# Ability of commercially available soybean *Bradyrhizobia* inoculants for cool growing conditions in Central Europe

STÉPHANIE ZIMMER[1,3], MONIKA MEßMER[2], THORSTEN HAASE[3,4], ANKE MINDERMANN[3], HANNES SCHULZ[3], KLAUS-PETER WILBOIS[5], JÜRGEN HEß[3]

**Key words:** Soybean, Nitrogen-fixation, inoculation, *Bradyrhizobium japonicum*

## Abstract

*In Central Europe the inoculation of soybean (Glycine max (L.) Merr.) with different Bradyrhizobia inoculants has led to unsatisfying nodulation results under low temperature conditions. The aim of this study was to test the capacity of commercially available inoculants under cool growing conditions in Central Europe. In 2011 and 2012 four Bradyrhizobia inoculants were tested on three early soybean varieties in a field trial in Germany. The number of nodules, yield and protein content were assessed. Two years data showed a successful nodulation of Product 4, Product 3 and Product 2 while Product 1 cannot be recommended. Independently of soybean variety, all of the three successful inoculants can be advised regarding grain yield. Protein content and protein yield depend on the combination of inoculants and soybean variety. Over the years Product 4 was the most reliable inoculant.*

## Introduction

Soybean is able to produce high quality protein for human and animal consumption. Under low temperature conditions in Central Europe the inoculation with different *Bradyrhizobia* inoculants, which were mainly developed for the conditions in USA, has led to unsatisfying nodulation results. The aim of this study was to test the ability of commercially available inoculants for cool growing conditions in Central Europe.

## Material and methods

A field trial was carried out under organic farming conditions, at the "Hessische Staatsdomäne Frankenhausen", the research farm of the University of Kassel-Witzenhausen (51,4 N; 9,4 E), located 230 m above sea level. Soil type was a Haplic Luvisol and soil texture a silty loam.

The field trial was conducted in two consecutive seasons (2011 and 2012), on fields, on which no soybean has been cultivated previously. Three early mature soybean varieties (Variety 1, Variety 2, Variety 3) were tested in combination with four different *Bradyrhizobia* inoculants (Product 1, Product 2, Product 3, Product 4) and non inoculated controls. Soybeans were sown on the 28.04.2011 and 08.05.2012, respectively, with 65 kernels per $m^2$ and a distance of 37,5 cm between rows and harvested the 05.10.2011 and 19.10.2012, respectively. Seeds were inoculated according to the recommendations of the manufacturer of the inoculants, except Product 1 which was applied in 20 fold concentration in 2012, because of the unsuccessful nodulation observed in 2011.

The factorial treatments were arranged in a split-plot design with inoculant (I) as main plot and variety of soybean (VS) as subplot with four replications (REP) and a subplot size of 1,5 m x 10 m.

Six weeks after sowing (Nodulation 1) and at flowering (Nodulation 2) 2 x 3 plants per subplot were harvested. Number of nodules, size of nodules (mm) and colour of nodules as well as shootlength (cm) were assessed. Grain yield (dt $ha^{-1}$ at 86 % DM) was determined at harvest. Crude protein content (%) was determined by NIRS and protein yield (dt/ha) was calculated.

Analysis of variance and comparison of means were analysed using the MIXED procedure of the software package SAS 9.2 (SAS Institute 2002-2008) and Tukey's honestly significant difference test.

## Results

Due to unsuccessful nodulation of Product 1 applied at recommended concentration in 2011 and at 20 fold concentration in 2012 all the assessed traits did not differ significantly from the not inoculated controls.

Nodulation 1 was significantly affected by the interaction of inoculant and year. Highest number of nodules per plant was determined on soybeans inoculated with Product 4 in 2012 and in 2011 (Fig. 1). Nodulation 2 was significantly affected by inoculant. Over two years, three soybean varieties and four replications, the significant highest number of nodules per plant was also observed in combination with Product 4, followed by Product 2 and then by Product 3 (Fig. 2).

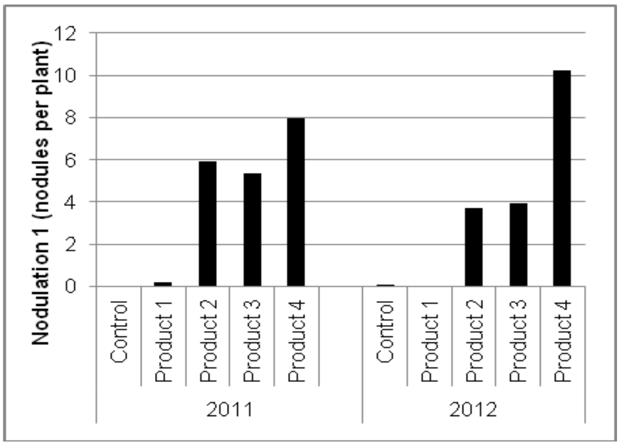



**Fig. 1:** Nodulation 1 (nodules per plant) in Frankenhausen as a function of inoculant and year. Average across three varieties of soybeans and four replicates.

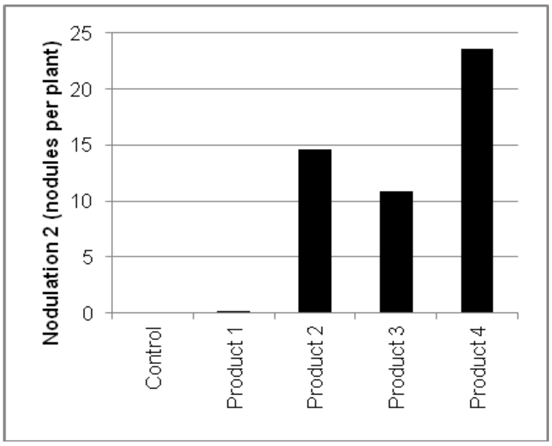
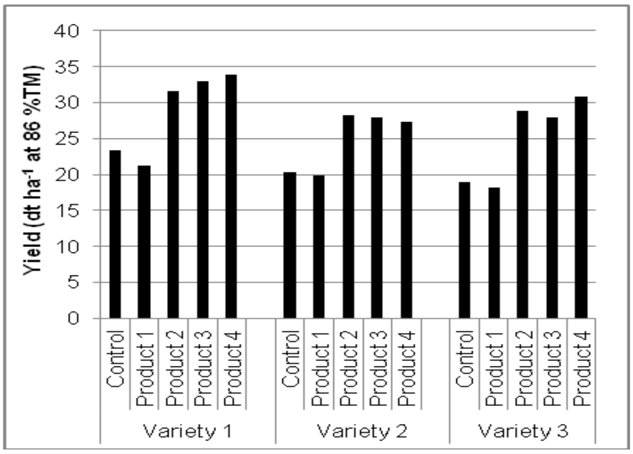
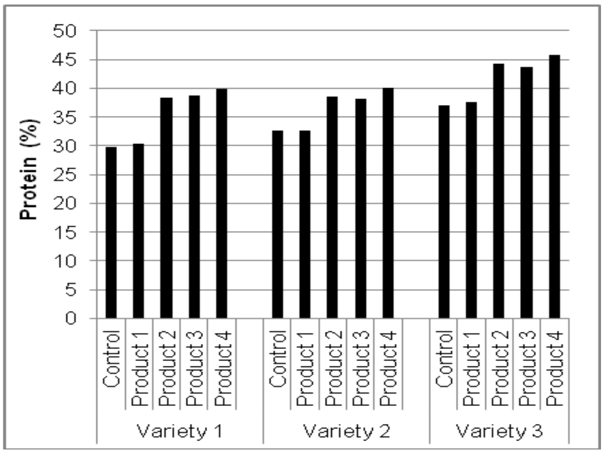



**Fig. 2:** Nodulation 2 (nodules per plant) in Frankenhausen as a function of inoculants. Average across three varieties of soybeans, two years and four replicates.

Grain yield was significantly affected by the interaction of year * variety of soybean. Grain yields of soybeans inoculated with Product 2, Product 3 or Product 4 were significantly higher than the non-inoculated control and Product 1 (Fig. 3). For all three varieties the combination with Product 2, Product 3 or Product 4 resulted in similar yields which did not differ significantly from each other. Mean yield was significantly higher in 2012 than in 2011.




Protein content was significantly affected by the interaction of inoculant * variety of soybean. For Variety 2 and Variety 3 the protein content was significantly highest in combination with Product 4, followed by Product 2 (Fig. 4). Variety 1 obtained the highest protein content in combination with Product 4 and with Product 3. These two combinations were statistically at par.

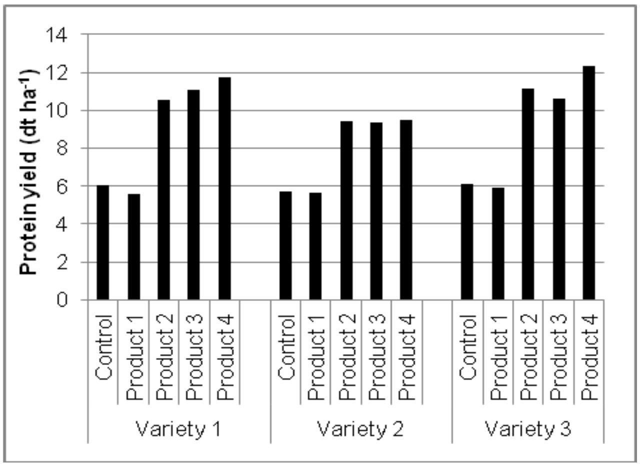



**Fig. 5:** Protein yield (dt ha$^{-1}$) in Frankenhausen as a function of inoculant and variety of soybean. Average across two years and four replicates.

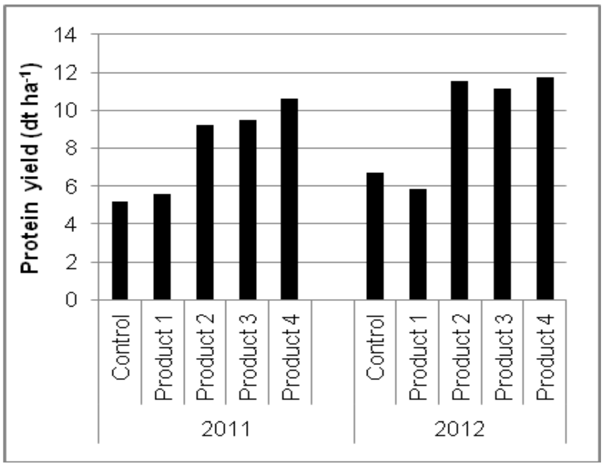



**Fig. 6:** Protein yield (dt ha$^{-1}$) in Frankenhausen as a function of inoculant and year. Average across three varieties of soybean and four replicates.

Protein yield was significantly affected by the interaction of inoculants * variety of soybean. Highest protein yield was determined for Variety 3 in combination with Product 4 and in combination with Product 2, and for Variety 1 in combination with Product 4 and in combination with Product 3 (Fig. 5). For the above named combinations protein yield was significantly higher than that of Variety 2, independent of the inoculant. Protein yield was also affected by the interaction of inoculants * year. Over three varieties of soybean and four replications soybeans inoculated with Product 4 had the highest protein yield in 2011 and in 2012 and were at par with the protein yield of soybeans inoculated with Product 2 and with Product 3 in 2012 (Fig. 6).

Over two years nodulation at flowering correlated positively with grain yield ($r_s$=0,74), with protein content ($r_s$=0,71) and protein yield ($r_s$=0,78) (Spearman rank correlation p<0,0001).

## Discussion

Nitrogen uptake has been identified as the limiting factor of soybean grain yield. On average 50-60% of soybean nitrogen demand can be covered by biological $N_2$ fixation (Salvagiotti et al. 2008).

It is therefore necessary to select for proper *Bradyrhizobia* inoculants for cold growing conditions in Central Europe to improve soybean yield and quality. The experiment confirmed the successful nodulation of Products 2, 3 and 4 while Product 1 cannot be recommended. Regarding grain yield, all the successful inoculants can be advised, independently of soybean variety. Concerning protein content, Product 4 was especially profitable in combination with Variety 2 and 3. For the Variety 1, Product 3 or 4 can be chosen to obtain high protein content, whereas Products 2 and 4 are recommended for Variety 3 to target high protein content and protein yield. Variety 2 showed the lowest yield and protein yield independent of the inoculant. Over the years Product 4 was the most reliable inoculant.

## Acknowledgment

The present project is supported by Federal Ministry of Food, Agriculture and Consumer Protection, Germany and by National Research Fund, Luxembourg.

## References

Salvagiotti F., Cassman K.G., Specht J.E., Walters D.T. Weiss A., Dobermann A. (2008): Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. Field Crops Res. 108, 1-13.