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TECHNOLOGICAL INFORMATION

Development of common bean as a function of herbicide application by unmanned aerial vehicle

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ABSTRACT. Plants are apparently factors responsible for productivity losses in beans and the use of herbicides is an efficient way to combat them. This article addresses the construction of an Unmanned Aerial Vehicle (UAV) with on-board electronic spraying and a comparison with conventional control methods for efficient plants. The objective was to evaluate the control of engineered plants by applying herbicides via UAV and conventionally in the vegetative and productive development of beans. The treatments consisted of a control without control of peculiar plants, a weeded control, herbicide applied with knapsack spraying and herbicide applied via UAV at 1, 2, and 3 meters in height. The experimental design was randomized blocks, with four replications and the number of pods per plant, grains per plant, grains per pod, mass of 100 grains, dry mass of the aerial part, final plant population and productivity were evaluated. It can be concluded that the lack of plant control harms the vegetative and productive development of the bean plant. Herbicide spraying via UAV at altitudes of 1, 2 and 3 meters above the ground proved to be as efficient as traditional methods of controlling organic plants.

Keywords: Drone; IPR Tangará; precision farming; yield; weeds.

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Introduction

Common bean is a major source of protein, particularly for low-income populations in Brazil. The crop is not only a low-cost food option but also an important part of the country's gastronomic culture (Tavares et al., 2018; Lima et al., 2020). Common bean has a short cycle, allowing for up to three annual harvests. It is produced by smallholder and large-scale farmers alike, of which a small property is one whose rural property has an area of up to four fiscal modules and a large property is a rural property with an area of more than fifteen fiscal modules, being an interesting crop for family farms in regions with less expressive agricultural production (Bastos et al., 2013; Silva and Wander, 2013). Brazilian bean production holds great prominence on the world stage, in the 23/24 harvest production was 3,325.7 thousand tons. Other leading producers include countries such as India, China, and the United States (Moraes and Menelau, 2017).

Bean yield is directly affected by the presence of weeds. The most efficient method to control these invasive plants is herbicide application, a method widely used for its practicality and proven results (Araújo et al., 2008; Galon et al., 2017; Silva et al., 2022). Weeds compete with crops for resources such as nutrients, sunlight, and water, exerting detrimental effects on agricultural production. These plants also release allelopathic substances as part of their secondary metabolism, which can cause prevention of germination, lack of vegetative vigor, leaf chlorosis, stunting or deformation of roots and even death of seedlings, impacting crop yield. Additionally, weeds may introduce fungi, pests, and diseases that disrupt crop development. Additionally, weeds may introduce fungi, pests, and diseases that disrupt crop development (Pessôa et al., 2017; Schiessel et al., 2019).

Silva et al. (2021) identified *Lolium multiflorum* (ryegrass), *Conyza bonariensis* (fleabane), *Digitaria insularis* (sourgrass), and *Amaranthus palmeri* (Palmer amaranth) as the major weeds infesting bean fields. The authors argued that these plants tend to have a negative effect on agricultural production, making it necessary to implement control measures.

Weed management is one of the great challenges of agronomic science. Several techniques can be used for this purpose, including preventive management and cultural, biological, physical, mechanical, and chemical control (Silva et al., 2018). Herbicides represent an important agricultural technology that may highly benefit crop production. However, the injudicious use of herbicides has led to the emergence of resistant weeds (Albrecht et al., 2021).

Herbicides and fertilizers can be applied as foliar treatments. According to Nachtigall and Nava (2010), the main advantages of foliar application include greater uniformity in distribution, improved efficiencies under adverse conditions, such as plant hydration status, genetics, leaf age, plant nutritional status, stomatal opening and the potential to address deficiencies during plant development. The main disadvantages, on the other hand, are related to incorrect application. These include plant injuries, the need for numerous applications, and high costs. An interesting strategy to minimize this problem is to use precision agriculture principles for pesticide application, using a variable syrup rate and applying the optimum rate to small areas, thereby maximizing treatment efficiency (Arantes et al., 2019; Bassoi et al., 2019).

Field traffic imparts mechanical stress on the soil, leading to soil compaction, compromising agricultural production, and causing environmental impacts, considering that the main consequences of compacted soil are felt in the reduction of root growth in depth, predisposing the plant to death in short periods of drought, as there is a reduction in water storage and oxygen in the soi. A solution to avoid direct contact of agricultural machinery with the ground is to use unmanned aerial vehicles (UAVs). These tools have several applications, being compatible with all types of agricultural production (Andrade et al., 2018; Dutta and Goswami, 2020). According to Sindag (2018), multirotor drones can spray in places with disease outbreaks in crops, replacing total area applications and resulting in significant product savings. Furthermore, they are equipment capable of operating in areas that are difficult to access and in places where agricultural aviation cannot operate. Costs on inputs are reduced by up to 80%, optimizing resources and applying pesticides at the correct time and place, in addition to reducing environmental impacts.

The use of UAVs for spray application has not yet become a widespread practice in agriculture. Few companies in the world produce UAVs on a commercial scale. In view of the foregoing, this study aimed to build a UAV, assess the efficiency of a post-emergent herbicide applied by the UAV at three heights, and compare the effects of UAV application and conventional weed control methods on the vegetative and productive development of common bean.

Material and methods

The experiment was conducted under field conditions over an agricultural cycle of common bean at the experimental farm (23°47′S 53°14′W, 370 m a.s.l.) of the State University of Maringá, Umuarama Campus, Paraná, Brazil. The climate is subhumid, with average temperatures above 22 °C in the hottest month and below 18 °C in the coldest month. There is no defined dry season, and frosts are rare. Summers are hot, with concentrated rainfall. Annual rainfall reaches 1,600 mm (IAPAR, 2014). The soil is a typic dystrophic Red Latosol with sandy texture, characterized by low fertility and high iron content (Empresa Brasileira De Pesquisa Agropecuária [EMBRAPA], 2018).

The experimental field has been managed under a no-till system since 2012. In recent years, it has been planted with *Crambe* in autumn–winter and left fallow in spring–summer. Soil samples were collected from the 0 to 20 cm layer at 90 days before crop establishment for determination of chemical properties (Table 1). If necessary, an acidity corrector would be applied to increase the base saturation to 70%, according to Pauletti and Motta (2019). However, there was no need for this practice, considering that base saturation was 60.75% and it only needs to be corrected when it is below 50%. Therefore, basal fertilization was performed using 400 kg ha^{-1} NPK 10-17-17 (N, P_2O_5, and K_2O, respectively), according to the recommendations of Pauletti and Motta (2017).

Table 1. Soil chemical properties at the experimental site before implementation of the experiment, in the 0–20 cm layer.

pH	P	OM	Ca	K	Mg	Al	CEC	BS
H_2O	mg dm^{-3}	g dm^{-3}	---------------------cmol$_c$ dm^{-3}---------------------					%
6.41	9.91	13.67	1.88	0.12	1.48	0.00	5.73	60.75

OM, organic matter; CEC, cation-exchange capacity; BS, base saturation. P and K were extracted with resin; OM was extracted by the Walkley–Black method; Ca, Mg, and Al were extracted with 1 mol L^{-1} KCl.

The bean cultivar used was IPR Tangará. This cultivar belongs to the pinto bean group and was developed by IAPAR in 1998 in Londrina, Paraná. It has an average cycle of 87 days (emergence to harvest maturity) and high yield potential. Plants have an erect habit and measure about 50 cm in height, which is conducive to mechanical harvesting. Leaves and stems are green, flowers are white and develop on average 42 days after emergence. Each plant produces on average 12 pods, 6 seeds per pod, 6 locules per pod. Pods measure 9 cm on average. IPR Tangará is recommended for cultivation in São Paulo, Mato Grosso do Sul, Paraná, Santa Catarina, and Rio Grande do Sul (IAPAR, 2017).

Mechanical sowing was carried out on April 8, 2022, at a row spacing of 0.45 m and a density of 12 seeds m^{-1}. Each plot comprised six 6 m rows. The four central rows were considered as useful area, excluding 0.5 m from the edges.

The experimental design was a randomized block design with six treatments and four replications. Treatments comprised an unweeded control, a weeded control, herbicide application at the recommended rate using a knapsack sprayer, and herbicide application at the recommended rate using UAV at heights of 1, 2, and 3 m from the ground.

The UAV was a hybrid hexacopter model assembled by combining parts from various manufacturers. It measured 0.90 m in diameter and 0.70 m in height and had a maximum load capacity estimated at 8 kg. The control program was developed by the project authors. DJI A2 Assistant® software was used for flight control programming. The receiver–transmitter communication protocol was Futaba FASST®. The manufacturer's datasheet (RC Timer, 2021) recommends using lithium polymer batteries with a nominal voltage of 22.2 V for the 4114 PRO motor. This battery model is also recommended by DJI (2021) for the S800 EVO frame arm. Propulsion is provided by six motors (RC Timer) with a nominal voltage of 22.2 V and Kv of 350 rpm V^{-1}. The Kv is a measure of the number of rotations per volt an electric motor can perform without load. A Kv value of 350 rpm V^{-1} indicates that the motor is capable of reaching approximately 7,800 rpm. Propellers (RC Timer) were made of carbon fiber and measured 14 inches. Brunetti's theory (2008), as well as the tool available on the Ecalc website (https://www.ecalc.ch/xcoptercalc.php), was used for determining the propeller size. A DJI A2 controller was used to control the motor, spatial data, and telemetry. For geolocation management by GPS, a DJI Datalink equipment was used. The UAV was powered by a Tattu® battery with a nominal voltage of 22.2 V and a charging capacity of 16,000 mAh.

The approximate cost for construction of the equipment was US$3,370.00. The high value of the developed equipment compared with that of traditional models is due to the device's high precision and ability to transport loads.

The spray device mounted on the UAV had an embedded circuit developed by the authors using a StepUP voltage control board, micro servo motor, contact switch sensor, pulse with modulation rotation controller board, and an RS385 hydraulic pump. The spray device had a maximum output pressure of 18 psi and a variable flow rate (0–3 L min^{-1}). The UAV and spray device were remotely controlled by an 18-channel 2.4 GHz 18 SZ Futaba® radio transmitter with a FASSTest bidirectional communication range using the S.Bus2 protocol to control servo motors. The following communication protocols can be used with the receiver embedded in the device: FASSTest18CH, FASSTest12CH, FASST MULT, FASST 7CH, T-FHSS, and S-FHSS. The transmission power was 100 mW. The radio was powered by a two-cell LiFe battery with a nominal voltage of 6.6 V (Futaba, 2022).

Chemical control of ants was performed using fipronil-based baits. No other pests or diseases were controlled, as no levels of economic damage were identified. The herbicide fenoxaprop-P-ethyl (Podium®) was used at a rate of 750 mL ha^{-1}, recommended for use in the post-emergence period of common bean. This herbicide has a selective and systemic mode of action, targeting weeds such as alexandergrass (*Brachiaria plantaginea*), Jamaican crabgrass (*Digitaria horizontalis*), sourgrass, and crowfoot grass (*Eleusine indica*). In the study area, alexandergrass and Jamaican crabgrass are frequent occurrences in bean fields (Barroso et al., 2010).

Herbicide treatments were applied on April 29, 2022, 15 days after plant emergence, when bean crops were between V3 (first trifoliate) and V4 (third trifoliate). On this day, weather).conditions were as follows: average temperature of 24.9°C, average relative humidity of 77.4 %, average wind speed of 1.1 m s^{-1}, and maximum wind speed of 3.5 m s^{-1}. For the weeded control, weeding was carried out from the beginning of the cycle until the closing of the inter-row, which occurred at R5 (beginning seed).

Harvest was performed manually on July 13, 2022 (about 90 days after emergence), when the crop was at R9 and pods and leaves had a straw color, as recommended by Rocha et al. (2017). Pods per plant, grains per plant, grains per pod, 100 grain weight, final population, shoot dry weight, and grain yield were determined.

At the time of harvest, 10 plants were collected from the useful area of each plot for estimation of pods per plant, grains per plant, and grains per pod. Grain weight and yield were determined by harvesting plants along two 1 m rows within the useful areas of plots. Plants were stored in burlap bags and evaluated for final plant population. The value was transformed to plants per hectare. Pods were threshed to obtain the grain weight and yield in kg ha^{-1}. Values were standardized to 13% moisture. Shoots were dried and weighed for determination of shoot dry weight.

Data were subjected to analysis of variance, and means were compared by Tukey's test at the 5% significance level using Sisvar® software (Ferreira, 2011).

Results and discussion

The UAV did not exhibit differences in maneuverability when equipped or not with the spraying device, whether empty or full. However, there was a decrease in autonomy when the UAV was loaded. This result was expected, given that motors make more effort to displace objects with greater weight.

Herbicide applications made using the UAV was as efficient as traditional application methods (Table 2).

Table 2. Number of pods per plant, grains per pod, and grains per plant in common bean crops under different weed management treatments, Umuarama, PR, 2021/22.

Treatment	Pods per plant	Grains per pod	Grains per plant
Weeded control	15.9 a	4.3 a	69.6 a
Unweeded control	6.9 b	3.1 b	28.3 b
Knapsack sprayer[1]	18.4 a	4.4 a	82.7 a
UAV[2], 1 m	14.4 a	4.3 a	62.9 a
UAV[2], 2 m	15.1 a	4.5 a	68.6 a
UAV[2], 3 m	12.9 a	4.4 a	57.8 a
CV (%)	17.3	10.2	18.9
F-test	*	*	*

[1]Herbicide application at the recommended rate using a knapsack sprayer. [2]Herbicide application at the recommended rate using an unmanned aerial vehicle (UAV) at heights of 1, 2, and 3 m from the ground. Means in a column followed by the same letter do not differ from each other by Tukey's test at the 5% significance level. CV, coefficient of variation; * $p < 0.05$.

Weed management treatments did not differ from each other. Only the unweeded control resulted in lower yield components (Table 2). The results were similar to those of Silva et al. (2014), who also did not observe differences between herbicide application and manual weeding. The coefficient of variation demonstrated homogeneity of variance for grains per pod and intermediate dispersion for pods per plant and grains per plant (Gomes and Garcia, 2002; Andrade and Ogliari, 2013).

Similarly, weed control methods did not produce significant differences in shoot dry weight, final plant population, 100 grain weight, or yield. Statistically lower values were only observed in the unweeded control (Table 3).

Table 3. Shoot dry weight, final plant population, 100 grain weight, and grain yield in common bean crops under different weed management treatments, Umuarama, PR, 2021/22.

Treatment	Shoot dry weight (kg ha^{-1})	Final population number	100 grain weight (g)	Yield (kg ha^{-1})
Weeded control	3,861 a	216,667 a	31.2 a	2,285 a
Unweeded control	1,416 b	83,333 b	21.8 b	446 b
Knapsack sprayer[1]	3,361 a	188,889 a	28.2 a	2,042 a
UAV[2], 1 m	2,777 a	188,898 a	28.6 a	1,593 a
UAV[2], 2 m	3,583 a	177,778 a	28.5 a	1,667 a
UAV[2], 3 m	3,694 a	200,000 a	29.9 a	1,686 a
CV (%)	25.5	22.5	11.2	26.6
F-test	*	*	*	*

[1]Herbicide application at the recommended rate using a knapsack sprayer. [2]Herbicide application at the recommended rate using an unmanned aerial vehicle (UAV) at heights of 1, 2, and 3 m from the ground. Means in a column followed by the same letter do not differ from each other by Tukey's test at the 5% significance level. CV, coefficient of variation; * $p < 0.05$.

The weed control methods used in the study did not produce significant differences in yield or vegetative parameters, differing only from the unweeded control. The mean shoot dry weight of weeded crops was 3,455 kg ha^{-1}, being markedly higher than that of the unweeded control (1,416 kg ha^{-1}). Such a finding can be explained by the competition for water, light, and nutrients generated by the presence of weeds. These factors delay bean development and decrease bean plant populations, as evidenced by the lower final plant population of the unweeded control. Mancuso et al. (2016), in investigating the selectivity of herbicides, observed similar results for common bean BRS Guariba and BRS Novaera: the unweeded control had lower final population levels than crops subjected to manual or chemical weeding.

Grain development was affected by the action of weeds, as shown by the 100 grain weight. Pereira et al. (2020) found that a lack of weeding negatively influenced grain development. The final yield of the unweeded control was significantly lower than that of weeded plots. Silva et al. (2017), in analyzing common bean yield as a function of herbicide treatment, observed low values in crops not subjected to weed management, as the action of weeds was greater.

The grain yield of common bean subjected to the different weed management strategies ranged from 1,593 to 2,042 kg ha^{-1}. These values are in line with reference values for common bean in the experimental area and period, as supported by Bordin-Rodrigues et al. (2021). The coefficient of variation revealed homogeneous data dispersion for 100 grain weight, and average dispersion for shoot dry weight, final population, and yield (Gomes and Garcia, 2002; Andrade and Ogliari, 2013).

Given that UAV spraying height did not significantly influence the parameters, it is recommended to use a height of 3 m, representing a safe distance from the ground and low risk of collisions and accidents. The lack of differences between the different application heights might be explained by the air displacement generated by UAV propellers, directing the sprayed product to the ground.

The herbicide used is a product recommended for bean plants, therefore its efficiency is proven, mainly due to the weeds found in the area. The usual application of this product provides effective control as well as the manual weeding method. The height of herbicide application in the conventional method can cause problems such as drift (Wang et al., 2020), however, when the UAV was used this did not occur, simply due to the fact that the vehicle's propellers promoted uniform application of the product. The aerial application was carried out on a day when there was no wind, as this is a problem in pesticide applications (Bish et al., 2021). This further contributed to preventing drift when applying the product via UAV. Precipito et al. (2023), studying the height of herbicide application and environmental conditions, found that when the product is applied in appropriate environmental conditions, the application height does not influence drift.

Conclusion

Absence of weed control hindered the vegetative and productive development of common bean. Herbicide spraying via UAV at heights of 1, 2, and 3 m proved to be as efficient as traditional weed control methods. No significant differences were observed between application heights because of the propeller-induced air displacement, directing the herbicide toward the ground, minimizing drift effects. Recommended to use a height of 3 m, representing a safe distance from the ground and low risk of collisions and accidents.

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References

Albrecht, L. P., Albrecht, A. J. P., Danilussi, M. T. Y., & Lorenzetti, J. B. (2021). Métodos de Controle de Plantas Daninhas. SENAR-AR/PR.

Andrade, D. F., & Ogliari, P. J. (2013). *Estatística para as Ciências Agrárias e Biológicas com Noções de Experimentação*. UFSC.

Andrade, J. M. A., Pretto, D. R., Carvalho, E. V., Bolonhezi, D., Scarpellini, J. R., & Vieira, B. C. (2018). Avaliação de RPAs para pulverização em diferentes culturas. *Revista Ingeniería y Región, 20*, 73-78. https://dx.doi.org/10.25054/22161325.1912

Arantes, B. H. T., Arantes, L. T., Costa, E. M., & Ventura, M. V. A. (2019). Drone aplicado na cultura digital. *Ipê Agronomic Journal, 3*(1), 14-18. https://doi.org/10.37951/2595-6906.2019v3i1.4323

Araújo, G. A. A., Silva, A. A., Thomas, A., & Rocha, P. R. R. (2008). Misturas de herbicidas com adubo molíbdico na cultura do feijão. *Planta Daninha, 26*(1), 237-247. https://doi.org/10.1016/j.jclepro.2020.122152

Barroso, A. L. L., Dan, H. A., Procópio, S. O., Toledo, R. E. B., Sandaniel, C. R., Braz, G. B. P., & Cruvinel, K. L. (2010). Eficácia de herbicidas inibidores da ACCase no controle de gramíneas em lavouras de soja. *Planta Daninha, 28*, 149-157.

Bassoi, L. H., Inamasu, R. Y., Bernardi, A. C. C., Vaz, C. M. P., Speranza, E. A., & Cruvinel, P. E. (2019). Agricultura de precisão e agricultura digital. *Revista Digital de Tecnologias Cognitivas, 20*, 17-36. https://dx.doi.org/10.23925/1984-3585.2019i20p17-36

Bastos, J. C. F., Cunha, F. N., Ribeiro, N. L., Silva, N. F., Rocha, A. C., & Teixeira, M. B. (2013). Resposta do feijão azuki à adubação nitrogenada sob irrigação. *Revista Brasileira de Agricultura Irrigada, 7*, 349-357. http://dx.doi.org/10.7127/rbai.v7n600187

Bish, M., Oseland, E., & Bradley, K. (2021). Off-target pesticide movement: A review of our current understanding of drift due to inversions and secondary movement. *Weed Technology, 35*(3), 345-356. http://dx.doi.org/10.1017/wet.2020.138

Bordin-Rodrigues, J. C., Silva, T. R. B., Soares, D. F. D. M., Stracieri, J., Ducheski, R. L. P., & Silva, G. D. (2021). Bean and chia development in accordance with fertilization management. *Heliyon, 7*(6), 1-7. http://dx.doi.org/10.1016/j.heliyon.2021.e07316

Brunetti, F. (2008). *Mecânica dos Fluidos*. Pearson Prentice Hall.

DJI. (2021). *Spreading Wings S800 EVO*. https://www.dji.com/spreading-wings-s800-evo/download

Dutta, G., & Goswami, P. (2020). Application of drone in agriculture: a review. *International Journal of Chemical Studies, 8*, 181-187. http://dx.doi.org/10.22271/chemi.2020.v8.i5d.10529

Empresa Brasileira De Pesquisa Agropecuária. (2018). *Sistema Brasileiro de Classificação dos Solos*. EMBRAPA/CNPSO.

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia, 35*(6), 1039-1042.

Futaba. (2022). *T18SZ*. https://futabausa.com/product/18sz/

Galon, L., Winter, F. L., Forte, C. T., Agazzi, L. R., Basso, F. J. M., Holz, C. M., & Perin, G. F. (2017). Associação de herbicidas para o controle de plantas daninhas em feijão do tipo preto. *Revista Brasileira de Herbicidas, 16*(4), 268-278. http://dx.doi.org/10.7824/rbh.v16i4.559

Gomes, F. P., & Garcia, C. H. (2002). *Estatística Aplicada a Experimentos Agronômicos e Florestais* (Vol. 11).

IAPAR. (2014). *Agrometeorologia: Redes de Estações Meteorológicas do Paraná. Estações Meteorológicas Convencionais. Umuarama*. Instituto Agronômico do Paraná.

Instituto Agronômico do Paraná. (2017). *Cultivar de Feijão IPR Tangará*. IAPAR.

Lima, A. R. S., Silva, J. A. S., Santos, C. M. G., & Capristo, D. P. (2020). Agronomic performance of common bean lines and cultivars in the Cerrado/Pantanal ecotone region. *Research, Society and Development, 9*(7), 1-19. https://doi.org/10.33448/rsd-v9i7.3666

Mancuso, M. A. C., Aires, B. C., Negrisoli, E., Corrêa, M. R., & Soratto, R. P. (2016). Seletividade e eficiência de herbicidas no controle de plantas daninhas na cultura do feijão-caupi. *Revista Ceres, 63*(1), 25-32. https://doi.org/10.1590/0034-737X201663010004

Moraes, E. S., & Menelau, A. S. (2017). Análise do mercado de feijão comum. *Revista de Política Agrícola, 26*(1), 81-92.

Nachtigall, G. R., & Nava, G. (2010). Adubação foliar: fatos e mitos. *Agropecuária Catarinense, 23*(2), 87-97.

Pauletti, V., & Motta, A. C. V. (2019). *Manual de adubação e calagem para o estado do Paraná* (pp. 478-480). SBCS/NEPAR.

Pereira, L. S., Souza, G. D., Oliveira, G. S., Silva, J. N., Costa, E. M., Ventura, M. V. A., & Lakelaitis. (2020). A Eficiência de herbicidas aplicados em pós-emergência na cultura do feijão-caupi. *Colloquium Agrariae, 16*(1), 29-42. https://doi.org/10.5747/ca.2020.v16.n1.a345

Pessôa, U. C. M., Oliveira, K. J. A., Souza, A. S., Pimenta, T. A., Muniz, R. V. S., & Araújo Neto, A. G. (2017). Desempenho fisiológicos e crescimento do feijão-caupi, sob manejos de plantas daninhas. *Revista Verde de Agroecologia e Desenvolvimento Sustentável, 12*(2), 246-250. http://dx.doi.org/10.18378/rvads.v12i2.5067

Precipito, L. M. B., Ferreira, L. A. I., Paduan, N. A., Lima, J. S. S., & Oliveira, R. B. (2023). Use of the test bench for spray drift assessment under subtropical climate conditions. *Revista Brasileira de Engenharia Agrícola e Ambiental, 27*(3), 223–229. https://doi.org/10.1590/1807-1929/agriambi.v27n3p223-229

RC Timer. (2021). *HP4114 350KV Pro Multirotor Brushless Motor*. https://www.rctimer.com/hp4114-350kv-multirotor-brushless-motor-universal-version-p0140.html

Rocha, M. M., Silva, K. J. D., Freire Filho, F. R., & Menezes Junior, J. A. N. (2017). *Cultivo de Feijão-Caupi* (Embrapa Meio-Norte, Vol. 2). Embrapa

Schiessel, J. J., Mello, G. R., Schmitt, J., Pastorello, L. F., Bratti, F., Oliveira Neto, A. M., & Guerra, N. (2019). Períodos de interferência de plantas daninhas na cultura do feijoeiro comum. *Revista de Ciências Agroveterinárias, 18*(4), 430-437. https://doi.org/10.1590/S1806-66902011000300019

Silva, A. F. M., Giraldeli, A. L., Silva, G. S., Araújo, L. S., Albrecht, A. J. P., Albrecht, L. P., & Victória Filho, R. (2021). Introdução à ciência das plantas daninhas. In A. A. Martins Barroso & A. T. Murata (Orgs.), *Matologia: estudos sobre plantas daninhas* (pp. 7–37). Fábrica da Palavra.

Silva, A. F., Concenço, G., Aspiazú, I., Galon, L., & Ferreira, E. A. (2018). Métodos de Controle de Plantas Daninhas. In M. F. Oliveira & A. M. Brighenti (Ed.), *Controle de plantas daninhas: métodos físico, mecânico, cultural, biológico e alelopatia* (pp. 11-33). Embrapa.

Silva, F. S., & Wander, A. E. (2013). *O Feijão-Comum no Brasil: Passado, Presente e Futuro*. Embrapa Arroz e Feijão.

Silva, K. S., Freitas, F. C. L., Linhares, C. S., Carvalho, D. R., & Lima, M. F. P. (2014). Eficiência de Herbicidas para a Cultura do Feijão-Caupi. *Planta Daninha, 32*(1), 197-205. https://doi.org/10.1590/S0100-83582014000100022

Silva, L. M., Reis, E. M. B., Santos, B. R. C., Pinedo, L. A., Montagner, A. E. A. D., Arévalo, B. R. S., Santos, A. M. P., & Maia, G. F. N. (2022). Controle químico de plantas daninhas com diferentes dosagens de herbicida a base de fluroxipir+picloram. *Research, Society and Development, 11*(12). http://dx.doi.org/10.33448/rsd-v11i12.34598

Silva, M. B. O. S., Alves, P. F. S., Teixeira, M. F. F., Silva, H. D., Alexandre Sá, R., Campos, R. G. C., Carvalho, A. J., & Aspiazu, I. (2017). Produtividade e componentes de rendimento de feijão-caupi sob efeito de herbicidas aplicados em pós-emergência. *Revista Unimontes Científica, 18*(2), 76-83. https://doi.org/10.24221/jeap.2.3.2017.1456.320-329

Tavares, T. C. O., Souza, S. A., Lopes, M. B. S., Veloso, D. A., & Fidelis, R. R. (2018). Divergência genética entre cultivares de feijão comum cultivados no estado do Tocantins. *Revista de Agricultura Neotropical, 5*(3), 76-82. http://dx.doi.org/10.32404/rean.v5i3.1892

Wang, G., Han, Y., Li, X., Andaloro, J., Chen, P., Hoffmann, W. C., Han, X., Chen, S., & Lan, Y. (2020). Field evaluation of spray drift and environmental impact using an agricultural unmanned aerial vehicle (UAV) sprayer. *Science of the Total Environment, 737*, 1-13. https://doi.org/10.1016/j.scitotenv.2020.139793