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# POTENTIAL ADOPTION AND ECONOMIC IMPACT OF DROUGHT-TOLERANT HB4 SOYBEANS IN ARGENTINA

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**Potential Adoption and Economic Impact of Drought-Tolerant HB4 Soybeans in Argentina**


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*JEL Classification: Q12, Q13, Q16*



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## Resumen

Analizamos el potencial de adopción de la tecnología HB4 en soja. La misma aporta tolerancia a la sequía para e. cultivo. Se emplea un procedimiento de dos pasos. En primer lugar, a fin de estimar predisposición a pagar (en inglés, "willingness to pay", WTP) se lleva a cabo un experimento de elección para la tecnología HB4. El mismo resulta en un valor de WTP de 145 kg/ha de grano de soja, equivalente a un 5 % del rinde promedio del cultivo en Argentina, y a 8 % de los costos directos de producción (excluyendo cosecha). El valor de WTP varía según zona productiva, siendo 26 % mas alto en zonas con brechas de rinde (rinde actual vs potencial) mayores a 20 %, en comparación al existente con brechas menores a 20 %. Los resultados de WTP permiten estimar la tasa de retorno mínima demandada por los productores para adoptar la tecnología HB4. En la segunda etapa se evalúa el potencial de adopción a nivel de partido/departamento, en función de precio fijado por el desarrollador, y tasa de retorno requerida por parte de los productores. Dependiendo del escenario de adopción la tecnología permitiría incrementos de producción de 1.4 a 3.8 millones de toneladas, equivalentes a 3-7 % de la producción agregada nacional.

## Abstract

We evaluate potential adoption of drought tolerant HB4 technology in soybeans. Empirical analysis focuses on Argentine agriculture. The following two-step approach is used. First, a choice experiment is carried out to estimate average willingness-to-pay (WTP) for the HB4 technology. Average WTP is estimated at 145kg/ha of soybean grain, equivalent to 5% of the average soybean yield in Argentina, and approximately 8 % of per-hectare direct soybean production costs (excluding harvest). WTP varies among regions, being 26% higher for farmers in regions with yield gaps (actual vs. potential yield) above 20% compared to farmers in regions with yield gaps below 20%. WTP results allow an estimate of the minimum rate-of-return demanded by farmers for adoption of the HB4 technology. In the second stage, county-level potential adoption of the technology is evaluated as a function of seed price charged by the developer and required rate-of return by producers. Under alternative adoption scenarios, results show that the HB4 technology has the potential to result in output increases ranging from 1.4 to 3.8 million tons, equivalent to 3 – 7 percent of aggregate soybean production.

*Keywords: biotechnology, contingent valuation, willingness to pay, technology adoption*

JEL Classification: Q12, Q13, Q16

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## I. INTRODUCTION

To feed a growing population, agriculture faces the challenge of increasing production while simultaneously reducing negative environmental impact. Current agricultural systems are characterized by substantial use of use of chemical inputs and fossil fuels, emission of greenhouse gases, and expanding crop areas (FAO, 2015). Over 64% of global cropping areas (24 million km$^2$) are at risk of pesticide pollution (Tang et. al, 2021). Crop production is responsible for 19 % of the anthropogenic greenhouse gas (GHG) emissions (Ritchie and Rosen, 2022). Additional crop production is highly dependent on land clearing. Indeed, as reported by FAO, nearly 90% of the deforestation occurred between 2000 and 2018 is due to agricultural expansion, with negative impacts on GHG emissions, soil health, and biodiversity (FAO, 2021).

The above suggests that attention should be focused on technologies that reduce the use of conventional inputs per unit of output. Increased productivity in currently cropped areas has the potential of reducing pressure for additional land clearing in fragile tropical and subtropical conditions. Reductions in yield gaps, defined as the difference between current and potential yields is an important objective of improved agronomic technologies. (Van Itersum et. al, 2013).

Climatic variation is responsible for 30% of global yield variability. Key factors to be considered are water availability and temperature, as well as interactions between these two factors (Ray et. al., 2015). Frequency of water stress is expected to increase in the next decades due to global warming, resulting in additional uncertainty in food production (Sarhadi et.al., 2018). Tolerance to water stress has been a key target in crop breeding. However, progress has been slow because this plant characteristic is a genetic trait regulated by several genes normally associated to stomata closure that reduce growth and yields (Fischer et.al., 2014).

The expectation that genetic engineering can help improve crop tolerance to water stress has yet to be fulfilled. The difficulty of introducing traits that confer tolerance to water stress (and other abiotic stresses) are explained by three main reasons: (a) negative public opinion that part of the society has about genetically modified crops (GMC), (b) complex and expensive

[1] Ideas and results presented in this paper are sole responsibility of the authors, and do not necessarily reflect those of the University of CEMA

regulatory processes to be completed, and (c) the non-binary nature of abiotic stress-tolerant technologies, which makes it difficult to estimate the value of the trait in different agroecosystems (Chan et.al., 2020).

Most GMC introduced commercially correspond to first generation traits such as herbicide tolerance and Bt proteins for insect control. These technologies are usually referred as *input traits*. The efficacy and added value of these traits is easily perceived by producers. As a result, it has been simple for the developers to price and position their technologies. Over 75% of the soybean produced worldwide is transgenic, being the two key technologies herbicide resistance and insect control with the Bt protein (ISAAA, 2019).

Second generation traits, also called *output traits* include tolerance to abiotic stresses. Abiotic stresses vary in occurrence, intensity, and duration with a strong interaction with germplasm and agronomic practices. These factors present a challenge for the development of successful business models (Chan et.al., 2020).

There is a limited knowledge on how farmers value tolerance to abiotic stresses: only one technology of this type (drought tolerant maize technology *Drought Guard)* is currently available in the market. This technology has shown an average yield increase of 4% and is marketed combined with herbicide tolerance and Bt for insect control. *DroughtGard* technology has been adopted in about 22% of the corn areas of the US. Farmers pay a premium of 7.5 USD/ha representing a 70:30 farmer-developer partitioning of the increased output allowed by the trait (based on data from McFadden et. al., 2019).

In Argentina, the biotech firm Bioceres developed HB4 technology that confers water stress tolerance to soybean and wheat. Results show lower yield shortfalls under conditions of water stress, but no yield penalties under non-stress conditions. HB4 is thus a transgenic technology that increases the water use efficiency of the plant. Field evaluations comparing HB4 varieties with its isoline have shown yield increases up to 25% in soybeans and up to 60% in wheat, according to the productivity of the agroecosystem and the intensity of the water stress (Ribichich et.al., 2020; Gonzalez et.al., 2019). Bioceres is currently developing "elite" soybean varieties that are incorporated into regenerative agriculture programs combining bio-based nutrition, integrated weed and pest management programs, no-till, precision farming, and crop rotations. HB4 soybeans have been approved for use in Argentina, Brazil, US, Paraguay, Uruguay, and Canada, and it has been approved for consumption in China.

This paper aims to contribute to the knowledge of how farmers value tolerance to abiotic stresses. The main empirical contributions of the paper are estimates of:

1. **1.** Willingness to pay (WTP) of Argentine producers for HB4 soybeans
2. **2.** The economic impact HB4 technology for the different soybean cropping areas of Argentina
3. **3.** The market price of the HB4 soybeans that optimizes developer revenue
4. **4.** The potential impact in of HB4 soybean in reducing the yield gap in Argentina?

The structure of this paper is as follows. In Section II we review the relevance of drought tolerance in soybean production, and we describe the HB4 technology. Section III describes the choice experiment used to estimate WTP for HB4 technology. These WTP results provide a cross-check on the reasonableness of results presented in Section IV, where estimates are presented on potential adoption and economic impact of the HB4 technology. Finally, conclusions are presented in Section V.

## II. RELEVANCE OF DROUGHT TOLERANCE IN SOYBEAN PRODUCTION

Soybeans are the most important protein crop worldwide. In the 1990-2019 period soybean consumption grew from 17 to 45 kg/person/year. In this same period, global production increased from 90 to 360 million tons (OECD, 2023). OECD statistics suggest that nearly 75% of the higher production is explained by an increase in planted area, while the other 25% corresponds to higher yields. Developing countries are responsible for 84% of the higher soybean demand. In particular China where soybean imports increased from 5 million tons in 1990 to over 100 million tons in 2019 (OECD, 2023). Deforestation that occurred in Brazil and to a lower extent in Argentina, occurs as a response to global opportunities resulting from strong global demand of soybeans (FAO, 2021). According to the OECD, during the current decade global soybean demand will continue to grow at a rate of 1.1% per year. In turn, soybean supply is expected to increase by the addition of 3.6 more million hectares of land and by an increasing productivity at a rate of 0,7% per year (OECD, 2023).

Argentina is the third largest soybean producer in the world. In the period 2000-2019 production grew from 19 to 50 million tons, reaching a peak in 2015 with 61.4 million tons. Increase in planted area explains 84% of the increased production. During the last 5 years, however, output has remained stagnant, with an average yield of 2,95 ton/ha (MAGyP data for 2022).

Climate variability explains 43% of yield risk in Argentina, as compared to 36% and 24%, respectively, in US and Brazil (Ray et.al., 2015). The volatility of precipitations and its interaction with temperatures explains 63% of soybean yields in the main production zone of Argentina (Peñalba et. al., 2007). The generalized drought occurring in the 2022/23 crop year in Argentina highlights the importance of inter-year climate variability. According to estimates, output loss was 12% in sunflower, 30% in corn, 45% in wheat, and 50% in soybeans. Overall output loss reached 20 billion US$ (AACREA, 2023). Water stress conditions, while exceptional in 2022/23, are by no means rare in dryland Argentine agriculture.

For rainfed agriculture, Yield Gap ($\mathbf{Y_g}$ ) of a crop is defined as the difference between the water-limited yield potential ($\mathbf{Y_w}$) and the actual yield ($\mathbf{Y_a}$) obtained by farmers: $\mathbf{Y_g} = \mathbf{Y_w} - \mathbf{Y_a}$ (Van Itersum et. al, 2013). The size of $\mathbf{Y_g}$ can be taken as a proxy for the current unexploited grain production capacity achieved by farmers (Cassman et al., 2003). Aramburu Merlos et.al (2015) show that climatic variability has an important impact on the yield gap ($\mathbf{Y_g}$) of soybeans in Argentina.

Average soybean $\mathbf{Y_g}$ in Argentina is estimated at 32%, ranging from 8% in the central area to 55% in more marginal areas that suffer frequent water deficits (Aramburu Merlos et. al., 2015, Murphy and Hurtado, 2006). Many areas of Argentina with a high $\mathbf{Y_w}$, have a high $\mathbf{Y_g}$ as a result of climate variability acting as a deterrent to input use. As a result, and in order to control the downside risk, farmer response is to reduce inputs (see also, Fisher, 2015). In relation to this point, evidence exists that $\mathbf{Y_g}$ across regions in Argentina are higher in humid as compared to dry years, suggesting that when water is not scarce, input use limits production (Aramburu Merlos et.al., 2015).

Because of the close relationship between water stress and $\mathbf{Y_g}$, technologies resulting in tolerance to water stress in soybeans have the potential for reducing $\mathbf{Y_g}$, therefore increasing output without additional land clearing. As an example, soybean $\mathbf{Y_w}$ in Argentina is 4.1 tons/ha (Aramburu Merlos et.al., 2015) as compared to the country average yield 2.9 tons/ha Assuming that "attainable yield" ($\mathbf{Y_{att}}$) is 80% of $\mathbf{Y_w}$, current attainable yield gap is $0.80^* \mathbf{Y_w} - \mathbf{Y_a} = 0.80^*4.1 - 2.9 = .38$ t/ha. For a planted area of 17.5 million hectares (average 2015-2019, MAGy P, 2022) reducing the $\mathbf{Y_g}$ from 32% to an attainable 20% would result in an increase of soybean production in Argentina of 6.65 million tons/year without adding any land.

Soybean production in Argentina is spread over a wide range of agri-climatic conditions with risks of water deficit at critical period ranging from 20% to 50%. An important potential demand thus exists for drought-tolerant soybean varieties.

## III. WILLINGNESS TO PAY (WTP) FOR THE HB4 TECHNOLOGY

The WTP concept is defined as the maximum price a demander is prepared to pay for a product. WTP methodology allows estimation of the price elasticity of a product or service. Choice experiments are used to calculate WTP by presenting the users with product alternatives at different prices so they can choose their preferred option. The alternatives represent a combination of attributes that define a utility function. Individuals maximize utility, choosing among alternatives according to income and time restrictions (Breidert et.al., 2006).

$$[\mathbf{1}]\ \boldsymbol{U_i} = \boldsymbol{V_i} + \boldsymbol{\varepsilon_i}$$

where Ui is the utility of alternative i, $V_i$ is a linear combination of attributes and $\varepsilon_i$ is the random error term. The contribution of the different attributes to the utility is represented in equation [2].

$$[2]\ V_i = \boldsymbol{\beta_{0i}} + \boldsymbol{\beta_{1i}X_{1i}} + \boldsymbol{\beta_{2i}X_{2i}} + \cdots + \boldsymbol{\beta_{ki}X_{ki}}$$

where $\beta_{ji}$ is the coefficient associated to attribute $X_j$ for the alternative i, and $\beta_{0i}$ is a parameter not associated to any attribute and it is considered the impact of all unidentified sources of utility.

The methodology has been used to evaluate pricing strategies of first- generation traits (Qaim and Janvry, 2004). Other studies have used the WTP approach to calculate the value of second- generation traits in the experimental or even conceptual stage (Jaramillo et.al., 2010; Kassie et.al., 2017; McCorkle 2007). Qaim and Janvry (2004) calculate the WTP for Bt cotton with Argentinean producers to identify the reasons for the low adoption of the technology. They show that the WTP is half the price the developer was charging in the market. Casellas et. al. (2012) use dichotomic surveys to calculate the WTP for herbicide-resistant rice that allows to control wild rice, a problematic weed. WTP for younger and larger farmers was found to be 19% higher than the average.

A few studies have used WTP experiments to value second generation transgenic traits that were at the conceptual or experimental stage. None of these traits have reached the market yet. Jaramillo et.al. (2010) show that the WTP for a transgenic drought tolerant maize was 10% lower than for maize with drought tolerance obtained through conventional breeding.

Also, higher drought risk is associated with higher WTP. The WTP for an experimental frost-tolerant wheat in Canada is estimated at 15 USD/ha. The WTP of younger farmers that farmed large areas is higher than the average (McCorkle, 2007). The WTP for a drought-tolerant maize is higher than that for seed with a trait that would potentially increase corn yields in Zimbawe. Thus, risk reduction is more important than higher production (Kassie et.al., 2017).

## Choice experiment

We conducted a choice experiment to obtain WTP for the HB4 technology, a second-generation trait in soybeans. In our experiment, potential users choose between hypothetical soybean seed bags with different attributes and price combinations. The choice experiment simulates the purchase of a 40 kg soybean seed bag with the combination of three technologies: (a) water stress tolerance (called drought tolerance, DT), (b) control of herbicide resistant weeds (CRW) and (c) professional seed treatment by biological and chemical agents to provide protection to the seed (PST). The price of the bag (PR) was the fourth attribute. The resulting number of alternatives is $L^A$ where L represent the number of levels of each attribute and A is the number of attributes. The total number of alternatives was 32, resulting from 3 attributes with two levels plus four levels for the price attribute ($2^3 * 4^1 = 32$). Alternatives were reduced to 24 using a D-efficiency design (Henscher et.al., 2005) combined in twelve cards with three options per card (**Figure 1).** Each card presented the option of the generic soybean bag without any attributes plus other two alternatives. The generic alternative was always priced at 30 USD/bag while the prices of the other alternatives ranged from 32 to 64 USD/bag.

**Table 1.** Example of Survey card used in Choice Experiment

**Questionnaire II; Situation 3**

| | **Option 1** | **Option 2** | **Option 3** |
|---|---|---|---|
| ***Drought Tolerance (10% yield Increase)*** | NO | NO | YES |
| ***Control of Resistant Weeds (>90%)*** | NO | YES | NO |
| ***Professional Seed Treatment (innoculant + fungicide)*** | NO | YES | NO |
| ***Price (USD/40 kg bag)*** | 30 | 54 | 38 |
| ***Choose only one option*** | | | |

Two hundred farmers were surveyed in three farm meetings during 2019. Each farmer was presented with four cards with three alternatives per card. We requested the farmers to choose only one alternative per card. The demographic variables collected from each farmer are summarized in **Table 2**.  Most producers were from the provinces of Buenos Aires, Santa Fe, and Córdoba (Pampean region). Over 90% of the participants were male with either secondary school or college degree (63%). The average reported yield resulting from the surveys was 3.3 tons/ha, 13% higher that the country average yield for the 2015-2019 period. Farmers were also asked to indicate the county where most of their activity takes place. We incorporated the following additional information for each county: average yield for the period 2015-2019 (MAgyP, 2022), and estimates $\mathbf{Y_w}$ and $\mathbf{Y_g}$ from Merlos et. al. (2015).

**Table 2**:  **Summary of demographic variables**

| **Variable** | |
|---|---|
| ***Producer identification*** | 1 to 200 |
| ***Planted area*** | Total hectares planted in previous season (ha) |
| ***Expected Yield*** | Expected yield (kg/ha) |
| ***Sex*** | M/F |
| ***Education*** | Primary, Secondary, Tertiary |
| ***Province*** | |
| ***County*** | |
| ***10-year average county yield*** | Ministry of Agriculture statistics (www.siia.gov.ar) |
| ***Yield Gap (Yg = Yw – Ya)*** | Merlos y col. (2009) |

We performed a logit regression analysis to estimate the parameters of the utility function

$$[3]\ V = \beta_1 DT + \beta_2 CRW + \beta_3 PST + \beta_4 PR$$

$WTP_i$ is calculated as the ratio between the coefficients of the attribute with the price coefficient.

$$[4]\ WTP_i = -\frac{\beta_i}{\beta_4}$$

**Willingness to Pay Estimates**

Results of the analysis are presented in **Table 3**. All attributes are significant at $\alpha = 0.01$. The WTP for DT is 19,6 USD/40-kg bag, equivalent to 29.3 USD/ha (on average, farmers plant 1.5 bags per ha) **(Table 4).** This figure is equivalent to some 146 kgs/ha of soybeans, at the prevailing soybean grain price at the time of the experiment, and approximately 5 % percent of expected per-hectare income, and 8 % of direct per-hectare costs (excluding harvest). [2]

[2] Domestic soybean price (date experiment) = US$ 250. Approximate marketing costs 20 % price. Net farmer price = US$ 250 x (1-0.20) = US$ 200.

**Table 3: Logit Results**

| Attribute | Coefficient | SE | P value |
|---|---|---|---|
| *All* | | | |
| ***Drought Tolerance*** | 1.36 | 0.11 | 0.00 |
| ***Control of Resistant Weeds*** | 1.22 | 0.09 | 0.00 |
| ***ProfessionalSeed Treatment*** | 0.36 | 0.11 | 0.00 |
| ***Price*** | -0.07 | 0.01 | 0.00 |
| $\mathbf{Y_g}$ < 20% | | | |
| ***Drought Tolerance*** | 1.08 | 0.18 | 0.00 |
| ***Control of Resistant Weeds*** | 1.27 | 0.19 | 0.00 |
| ***Professional Seed Treatment*** | 0.47 | 0.17 | 0.01 |
| ***Price*** | -0.07 | 0.01 | 0.00 |
| $\mathbf{Y_g}$ > *20%* | | | |
| ***Drought Tolerance*** | 0.46 | 0.23 | 0.04 |
| ***Control of Resistant Weeds*** | -0.09 | 0.23 | 0.71 |
| ***Professional Seed Treatment*** | -0.1782 | 0.21 | 0.39 |
| ***Price*** | -0.0088 | 0.01 | 0.54 |

**Table 4:** WTP Results

| Attribute | WTP | SE | P Value |
|---|---|---|---|
| *All* | | | |
| ***Drought Tolerance*** | 19.6 | 2.2 | 0.00 |
| ***Control of Resistant Weeds*** | 17.5 | 1.4 | 0.00 |
| ***Professional Seed Treatment*** | 5.2 | 1.4 | 0.00 |
| $\mathbf{Y_g}$ < 20% | | | |
| ***Drought Tolerance*** | 15.89 | 2.91 | 0.00 |
| $\mathbf{Y_g}$ > 20% | | | |
| ***Drought Tolerance*** | 20.06 | 2.27 | 0.00 |

The WTP estimate of 146 kg/ha may be compared to the (expected) yield increase resulting from the assumed (in the experiment) 10 percent yield advantage of HB4 and the average soybean yields reported by the surveyed farmers (3,300 kg/ha). Thus, for the - ith county, the implied rate of return (net of soybean marketing costs) of the estimated WTP ($\boldsymbol{RR_i^{WTP}}$) is:

$$[\mathbf{5}]\ \boldsymbol{RR_i^{WTP}} = 100 * [(1 - 0.2)\frac{0.10 * \ \boldsymbol{R_i}}{\boldsymbol{WTP}} - 1]$$

Where $\boldsymbol{R_i}$ is the average county yield. Expressed in terms of rates of return on the 146 kg/ha investment in the trait, and assuming as before 20 percent marketing costs on output, this represents a 81 % rate of return: for each $1 invested in the HB4 technology, additional output has to be $ 1.81. WTP of 146 kg/ha for the HB4 technology results in a "partition ratio" between producer and developer of 0.44:0.56, lower than the 0.70:0.30 partition of returns between producer and developer reported in previous literature (Shakya et.al. 2012, Brooks and Barefoot, 2018).

Further comments can be made on WTP estimates reported here. First, WTP of farmers from counties with $\mathbf{Y_g}$ > 20% ($\mathbf{Y_g}$ calculated as [0.80 * $\mathbf{Y_w}$ – $\mathbf{Y_a}$]) is 26% higher than from counties with $\mathbf{Y_g}$ < 20% (**Table 4**). As discussed previously, higher $\mathbf{Y_g}$ is associated with higher variability in water supply, thus it is reasonable to expect higher WTP for the HB4 varieties in these counties. The HB4 technology, in addition, by putting a floor on yields in moderately to dry years, may allow farmers to aim for higher input (in particular, fertilizer) use than would be the case with conventional, more drought-sensitive varieties.

As related to the impact of human capital on the adoption decision of HB4 technology, WTP of farmers with completed secondary education is 9% higher than farmers with only elementary school (19,56 vs 17,91 USD/ha). A possible explanation is that education allows a better understanding of the impact of the HB4 technology on risk reduction, thus resulting in a higher predisposition for innovation. Similar results were obtained by Casellas et.al., (2012) with WTP for herbicide resistant rice.

The WTP for CRW is 17.5 USD/bag which represents 26.3 USD/ha, equivalent to 131 kg/ha of soybean grain. Results thus suggest that resistant weeds are a severe problem for farmers, as WTP for this this technology is only slightly lower than that of drought tolerance. The WTP value shows that farmers are ready to adopt innovative technologies for weed control, a growing problem in Argentina. In contrast for the case of drought tolerance, WTP for the CRW trait result to be inversely related to educational level. A possible explanation is that these farmers have a more efficient weed management program and therefore assign lesser value to the CRW technology. Finally, a value of 5.2 USD/bag (7.8 USD/ha) was estimated for professional seed treatment (PST). This represents a similar value of other treatments available in the market.

## IV. POTENTIAL ADOPTION AND ECONOMIC IMPACT

The impact of the HB4 technology (HB4E) is defined as per-unit yield increase comparing HB4 soybeans with its isoline (Ribichich et. Al., 2020).

$$[6]\ \boldsymbol{HB4E} = \left[\frac{\boldsymbol{HB4Y - ISOY}}{\boldsymbol{ISOY}}\right]$$

where HB4Y and ISOY are the yields of HB4 soybean and its isoline calculated with the regression models published by Ribichich et. al. (2020). The authors report both HB4Y and ISOY as a function of an environmental index (EI) built with the average yield of trials in all available locations. To predict county-level values of HB4E we calculate HB4Y and ISOY using the regression models in a range of 1.000 to 5.000 kg/ha. We then fit an exponential equation to the calculated HB4E (regression results in **Table 5**).

**Table 5:** HB4 Impact

| | **Coefficient** | **SE** |
|---|---|---|
| ***Intercept*** | 0.845 | 0.184 |
| ***EI*** | -0.00099 | 5.6 E-5 |
| ***n*** | 9 | |
| ***Rsq*** | 0.975 | |

Resulting in:

$$[7]\ \boldsymbol{HB4E} = (0.845 * e^{-0.00991 * \boldsymbol{EI}}) * 100$$

We estimate a county-specific estimate of HB4E replacing ***EI*** by the average yield of the county for the period 2015-2019 (MAGyP, 2022). The product of the county-specific HB4E times the average county yield and soybean price results in an average value of this technology.

Adoption of the HB4 soybeans is expected to occur if marginal returns are higher than marginal costs. Marginal costs should include not only the direct price charged by the patent owner for the HB4 trait, but also a surcharge resulting from uncertainty on the part of the farmer as to the actual impact of the technology. In particular, the impact of HB4 on yields is only expressed in water stress conditions, and even then, for the farmer a comparison of HB4 vs conventional yields may be in practice extremely difficult. Substantial excess returns in terms of additional yield above the technology price appears to be a necessary condition for widespread adoption. In the results presented below, adoption is assumed to occur if, for the ith county:

$$[\mathbf{8}]\ \Delta \boldsymbol{R_i^{HB4}} \geq\ \boldsymbol{P_i^S}\ (\mathbf{1}+\boldsymbol{\delta})$$

Where:

$$[9]\ \Delta \boldsymbol{R_i^{HB4}} =\ (\mathbf{1}-\boldsymbol{t})\boldsymbol{HB4E_i} * \boldsymbol{R_i}$$

where $\Delta \boldsymbol{R_i^{HB4}}$ is the (net of marketing costs *t*) marginal returns from the HB4 technology (kg/ha), $\boldsymbol{P_i^S}$ is the price of the HB4 trait expressed in terms of soybean grain, $R_i$ is the county average yield and $HB4E_i$ is as defined in equation [3]. Constant $\boldsymbol{\delta}$ ($0 \leq \boldsymbol{\delta}$) is a cost-adjustment function of farmer conservatism associated with the uncertainty surrounding the impact of the HB4 technology, risk-discount factor.

To estimate the demand schedule for the HB4 technology, we parametrize HB4 seed values $\boldsymbol{P_i^S}$ ranging from 20-100 kg/ha. For a given $\boldsymbol{P_i^S}$, and as per [8] above, adoption decision will hinge on the required rate of return demanded by producers. In relation to this, results reported in the previous section suggest a WTP of the order of 146 kg/ha of soybean grain, for a (hypothesized) 10 percent yield increase. As discussed, this implies a "required rate of return" of the order of 81 percent (return equal to 1.81 times seed cost). We use this figure as a (lower bound) anchor to parameterize the minimum "discount factor" (δ) used by producers in their adoption decision. These scenarios are interpreted as shifters of the demand schedule. Plausible adoption levels are estimated for values of $\boldsymbol{\delta}$ ranging from 1.8 to 2.4.

**Table 6** shows adoption expressed as percentage of planted area (as of average 2015-2019, approximately 17.3 million hectares) as a function of HB4 trait price and risk-discount factor. As reported, prices of 40 kg/ha result in adoption levels ranging from 55 to 88 percent of planted area.

**Table 6: Adoption of HB4 trait**

| | Seed Price (in soybeans kg) | | | | |
|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 100 |
| Delta Risk | % of Planted Area | | | | |
| 1.80 | 100 | 88 | 44 | 24 | 7 |
| 2.00 | 100 | 76 | 38 | 15 | 3 |
| 2.20 | 100 | 64 | 34 | 9 | 2 |
| 2.40 | 100 | 55 | 24 | 3 | 0 |

For a seed price of 80 kg/ha, and excepting the lowest risk-discount factor, adoption levels are less than 20 percent of planted area. Assuming a risk-discount factor of 2.0, a reduction of the seed price from 80 to 40 kg/ha would result in an increase in adoption from 15 to 76 percent of planted area. A demand elasticity of approximately 2.0 results from these figures. Given relatively low marginal cost of producing the trait ("fixed" R&D expenditures are expected to be main cost drivers), the above suggests that the seed developer should aim at relatively low prices for this innovation. As an example of revenues to the developer as a function of seed price, Table 7 presents some figures.

**Table 7: Developer revenue HB4 trait**

| | Seed Price (in soybeans kg) | | | | |
|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 100 |
| Delta Risk | Million tons soybeans | | | | |
| 1.25 | 0.36 | 0.62 | 0.47 | 0.34 | 0.13 |
| 1.50 | 0.36 | 0.54 | 0.40 | 0.22 | 0.05 |
| 1.75 | 0.36 | 0.46 | 0.36 | 0.13 | 0.04 |
| 2.00 | 0.36 | 0.39 | 0.26 | 0.05 | 0.00 |

As shown, “optimum” seed price $P^S$ (among the discrete values considered) is 40 kg/ha. This value appears robust to changes in assumptions of the risk-discount factor δ. At this price, the estimated HB4 adoption is 64% (data not shown) resulting in an extra soybean production of 2.2 million tons/year, 4.3% increase to the 2015-2019 country average.

The above results implicitly assume “full compliance” in relation to the payment for seed use on the part of producers. This assumption probably results in under-estimation of the producer response to seed price reported in **Table 6.** Thus**,** if farmers increasingly resort to non-payment for the HB4 seed as price increases, revenues to developer will fall – as seed price increases – faster than those reported here.

## V. CONCLUSIONS

This paper focuses on the adoption of the HB4 drought-resistant soybean trait in Argentine agriculture. A WTP choice experiment is used to estimate value placed by producers on the HB4 technology which allows a value to be put on resistance of soybean varieties to herbicides used to control weeds resistant to conventional herbicides.

Results of the WTP experiment suggest that farmers are, on average, willing to pay the equivalent of approximately 146 kg/ha of soybean grain for the purchase of HB4 seed resulting in an average 330 kg/ha additional output. The “implied rate of return” of this WTP figure is 81 percent: an additional 1.81 kg extra output of soybeans (net of marketing costs) is required for every 1 kg invested in HB4 seed.

WTP for the HB4 seed is higher for counties with higher yield gaps. A possible explanation is that yield gaps (difference between “attainable” and observed output) are partially the result of conservative input use and technology uptake caused, in turn, by higher production risk in these areas. The HB4 technology reduces yield losses under water deficit conditions thus placing a higher floor on crop yields than that of conventional varieties. Risk-related constraints are thus relaxed. This interaction effect of risk reduction and technology adoption has been shown for flood tolerance in rice (Emerick et.al., 201&).

Over 11 million hectares (63 percent of total soybean area of Argentina) are characterized by yield gaps above 20 percent. Thus, the HB4 technology can potentially contribute both directly reducing the impact of water stress, but indirectly facilitating the adoption of yield-increasing technological packages. The development of integrated technology packages for areas with high yield gaps should favor the adoption of the technology.

HB4 soybeans are resistant to a herbicide to control weeds that are resistant to glyphosate herbicide. Over 27% of the soybean area with yield gaps above 20% are heavily infested with weeds resistant to this herbicide. In these locations, the value proposal of the HB4 seeds includes not only resistance to water stress, but also improved control of weed populations.

The analysis presented here is based on the comparison of the transformed variety Williams 82 against its isoline without the trait. Our conjecture is that the commercial success of the technology will be highly dependent on the capacity of the seed company to match HB4 technology with high yielding germplasm adapted to the different agroecological areas.

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