sushil Kumar	2007-2016

Photo Gallery

Dr. B.B. Singh, Ex-soybean breeder with US delegation apprising potential of soybean crop at Pantnagar

Dr. S.C. Mudgal, Ex-Vice Challcellor, visited soybean programme

G. Soja (wild relative of cultivated soybean)

YMC resistant variety of soybean developed at Pantnagar

Dr. S.B. Singh, Ex-Vice Chancellor visited soybean research programme

Dr. Mangla Rai, Ex-DG, ICAR/Ex-Vice chancellor of GBPUA&T, Pantnagar visited AICRP on soybean programme











Soybean Research Team at Pantnagar

Dr. Pushpendra
Professor
Department of Genetics and Plant Breeding
& Programme Coordinator

Dr. Kamendra Singh
Professor
Department of Genetics
and Plant Breeding

Dr. S.C. Saxena
Professor
Department of Agronomy

Dr. Narendra Kumar
Professor
Department of Soil Science

Dr. K.P. Singh
Professor
Department of Plant Pathology

Dr. K.P. Raverkar
Professor (Soil Sci. & Microbiol.)
Department of Soil Science

Dr. P.S. Shukla
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Department of Agronomy

Dr. Dal Chand
Senior Technical Assistant
Department of Agronomy

Dr. Manoj Kumar Gupta
Technical Assistant
Department of Genetics and
Plant Breeding

Sri. Shshil Kumar
Technical Assistant
Department of Soil Science

Sri. R.B. Sachan
Technical Assistant
Department of Plant Pathology

About Pantnagar

After independence, development of the rural sector was considered the primary concern of the Government of India. In 1949, with the appointment of the Radhakrishnan University Education Commission, imparting of agricultural education through the setting up of rural universities became the focal point. Later, in 1954 an Indo-American team led by Dr. K.R. Damle, the Vice-President of ICAR, was constituted that arrived at the idea of establishing a Rural University on the land-grant pattern of USA. As a consequence a contract between the Government of India, the Technical Cooperation Mission and some land-grant universities of USA, was signed to promote agricultural education in the country. The US universities included the universities of Tennessee, the Ohio State University, the Kansas State University, The University of Illinois, the Pennsylvania State University and the University of Missouri. The task of assisting Uttar Pradesh in establishing an agricultural university was assigned to the University of Illinois which signed a contract in 1959 to establish an agricultural University in the State. Dean, H.W. Hannah, of the University of Illinois prepared a blueprint for a Rural University to be set up at the Tarai State Farm in the district Nainital, UP. In the initial stage the University of Illinois also offered the services of its scientists and teachers. Thus, in 1960, the first agricultural university of India, UP Agricultural University, came into being by an Act of legislation, UP Act XI-V of 1958. The Act was later amended under UP Universities Re-enactment and Amendment Act 1972 and the University was rechristened as Govind Ballabh Pant University of Agriculture and Technology keeping in view the contributions of Pt. Govind Ballabh Pant, the then Chief Minister of UP. The University was dedicated to the Nation by the first Prime Minister of India Pt Jawaharlal Nehru on 17 November 1960.

The G.B. Pant University is a symbol of successful partnership between India and the United States. The establishment of this university brought about a revolution in agricultural education, research and extension. It paved the way for setting up of 31 other agricultural universities in the country.

The credit for starting the functioning of the University without losing any time goes to the warm and resourceful personality of the first Vice-Chancellor, late Dr. Kenneth Anthony Parker Stevenson (1-12-58 to 2-1-64), who could keep people fruitfully engaged on the university farm, the labs and the classrooms despite the lurking fear of wild animals roaming the area.

The Campus appears impressive today with its well-tended fields, a network of roads, housing colonies, street lighting, a telephone exchange, hospitals, marketing centres, a water supply section, 6 primary schools and 3 secondary schools. The main campus lies in Udham Singh Nagar district of Uttarakhand at 29 N latitude and 79 E longitude at an elevation of 243.8 m above the mean sea level. This main campus has the area responsibility for the entire Uttarakhand representing plains, Tarai, Bhabar and hill areas. However, to provide service to the hill region its other stations are situated at Ranichauri (Tehri district), Majhera (Nainital district) and at Lohaghat-Sui (Champavat district).