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AgroDecisor EFC: First Android™ app decision support tool for timing fungicide applications for management of late-season soybean diseases

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ABSTRACT

A current problem in the chemical control of late-season soybean diseases (LSD) is the lack of scientific guidelines to determine whether or not a fungicide application is needed, and if needed, to further determine a better fungicide application timing. To help in that decision process, Carmona et al. developed a scoring system (SS) based on weather, disease pressure, and other factors that are useful in estimating the probability of expected net return to fungicide treatment. Based on the SS, we developed an Android™ app named AgroDecisor EFC. In the app, the factors from which the SS stems are presented to users for them to quickly select available options to obtain a guiding recommendation on whether or not to apply a fungicide within the R3-R5 soybean growth stages. Scoring greater than 33 indicates a higher probability of obtaining a positive yield response, whereas scoring below 23 indicates no expected response and thus no need for fungicide applications. Intermediate values indicate that the application of fungicides would produce uncertain results thus detailed analysis of risk factors would be required. The app also provides a weather prediction system for the location where the device is located (according to the GPS receiver). The AgroDecisor EFC can help farmers and crop consultants assess the risk of LSD epidemics as well as yield and economic response from foliar fungicide applications. The AgroDecisor EFC smartphone/tablet application will be available in the near future and can be downloaded at no cost from the Google Play™ website (https://play.google.com/store/apps/details?id=mapplics.sistemadedecision.soja&hl=en) to any phone that has the Android™ system.

1. Introduction

Late-season soybean diseases (LSD) are a combination of various diseases that affect soybean leaves, stems, pods and seeds; cause premature senescence and reduce grain yield and seed quality (Hartman et al., 2015). LSD are important diseases of soybean (*Glycine* max (L.) Merr.) in commercial soybean growing regions throughout the world, including Argentina (Wrather et al., 2010). The main LSD are caused by *Septoria glycines* Hemmi, *Cercospora kikuchii* (Tak. Matsumoto & Tomoy.) M. W. Gardner 1927, *Phomopsis sojae* (Lehman) Wehm) and *Glomerella glycines* Lehman & F. A. Wolf 1926.

Currently, the decision criteria on whether or not and when to apply fungicides for control of LSD are diverse. One of the most commonly used criterion is the application of fungicide when the crop reaches a certain phenological stage, regardless of disease epidemic level and environmental conditions. In this case, the application decision is based on a crop growth stage, typically between the R3 and R5 stages (Fehr and Caviness, 1977; Grichar, 2013; Cruz et al., 2010; Mahoney et al., 2015; Kandel et al., 2016). Beginning pod (R3) through full seed (R6) are critical soybean growth stages, as it is within this period that number of grains is defined (Jiang and Egli, 1993, 1995; Egli, 1997). Clear understanding of host phenology and the critical period when grain yield is defined is very important (Board et al., 2011; Owen et al., 2013), but should not be the only information to decide on fungicide applications. Pathogen presence and environmental variables conducive to epidemic development are crucial to define yield response when fungicides are used to control LSD (Carmona et al., 2010, 2011). The main problem in deciding to apply a fungicide in soybean is that LSD have long incubation and latent periods. Hence, there is low correlation between LSD symptoms and severity at growth stages where fungicides should be applied. LSD symptoms become evident at the end of the soybean growing season (mainly at R6–R7), when fungicide applications are rendered late to prevent yield loss. This explains in part why the results of fungicide applications for LSD control are erratic in different growing seasons and in different geographic locations.

To help in the decision making for fungicide application in soybean,

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Table 1
Expected grain yield response (kg/ha) in fungicide-treated fields at R3 or R5, predicted by the SS according to the amount of precipitation (mm) recorded between the R3 and R5 growth stages.

Rain (mm) R3–R5	Expected grain yield response (kg/ha)	
	R3	R5
50	75	77
80	184	161
100	292	246
120	400	330
140	509	415

Table 2
Grain yield response (kg/ha) required to pay fungicide application costs, according to soybean price and application cost.

Soybean price (USD/tn)	Application cost (USD/ha)				
	20	25	30	35	40
185	108	135	162	189	216
228	88	110	132	154	176
256	78	98	117	137	156
282	71	89	106	124	142
315	63	79	95	111	127
325	62	77	92	108	123

a scoring system (SS) has been developed by Carmona et al. (2015). The SS was developed based on the impact of weather, disease pressure and other factors useful to estimate the probability of expected next return to fungicide treatment. Based on previous research, we have identified major agronomic and weather variables that determine greater risk of LSD epidemics in Argentina soybean growing conditions (Carmona et al., 2011, 2015):

(A) Rainfall (both occurred and predicted) between R3 and R5 (Carmona et al., 2011).
(B) Intensity of rainfall between R3 and R5: Rain level above a 7-mm threshold (excluding drizzle and light rain) (Carmona et al., 2010).
(C) Crop rotation: fields rotated with LSD non-host crops have lower inoculum density than fields in monoculture (Smirnoff et al., 2013).
(D) Tillage system (conventional tillage or no-tillage –direct seeding): the more crop residue accumulated on the soil surface under conservation tillage the higher the risk for LSD epidemics (Wrather et al., 1993; Almeida et al., 2015).
(E) LSD presence in soybean crop residue from previous season.
(F) Sanitary quality of the seed: seed treatment can reduce the probability of introducing or increasing pathogens that cause LSDs when seed is infected with causal pathogens of LSD (Neto and West, 1989).
(G) Length of growing season: the longer the crop cycle the greater the probabilities of a crop to undergo LSD epidemics.
(H) Grain destination: the system takes into account the destination of production by weighing whether the harvested grain will be used as future seed or for marketing. If the grain will be destined as seed in the sowing of the next growing season, the risk increases since a greater control of LSD is required.
(I) Field potential productivity: yield potential measurement refers to the ability of the field to allow economic return after a fungicide application.
(J) Presence of LSD symptoms in the field: symptoms pre-announce the epidemiological triggering of LSDs. The visual presence or absence of LSDs is valuated as a risk factor, which is an indicator that the inoculum source is present in the field. LSD symptoms must be observed during scouting.

Of all the factors selected, one of the most important on disease development is the quantity (factor A) and intensity (factor B) of

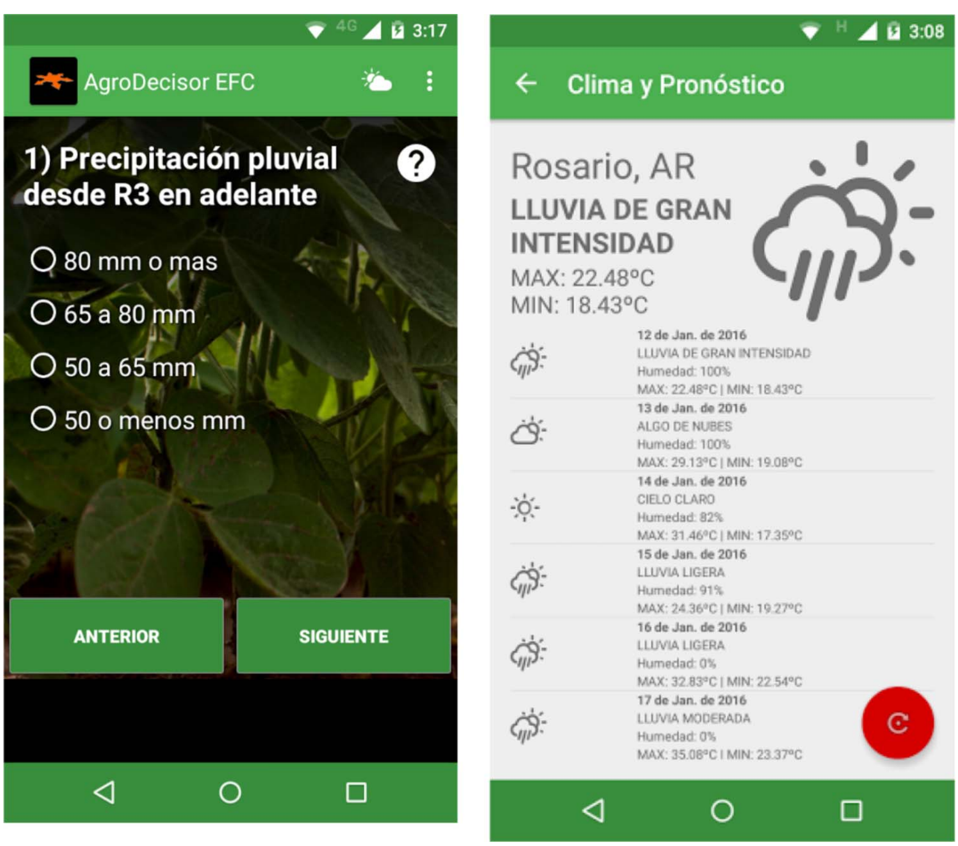

Fig. 1. The AgroDecisor EFC app runs on small, mobile devices such as cell phones, tablets, and other mobile technology for Android™. The app presents to the user a series of questions related to the epidemiology of LSD, providing different options for each particular agronomic situation. As a result, the software weights each factor and sums the points, indicating the recommended action: apply fungicide or wait to accumulate points, usually rainfall greater than 7 mm within the "window of opportunity" between growth stages R3–R5. The app also provides a weather prediction system for the location where the device is located (according to the GPS receiver).

Table 3
Validation data set for the AgroDecisor EFC app. The net yield return (kg/ha) in each of the 19 trials is shown in the farthest right column.

Season[a]	Location[b]	Variety[c]	Application timing[d]	Yield[e] (kg/ha)	Yield response[f] (kg/ha)	Scoring system outcome and recommendation[g]	Net economic return (kg/ha)[h]
2012	Tucumán	A8000RG	Non-treated	2077	0	–	0
			R3	2065	−13	22 ≥ No Application	−105
			R5	2160	83	22 ≥ No Application	−9
2009	Pergamino	DM4800	Non-treated	1634	0	–	0
			R3	1567	−67	22 ≥ No Application	−159
			R5	1588	−46	22 ≥ No Application	−136
2009	América	DM4670	Non-treated	4044	0	–	0
			R3	4086	42	28 ≥ No Application	−51
			R5	4036	−7	28 ≥ No Application	−100
2008	Carlos Casares	DM3700	Non-treated	4000	0	–	0
			R3	4111	111	35 ≥ R3	19
			R5	4222	222		130
2008	Lincoln	DM4870	Non-treated	4917	0	–	0
			R3	5217	300	31 ≥ R3	207
			R5	5133	217		7
2009	Gualeguaychú	N6411	Non-treated	2325	0	–	0
			R3	3058	733	32 ≥ R3	640
			R5	2677	352		259
2010	América	DM4670	Non-treated	3836	0	–	0
			R3	4882	1047	44 ≥ R3	954
			R5	4239	403		311
2010	Pergamino	DM4970	Non-treated	3781	0	–	0
			R3	4299	518	35 ≥ R3	426
			R5	3838	57		−35
2011	América	DM4670	Non-treated	4011	0	–	0
			R3	4366	355	36; R3	263
			R5	4098	87		−6
2008	Villegas	DM4870	Non-treated	3787	0	–	0
			R3	3773	−14		−107
			R4	4233	446	35; R4	354
			R5	4076	289		197
2009	Lincoln	DM4870	Non-treated	1657	0	–	0
			R3	1731	74		−19
			R4	1991	333	34, R4	241
			R5	1917	259		167
2010	Gualeguaychú	N6126	Non-treated	3665	0	–	0
			R3	4203	538		445
			R4	4215	550	30; R4	457
			R5	3903	238		145
2011	América	DM3700	Non-treated	2420	0	–	0
			R3	2328	−92		−185
			R4	2546	126	42, R4	34
			R5	2202	−218		−310
2011	Gualeguaychú	RA625	Non-treated	4051	0	–	0
			R3	4520	469		376
			R4	4350	299	44, R4	206
			R5	4252	201		109
2012	Paraná	NA5909	Non-treated	3014	0	–	0
			R3	3214	200		108
			R4	3345	331	35; R4	238
			R5	3309	295		203
2008	Pergamino	DM3700	Non-treated	3632	0	–	0
			R3	3731	98		6
			R5	3846	214	30; R5	121
2008	Daireaux	DM4870	Non-treated	4127	0	–	0
			R3	4280	154		61
			R5	4478	351	35; R5	258
2010	Pergamino	4613	Non-treated	3013	0	–	0
			R3	3251	237		145
			R5	3328	314	41, R5	222
2011	Pergamino	A4613	Non-treated	2191	0	–	0
			R3	2317	126		34
			R5	2503	313	32, R5	220

[a] Crop season.

[b] Trial location.

[c] Soybean variety.

[d] Treatment: consisted in applying a mixture of quinone outside inhibitor and demethilation inhibitor (trifloxystrobin + cyproconazole) at three different timings: (a) at the fixed growing stage R3; (b) R5 and (c) at the growing stage indicated by the scoring system (in the cases it did not coincide with R3 or R5). A control plot without application was also included.

[e] Grain Yield of soybean, expressed in terms of *kg/ha* (kilograms of *grain* per hectare).

[f] Grain yield response = yield from treated plots – yield from untreated plots.

[g] Scoring system outcome: In this column the total sum points is presented followed by the growth stage when the scoring system indicated to proceed with fungicide application.

[h] Return from fungicide application, calculated as: grain yield response – fungicide application cost (expressed as kg/ha); being grain yield response = yield from treated plots – yield from untreated plots; and fungicide application cost = fungicide average cost plus application average cost (equal to 25 USD/ha)/soybean average price (equal to 270 USD/Tn) = equal to 92.6 kg/ha; Septoria + Cercospora Severity (%): Severity of *S. glycines* and *C. kikuchii* was visually estimated at R6–R7 on all leafs of 20 plants per plot randomly chosen.

rainfall. This result is in agreement with those reported by Kyveryga et al. (2013).

The SS accumulates the probability of yield response to the fungicide application and consequent economic return. Table 1 shows an example of the expected grain yield response in fungicide-treated fields at R3 or R5 according to the amount of precipitation recorded between R3 and R5 growth stages. The linear regression equation generated with such data is $y = 5.429x - 251.5$ ($R^2 = 0.81$) when the fungicide application was carried out at R3, and $y = 4.2313x - 177.89$ ($R^2 = 0.84$) when the application is carried out at R5 (Carmona et al., 2011). Grain yield response required to pay fungicide application costs (breakeven point) at different soybean prices and application costs is shown in Table 2.

2. New Android™ app decision support tool for timing fungicide applications for control of LSD in soybean

Due to the lack of scientific guidelines to determine the need for a fungicide application, and if so, a better application timing, we developed an Android™ app named AgroDecisor EFC in order to help making fungicide spray decisions on soybeans for control of LSD. In the app, the users are presented with the A to J aforementioned factors, which can be quickly selected from available options to obtain a guiding recommendation on whether or not to apply a fungicide within the R3–R5 growth stages (see Fig. 1). The app also enables the user to calculate a value indicating whether or not a fungicide treatment results in a soybean yield response. The application weighs each factor according to its contribution to LSD epidemics, indicating whether or not to apply a fungicide, based on whether the probability of yield response and consequent positive economic margin is high. The app recommends application of foliar fungicides based on the total points accumulated from the risk factors. Scoring greater than 33 indicates a higher probability of obtaining a positive yield response, whereas scoring below 23 indicates no expected response and thus no need for fungicide applications. Intermediate values indicate that the application of fungicides would produce uncertain results thus detailed analysis of risk factors would be required. The app can be downloaded from the Google Play™ website (https://play.google.com/store/apps/details?id = mapplics.sistemadedecision.soja&hl = en).

The app was validated on data from 19 field experimental trials carried out during the 2007/2008, 2008/2009, 2009/2010, 2010/2011 and 2011/2012 seasons in the Argentine provinces of Buenos Aires, Entre Ríos and Tucuman (Carmona et al., 2015; Table 3). The app performance in recommending fungicide applications guided by the SS showed positive net margins followed by positive yield responses in all cases (Table 3).

Although the SS was validated in Argentina, it is currently being validated for other production areas, and it is expected to perform well for other soybean growing regions other than Argentina.

3. Conclusion

This paper introduces the first Android™ app decision support tool: AgroDecisor EFC, for timing fungicide applications for management of LSD in soybean. The AgroDecisor EFC app can be a valuable tool to reduce the number of fungicide applications in soybean crops, especially in seasons when conditions for LSD development are not favorable. We consider that the app is user-friendly and dynamic thus it can be easily adopted by farmers and crop consultants.

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References

Almeida, A.M.R., Hau, B., Amorim, L., Bergamin Filho, A., Mariano, J.C., 2015. Tillage system effect on the epidemic of soybean brown spot. Trop. Plant Pathol. (Online). http://dx.doi.org/10.1007/s40858-015-0052-6.

Board, J., Kumudini, S., Omielan, J., Prior, E., Kahlon, C., Weaver, D., 2011. Light interception as a yield-loss prediction tool for defoliation-induced yield loss in soybean. Crop Manage. http://dx.doi.org/10.1094/CM-2011-0722-01-RV.

Carmona, M., Moschini, R., Cazenave, G., Sautua, F., 2010. Relación entre la precipitación registrada en estados reproductivos de la soja y la severidad de *Septoria glycines* y *Cercospora kikuchii*. Trop. Plant Pathol. 35, 71–78. http://dx.doi.org/10.1590/S1982-56762010000200001.

Carmona, M., Sautua, F., Perelman, S., Reis, E., Gally, M., 2011. Relationship between Late Soybean Diseases Complex and rain in determining grain yield responses to fungicide applications. J. Phytopathol. 159, 687–693. http://dx.doi.org/10.1111/j.1439-0434.2011.01828.x.

Carmona, M., Sautua, F., Perelman, S., Gally, M., Reis, E.M., 2015. Development and validation of a fungicide scoring system for management of late season soybean diseases in Argentina. Crop Prot. 70, 83–91. http://dx.doi.org/10.1016/j.cropro.2015.01.019.

Cruz, C.D., Mills, D., Paul, P.A., Dorrance, A.E., 2010. Impact of brown spot caused by *Septoria glycines* on soybean in Ohio. Plant Dis. 94, 820–826. http://dx.doi.org/10.1094/PDIS-94-7-0820.

Egli, D.B., 1997. Cultivar maturity and response of soybean to shade stress during seed filling. Field Crops Res. 52, 1–8. http://dx.doi.org/10.1016/S0378-4290(97)00005-1.

Fehr, W.R., Caviness, C.E., 1977. Stages of Soybean Development. Iowa State University Special Report 80, p. 11.

Grichar, J.W., 2013. Soybean (*Glycine max* L.) response to fungicides in the absence of disease pressure. Int. J. Agron. (Online). http://dx.doi.org/10.1155/2013/561370.

Hartman, G.L., Rupe, J.C., Sikora, E.J., Domier, L.L., Davis, J.A., Steffey, K.L., 2015. Compendium of Soybean Diseases and Pest, fifth ed. APS Press, Mn. USA. http://dx.doi.org/10.1094/9780890544754.

Jiang, H., Egli, D.B., 1993. Shade induced changes in flower and pod number and flower and fruit abscission in soybean. Agron. J. 85, 221–225. http://dx.doi.org/10.2134/agronj1993.00021962008500020011x.

Jiang, H., Egli, D.B., 1995. Soybean seed number and crop growth rate during flowering. Agron. J. 87, 264–267. http://dx.doi.org/10.2134/agronj1995.00021962008700020020x.

Kandel, Y.R., Mueller, D.S., Hart, C.E., Bestor, N.R.C., Bradley, C.A., Ames, K.A., Giesler, L.J., Wise, K.A., 2016. Analyses of yield and economic response from foliar fungicide and insecticide applications to soybean in the North Central United States. Plant Health Prog. (Online). http://dx.doi.org/10.1094/PHP-RS-16-0038.

Kyveryga, P.M., Blackmer, T.M., Mueller, D.S., 2013. When do foliar pyraclostrobin fungicide applications produce profitable soybean yield responses? Online. Plant Health Prog. (Online). http://dx.doi.org/10.1094/PHP-2013-0928-01-RS.

Mahoney, K.J., Vyn, R.J., Gillard, C.L., 2015. The effect of pyraclostrobin on soybean plant health, yield, and profitability in Ontario. Can. J. Plant Sci. 95, 285–292. http://dx.doi.org/10.1139/CJPS-2014-125.

Neto, J.B.F., West, D.H., 1989. Effects of *Colletotrichum truncatum* and *Cercospora kikuchii* on viability and quality of soybean seed. J. Seed Technol. 13, 136–149.

Owen, L., Catchot, A., Musser, F., Gore, J., Cook, D., Jackson, R., Allen, C., 2013. Impact of defoliation on yield of group IV soybeans in Mississippi. Crop Prot. 54, 206–212. http://dx.doi.org/10.1016/j.cropro.2013.08.007.

Smirnoff, C., Gally, M., Asciutto, K., Gatica, S., Romero, A., Carmona, M., 2013. Effect of rotation and monoculture system on soybean foliar diseases. Abstract 400. In: World Soybean Research Conference 2013 d Durban South Africa. February, pp. 17–22.

Wrather, J.A., Anderson, S.H., Wollenhaupt, N.C., Anand, S.C., Kendig, S.R., 1993. Effects of tillage, row width, and cultivar on foliar diseases of double-crop soybean. Plant Dis. 77, 1151–1152.

Wrather, A., Shannon, G., Balardin, R., Carregal, L., Escobar, R., Gupta, G.K., Ma, Z., Morel, W., Ploper, D., Tenuta, A., 2010. Effect of diseases on soybean yield in the top eight producing countries in 2006. Plant Health Prog. (Online). http://dx.doi.org/10.1094/PHP-2010-0125-01-RS.