University of São Paulo
“Luiz de Queiroz” College of Agriculture

**How breeding of Brazilian soybean cultivars modified morphophysiological
attributes of plants?**

Renan Caldas Umburanas

Thesis presented to obtain the degree of Doctor in Science.
Area: Crop Science

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DEDICATION

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to me of the importance of a family;

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RESUMO

Como a seleção de cultivares brasileiros de soja alterou atributos morfofisiológicos da planta?

A produtividade média brasileira de soja aumentou consideravelmente desde o início da revolução verde até a época atual. Entre os fatores que contribuíram no aumento da produtividade, estão as novas tecnologias e práticas agrícolas, bem como o ganho genético propiciado pelo melhoramento vegetal. Enquanto a produtividade de soja aumentou através dos esforços do melhoramento, as modificações morfofisiológicas ocorridas nos cultivares brasileiros que contribuíram para o aumento da produtividade são amplamente desconhecidas. Neste estudo objetivou-se compreender como as mudanças morfofisiológicas aumentaram a produtividade em cultivares de soja cultivadas nos últimos 50 anos no sul do Brasil. O estudo foi dividido em três capítulos: o primeiro capítulo refere-se ao experimento conduzido a campo para avaliar produtividade e seus componentes em 26 cultivares; o segundo capítulo refere-se ao experimento conduzido em vasos para avaliar as raízes de 25 cultivares; e o terceiro capítulo refere-se a dois experimentos em que avaliou-se atributos de eficiência de conversão de energia, envelhecimento foliar e resposta das plantas a elevação do CO₂ atmosférico em 5 cultivares. Os resultados obtidos demonstram que o aumento da produtividade foi consistente ao longo do ano de lançamento dos cultivares e a taxa de aumento foi de 46 kg ha⁻¹ ano⁻¹. Entre os componentes de produtividade que contribuem para este aumento destacam-se o aumento da biomassa por área e do índice de colheita que, por consequência, propiciam maior número de sementes por área, em decorrência de um maior número de vagens e sementes por vagem. A resistência ao acamamento melhorou ao longo do ano de lançamento dos cultivares. Para aumentos futuros na produtividade, alvos potenciais para serem buscados nas cultivares futuras são maior teor de nitrogênio foliar no estádio R₅ e maior fixação biológica de nitrogênio. O diâmetro médio de raízes reduziu ao longo do ano de lançamento de cultivares, enquanto os atributos comprimento, volume, área projetada e comprimento total da raiz principal não foram modificados de modo consistente. Os cultivares de soja avaliados apresentam mudanças consistentes sob atmosfera de CO₂ elevado [720 ppm]: o teor de clorofila nas folhas reduziu, a área foliar específica reduziu e a partição de biomassa para haste aumentou. As folhas velhas apresentaram menor assimilação, menor condutância estomática, e menor temperatura foliar em relação as folhas novas. Entretanto elas apresentaram maior concentração de CO₂ intercelular, maior área foliar específica e maior teor de clorofila. Os resultados obtidos neste estudo contribuem para estratégias em programas de melhoramento no desenvolvimento de cultivares de soja mais produtivas para o futuro. Os resultados obtidos identificaram mudanças morfofisiológicas ocorridas em uma seleção de cultivares de soja cultivadas na região sul do Brasil

Palavras-chave: Fixação biológica de nitrogênio; Índice de colheita; Assimilação de CO₂; *Glycine max*; Simbiose

ABSTRACT

How breeding of Brazilian soybean cultivars modified morphophysiological attributes of plants?

The average Brazilian soybean yield increased considerably from the beginning of the green revolution to the present day. Among the factors that contributed to the yield increase are the new technologies and agricultural practices, as well as the genetic gain provided by plant breeding. While soybean yield increased through breeding efforts, morphophysiological changes in Brazilian cultivars that contributed to yield increase are largely unknown. The objective of this study was to understand how morphophysiological changes increased yield in soybean cultivars grown in the last 50 years in Southern Brazil. The study was divided into three chapters: the first chapter refers to the experiment conducted in the field to evaluate yield and its components in 26 cultivars; the second chapter refers to the experiment conducted in pots to evaluate the roots of 25 cultivars; and the third chapter refers to two experiments in which attributes of energy conversion efficiency, foliar aging and plant response to elevated CO₂ in the atmosphere were evaluated in 5 cultivars. The results showed that the yield increase was consistent throughout the years of cultivar release and the rate of increase was 46 kg ha⁻¹ year⁻¹. Among the yield components contributing to this increase we include the increase of biomass per area and harvest index, which therefore provide more seeds per area, due to a greater number of pods and seeds per pod. The lodging resistance improved during the year of cultivar release. For further increases in soybean yield, potential targets in future cultivars are increasing leaf nitrogen content at the R₅ growth stage and the biological nitrogen fixation. Mean root diameter was reduced throughout the years of cultivar release, while the attributes total length, volume, projected area and root length were not consistently modified. The evaluated soybean cultivars presented consistent changes under elevated CO₂ atmosphere [720 ppm]: the leaf chlorophyll content was reduced, the specific leaf area reduced, and the stem biomass partition increased. The old leaves presented less assimilation, less stomatal conductance, and lower leaf temperature in relation to the new leaves. However, they presented higher concentration of intercellular CO₂, higher specific leaf area and chlorophyll content. The results obtained in this study will certainly contribute to strategies in breeding programs in the development of soybean cultivars that are more productive in the future. The results obtained identified morphophysiological changes in a selection of soybean cultivars grown in Southern Brazil.

Keywords: Cultivar; Biological nitrogen fixation; Harvest index; CO₂ assimilation; *Glycine max*; Symbiosis

1 INTRODUCTION

Between 1976 and 2017, the on-farm average Brazilian soybean yield increased 43.9 kg ha⁻¹ yr⁻¹, resulting in more than 72% yield increase over 41 years (CONAB, 2019, Figure 1). Yield is the result of phenotypic expression between genetic material and environment (climate and soil). During this period, the breeders gave their contribution and, from time to time, made available new soybean cultivars. It is a fact that the country has made great strides in terms of fertility, soil and water conservation through no-till, and in relation to the management of biotic factors. With this research, it was intended to understand how the genetic improvement for yield of Brazilian soybean cultivars modified aspects of plant morpho physiology.

Figure 1. Brazil soybean harvested area (A, left y axis), production (A, right y axis), and yield. Panel B display the linear model fit to those data. Adapted from CONAB (2019)

To determine the genetic basis of yield increase, cultivars released in different years should be sown in a common environment (Specht et al., 1999; De Bruin e Pedersen, 2008; Rincker et al., 2014). Such research carried out in several soybean-producing countries has shown plant-specific morphophysiological changes for each site because of yield improvement (Okabe et al., 2006; Yu et al., 2009; Jin et al., 2010; Fox et al., 2013; Rincker et al., 2014; Koester et al., 2016; Wu et al., 2015). The increase of soybean yield in Brazil, carried out through breeding, was not accompanied by researches that could clarify the morphophysiological changes that occurred in the plant, and their contribution to the main objective of breeding. Thus, the yield of each cultivar depends only on the efficiency of carbohydrate partitioning, light interception and its energy conversion efficiency (Monteith, 1977).

The carbohydrate partition refers to the amount of mass of dry matter distributed among the different parts of a plant. The plant can produce more grains only with a more efficient carbohydrate distribution. Modern North American soybean cultivars partition more carbohydrates into grains (Koester et al., 2014). In this context, among the yield components that contributed most to yield increase was the number of grains per plant, both in Chinese (Jin et al., 2010; Wu et al., 2015) and in North American (De Bruin e Pedersen, 2008; Rincker et al., 2014) cultivars.

Concurrently, with the increase in yield, cultivars from United States have also shown an increase in oil content, and a decrease in protein content (Rincker et al., 2014). In Japanese cultivars, yield was stable over time, and protein content increased without decrease of oil content (Okabe et al., 2006). Chinese cultivars have not undergone changes in grain composition (Jin et al., 2010). And in Brazil, did the genetic improvement for yield purposes alter or not the modern soybean cultivars seed composition? There is few information about the biomass partition between the parts of the soybean (allometry), and in relation to the concentration of N among them (Salvagiotti et al., 2008), and about how N and biomass partition behaved throughout the selection of Brazilian cultivars.

Light interception refers to the use of solar radiation, which is related to phenology, with the leaf insertion angle, the leaf area, the canopy closure (plant density), the height of the plant, and, mainly, the resistance to lodging. Modern North American soybean cultivars increased light interception because they are upright and less susceptible to lodging (Koester et al., 2014).

Energy conversion refers to the plant ability to convert photosynthetically active radiation into carbohydrates. The energy conversion capacity is determined by several physiological attributes such as: photosynthetic rate, higher leaf N concentration, chlorophyll and RuBisCO enzyme (Maekawa e Kokubun, 2005; Jin et al., 2011; Koester et al., 2016). The most productive Chinese cultivars have a high concentration of N in the leaves and are also efficient in relation to biological nitrogen fixation (BNF) (Jin et al., 2011).

During the soybean grain filling, nitrogen (N) is remobilized from the leaves to the seeds, decreasing the concentration of chlorophyll and RuBisCO (Abu-Shakra et al., 1978). This process, called programmed senescence, impairs photosynthesis (Sinclair and De Witt, 1975). In modern North American cultivars, the increase in chlorophyll concentration (Koester et al., 2016), probably led to the remobilization of a greater quantity of photo assimilates from the leaves to the grains.

The yield-oriented breeding indirectly increased the biomass per area and plant growth rate (Jin et al., 2010; De Bruin; Pedersen, 2009). Modern North American cultivars with higher biomass has also higher sink in the reproductive organs at the end of the plant cycle (Koester et al., 2016).

It is known that the genetic basis of Brazilian soybean cultivars has narrowed over time (Wysmierski e Vello, 2013). It is possible that morphophysiological attributes of old cultivars have been lost, however, it is important to know them if there is an interest in recovering these attributes in future.

The objective of this study is to understand how the genetic improvement for yield of Brazilian soybean cultivars modified aspects of plant morpho physiology.

2 FINAL CONSIDERATIONS

This study highlights the changes that a set of Brazilian historical cultivars from Southern Brazil underwent during the 50 years of breeding. The major findings from this study are presented below:

Over the last 50 yr. the breeders have successfully contributed to the annual rate of soybean yield increase in Southern Brazil. The main contributors to this yield increase is the increase in the seed number per area, harvest index and aboveground biomass, as well the reduction in lodging susceptibility. The seed oil content increased, and seed protein decreased over time by genotypic alterations. For further increases in soybean yield, potential targets in future cultivars are increasing leaf nitrogen content at R₅ and the biological nitrogen fixation.

The root diameter reduced over the release of new soybean cultivars in Southern Brazil, while other root attributes did not change consistently at V₄ growth stage. The main root length could be an indicator of greater vigor in root growth in soybean plants at V₄ growth stage.

The photosynthetic attributes show that the cultivar “Pérola” presented the highest maximum rates of RuBisCO carboxylation in relation to the other evaluated Brazilian cultivars. The soybean plants undergo consistent modifications under elevated CO₂ [720 ppm]: the chlorophyll content in soybean leaves reduced; specific leaf area reduced; and the biomass partition to stem increased.

In general, the bottom (older) leaves of soybean plants had lower assimilation, stomatal conductance, and leaf temperature. They have however higher intercellular CO₂ concentrations, specific leaf area and chlorophyll content. In this context, the old leaves of cultivar “BRS284”, a modern cultivar, has higher photosynthetic activity when compared to the other cultivars. In the evaluation of photosynthetic activity at midday, an oxidative stress condition, the cultivar “Pérola” presented the highest assimilation of carbon in the top leaf in relation to the other cultivars.

Finally, the work covered some aspects of the Brazilian soybean cultivars. The results obtained can give insights to breeders in strategies for the development of higher yielding cultivars in the future and will certainly contribute to better understand some attributes of the soybean crop.

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