Enhancing Plantation Productivity: A Screen-house Investigation into the Impact of Indaziflam on Amaranthus, Maize, Melon, and Tomato in Intercropping Systems

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ABSTRACT

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The potential impact of the new indaziflam pre-emergence herbicide on common plantation intercrops of amaranthus, maize, melon, and tomato, was assessed in a screenhouse study. The experimental treatments comprised the following inclusion of indaziflam to soil at sowing: 0, 0.15, 0.30, 0.45, 0.60, and 0.75 mg/kg. These treatments were laid out in a completely randomized design with four replications. The effect of indaziflam was evaluated through destructive sampling after 8 weeks of growth, and its residual effect was examined post-replanting after the same period, specifically at 16 weeks following indaziflam application. Data on plant height, number of leaves, leaf area, plant fresh weight, and plant dry weight were recorded in each planting instance. The collected data were subjected to analysis of variance, and the treatment means were separated using Duncan's New Multiple Range Test at a significance level of 5%. The study revealed significant reductions ($p \leq 0.05$) in growth of the test crops due to indaziflam application, with the most pronounced effects at higher concentrations. Amaranthus and tomato seedlings failed to emerge at concentrations > 0.15 mg/kg and ≥ 0.15 mg/kg, respectively. Maize and melon exhibited reduced growth at concentrations > 0.3 mg/kg. Residual effects were significant, notably reducing plant growth parameters at higher indaziflam concentrations, particularly at 0.6 and 0.75 mg/kg. In conclusion, indaziflam at concentrations greater than 0.15 mg/kg significantly inhibits the growth of common plantation intercrops, with persistent residual effects, suggesting its limited suitability for use in such contexts.

Keywords: Herbicide persistence, indaziflam, intercropping, plantation, pre-emergence herbicide

Establishing and maintaining permanent crops often face challenges associated with the vigorous growth of weeds, especially during the critical early stages. The absence of canopy cover in newly planted fields exposes them to intense weed competition (Kumar et al. 2023), making it imperative to implement effective weed management strategies to successfully establish crops. Weeds in

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plantations present substantial hurdles to both crop productivity and quality. Hence, implementing effective weed management strategies is essential to alleviate these concerns and optimize crop production. One promising approach to enhance productivity and diversify yields in plantation is intercropping. This cropping system involves cultivating multiple crops simultaneously on the same land (Ha et al. 2024). Intercropping offers several advantages, including reduced dependence on monoculture, improved soil fertility management, and efficient weed control (Vlahova 2022). However, the successful adoption of intercropping needs a profound understanding of crop-crop interactions and their responses to various management practices, including the judicious use of herbicides.

Indaziflam (N-[(1R,2S)-2,3-dihydro-2,6-dimethyl-1H-inden-1-yl]-6-[(1R)-1-fluoroethyl]-1,3,5-triazine-2,4-diamine), an alkylazine herbicide renowned for its distinctive capacity to selectively control both monocots and dicots (Sebastian et al. 2017), has emerged as a viable solution for weed management during the initial phases of tree crop establishment (Grey et al. 2016). Its protracted residual activity and efficacy against a broad spectrum of weed species position it as a compelling candidate for augmenting weed suppression in plantation agriculture. Moreover, unlike many pre-emergence herbicides, indaziflam exhibits a longer soil half-life of over 150 days (Kaapro and Hall 2012). Notably, indaziflam ability to effectively inhibit cellulose biosynthesis makes it a suitable option for weed control (Jeschke 2022). The tolerance demonstrated by tree crops adds to their potential suitability for integration into intercropping and multiple cropping systems. Nevertheless, safeguarding susceptible crops within these cropping systems remains essential.

The persistence of herbicides applied to soil varies by location due to environmental and biological differences (Das 2024). Therefore, it is essential to evaluate crop response when introducing a herbicide to a new region. Indaziflam has recently become available in Nigeria for pre-release testing. However, the use of indaziflam does not come without challenges. A study conducted in North Carolina, USA, has revealed that even at a low simulated indaziflam drift rate of 2.5%, off-target plant injury risk remains a concern. For example, this low drift rate resulted in greater than 20% root mass reduction in several crops, including cotton, bell pepper, soybean, squash, and tomato (Jeffries et al. 2014). While indaziflam shows promise for use in monocropping systems involving tolerant tree crops, these findings underscore the importance of thoroughly understanding its potential impact on non-target intercrops and rotational crops.

Given the potential phytotoxic effects of indaziflam on non-target crops, this study embarked on a comprehensive exploration to assess its impact on the growth of amaranthus, maize, melon, and tomato. These crops are frequently grown as intercrops in Nigerian plantations, and the study specifically aimed to evaluate their suitability for intercropping and multiple cropping systems.

MATERIALS AND METHODS

Materials.

Seeds of amaranthus (*Amaranthus hybridus*, cv. NH84/457-IL), maize (*Zea mays*, cv. Ak 96 dmr sr-w), melon (*Cucumis melo*, cv. URANUS F1), and tomato (*Solanum lycopersicum*, cv. ROMA VF) were sourced from the Agricultural Development Project (ADP) Office in Benin City. The topsoil, used as the growing medium for the test crops, was collected from the University of Benin

Teaching and Research Farm. Alion® herbicide, formulated as 19.05% indaziflam in soluble concentrate was supplied by Bayer CropScience.

Preparation of a standardized stock solution.

A standardized stock solution of indaziflam was prepared meticulously at the Chemistry Laboratory of the Nigerian Institute for Oil Palm Research (NIFOR), located near Benin City. Through a series of precise and calibrated serial dilutions, concentrations of 0.2, 0.4, 0.6, 0.8, and 1 mg/L of indaziflam were prepared such that, when 250 ml of each was applied directly to the soil, the desired experimental treatment was achieved.

Experimental site.

The study was conducted within a screenhouse at the Teaching and Research Farm of the University of Benin, Benin City, situated in the humid rainforest zone of southern Nigeria (latitude 6.02°N and longitude 5.06°E). The experiments were carried out from March to June 2016, during which meteorological data indicated temperatures ranging from 24.5 to 32.7°C, with a mean of 28.6°C. Relative humidity fluctuated between 63.31 and 81.71%, while daily sunshine duration varied from 5.85 to 7.50 hours. The topsoil, sieved using a 2 mm mesh, was used to fill pots arranged in the screenhouse. Each pot, measuring 12 cm in depth, 7 cm in top diameter, and 4.5 cm in basal diameter, contained 311 cm^3 (0.3 kg) of sieved topsoil arranged in a 5 × 15 cm spacing within the screenhouse. The soil detailed physico-chemical characteristics are presented in Table 1.

Table 1. Physico-chemical properties of pre-treatment soil

Parameter	Value
pH in (H_20)	5.60
Total Nitrogen (g/kg)	2.80
Available P (mg/kg)	2.55
Organic carbon (g/kg)	17.76
Organic matter (g/kg)	30.62
CEC (cmol/kg)	4.63
ECEC (cmol/kg)	5.16
Ca (cmol/kg)	0.25
Mg (cmol/kg)	0.22
K (cmol/kg)	0.43
Na (cmol/kg)	0.19
Silt (%)	9.42
Sand (%)	73.95
Clay (%)	16.60
Textural class	Sandy loam
Exchange Acidity (cmol/kg)	2.03
Base saturation (%)	58.57

Seeds viability test.

Initial seed viability test was thoroughly conducted by immersing the seeds of selected crops in water within a bowl and hand-picking the submerged seeds. Following this careful selection process, the seeds were gently air-dried before being used for planting.

Experimental design and treatments.

The experiment was set up following a completely randomized design, with the experimental treatments consisting of six doses of indaziflam (0, 0.15, 0.30, 0.45, 0.60, and 0.75 mg/kg soil). These concentrations were obtained by applying dilutions of Alion® (indaziflam herbicide) to appropriate quantity of soil. Twenty-four pots were allocated for cultivating each of maize, melon, amaranthus, and tomato, with experimental treatments replicated four times, totaling ninety-six pots.This layout ensured separate and distinct evaluations for each crop and dose combination. After applying indaziflam at each dose, three seeds of each crop were sown in twenty-four pots at a depth of approximately 3 cm. Following the emergence of the seedlings, multiple seedling stands were thinned down to one plant per pot 2 weeks after sowing.

Growth parameter measurement.

At 8 weeks after treatmant, data were collected on various variables. Plant height (cm), number of leaves, leaf area (cm^2), fresh weight (g), and dry weight (g) of plants were measured. Plant height was determined using a measuring tape from the base to the tip. The number of leaves per pot was counted, and leaf area was determined following the method of Gates (1991). Plants were carefully removed by hand for fresh weight measurement, and the soil sticking to the root region was washed back into the pots with clean water. The plants were weighed using an electronic precision balance (Kerro BL 2001). Dry weights were obtained by oven-drying the harvested plants at 80ºC until a constant weight was achieved.

Follow-up trial.

Following the termination of the initial experiment at 8 weeks after treatmant, a subsequent follow-up trial was conducted using the same pots for replanting, with no additional application of indaziflam. Data were collected similarly to the first trial at 8 weeks after treatmant, coinciding with 16 weeks after the treatment application.

Data analysis.

The data obtained from the trials were analyzed using Genstat 8 software through analysis of variance. The treatment means were then separated using the Duncan New Multiple Range Test (DNMRT) at a 5% probability level.

RESULTS

Effects of indaziflam and its residues on the growth of amaranthus.

At 8 weeks after treatment and sowing, the application of indaziflam resulted in a significant reduction ($p \leq 0.05$) in various growth parameters of the amaranthus plant (Tables 2, 3). These parameters included plant height, number of leaves, leaf area, as well as fresh and dry weights. Visible reduction in these growth parameters was observed specifically at indaziflam level of 0.15 mg/kg soil. Notably, amaranthus seedlings failed to emerge in pots treated with indaziflam concentrations greater than 0.15 mg/kg soil.

At 8 weeks after re-sowing, corresponding to 16 weeks after treatment, the height of the amaranthus plant showed a significant reduction ($p \leq 0.05$) due to the residues from concentrations of indaziflam greater than 0.15 mg/kg soil. Additionally, it was observed that the indaziflam residues from 0.15, 0.3, 0.45 mg/kg of soil significantly reduced the number of leaves, leaf area, and the plant fresh and dry weights. The extent of reduction in the amaranthus growth parameters exhibited an upward trend as the concentrations of indaziflam increased Remarkably, amaranthus seedlings did not emerge in pots containing indaziflam residues from 0.75 mg/kg of soil (Tables 2, 3).

Table 2. Effect of indaziflam and its residues on growth of amaranthus

Indaziflam dose (mg/kg soil)	Plant height (cm)	Number of leaves	Leaf Area (cm^2)	Fresh plant weight (g)	Dry plant weight (g)
8 weeks after treatment					
0	18.68a	13.00a	23.90a	13.54a	4.07a
0.15	0.50b	1.00b	0.12b	0.00b	0.00b
0.3	0.00b	0.00b	0.00b	0.00b	0.00b
0.45	0.00b	0.00b	0.00b	0.00b	0.00b
0.6	0.00b	0.00b	0.00b	0.00b	0.00b
0.75	0.00b	0.00b	0.00b	0.00b	0.00b
SE±	0.38	0.57	0.31	0.53	0.16
16 weeks after treatment					
0	14.00a	12.00a	14.68a	16.30a	4.90a
0.15	12.25a	7.00bc	6.58b	10.80b	2.20b
0.3	7.75b	5.00cd	6.45b	2.20c	0.00c
0.45	7.25b	8.00b	5.57b	1.10d	0.00c
0.6	1.50c	2.00de	0.57c	0.00e	0.00c
0.75	0.00c	0.00e	0.00c	0.00e	0.00c
SE±	0.98	0.92	0.68	0.54	0.01

Means in a column followed by similar letters are not significantly different at 5% level of probability by Duncan's New Multiple Range Test (DNMRT).

Table 3. Symbolic depictition of the effect of indaziflam and its residues on growth of amaranthus

Amaranthus	8 weeks after treatment						16 weeks after treatment					
	Indaziflam dose (mg/kg soil)											
	0	**0.15**	**0.3**	**0.45**	**0.6**	**0.75**	**0**	**0.15**	**0.3**	**0.45**	**0.6**	**0.75**
Plant height (cm)	18.68	-	-	-	-	-	14.00	*	-	-	-	-
Number of leaves	13.00	-	-	-	-	-	12.00	-	-	-	-	-
Leaf area (cm^2)	23.90	-	-	-	-	-	14.68	-	-	-	-	-
Fresh plant weight (g)	13.54	-	-	-	-	-	16.30	-	-	-	-	-
Dry plant weight (g)	4.07	-	-	-	-	-	4.90	-	-	-	-	-

Symbols: * indicates no significant difference from the control, and - indicates a value significantly lower than the control, based on Duncan's New Multiple Range Test (DNMRT) at the $p = 0.05$ significance level.

Effects of indaziflam and its residues on the growth of maize.

At the 8 week after planting and treatment application, it became evident that varying concentrations of indaziflam significantly influenced critical parameters of maize growth (Tables 4, 5). Maize plant height experienced a notable reduction ($p \leq 0.05$) due to indaziflam concentrations, showing a corresponding decrease in height as herbicide concentration increased. The most substantial decrease occurred at 0.6 mg of indaziflam per kg of soil, as maize seedlings failed to emerge in pots treated with higher concentration. Similarly, the number of leaves per plant demonstrated reductions linked to indaziflam concentrations, except for 0.15 and 0.3 mg/kg. This reduction in leaf count exhibited an upward trend with increasing herbicide concentration. Furthermore, the impact of different indaziflam concentrations (0.15, 0.3, 0.45, 0.6, 0.75 mg/kg) on maize leaf area and fresh plant weight was notable, revealing statistically significant reductions ($p \leq 0.05$) across all concentrations. Notably, as the herbicide concentration increased, the leaf area and fresh plant weight reduction became more pronounced, with the highest reduction observed at 0.6 mg/kg and no plant emerged at 0.75 mg/kg. Moreover, the dry weight of maize plants exhibited a similar pattern, displaying significant reductions ($p \leq 0.05$) at indaziflam concentrations of 0.3, 0.45, 0.6, and 0.75 mg/kg.

Table 4. Effect of indaziflam and its residue on growth of maize

Indaziflam dose (mg/kg soil)	Plant height (cm)	Number of leaves	Leaf area (cm^2)	Fresh plant weight (g)	Dry plant weight (g)
			8 weeks after treatment		
0	29.85a	7.00a	98.70a	30.04a	10.49a
0.15	16.80b	5.00a	46.00b	25.20b	8.78a
0.3	7.90c	6.00a	16.20c	12.47c	4.34b
0.45	4.00d	2.00b	5.10cd	2.77d	0.89c
0.6	1.80de	2.00b	2.80d	0.67e	0.00d
0.75	0.00e	0.00c	0.00d	0.00e	0.00d
SE±	0.76	0.53	3.98	0.22	0.08
			16 weeks after treatment		
0	19.50a	7.00a	26.70b	12.60b	4.40bc
0.15	18.50a	7.00a	38.50a	15.50a	5.40a
0.3	17.50a	7.00a	36.50a	13.50ab	4.70ab
0.45	17.25a	6.00a	30.30ab	11.50bc	3.70c
0.6	11.25b	6.00a	22.00b	10.10c	2.90d
0.75	6.50c	4.00b	6.30c	3.30d	0.60e
SE±	1.54	0.61	2.79	1.68	0.6

Means in a column followed by similar letters are not significantly different at 5% level of probability by by Duncan's New Multiple Range Test (DNMRT).

At 8 weeks after re-sowing, corresponding to 16 weeks after treatment application, the height of maize plants associated with residues from 0.15, 0.3, and 0.45 mg of indaziflam per kg soil exhibited comparability ($p \leq 0.05$) with the indaziflam-free treatment (control). Conversely, the residues from 0.6 and 0.75 mg/kg reduced the height of maize plants. The leaf count per maize plant was not significantly affected ($p \leq 0.05$) by the residues from0.15, 0.3, 0.45 and 0.6 mg of indaziflam per kg of soil. However, the residues of 0.75 mg/kg resulted in a reduction in maize leaf count. The leaf area of maize showed a significant increase ($p \leq 0.05$) due to residues from 0.15 and 0.3 mg of indaziflam per kg soil. Residues from 0.45 and 0.6 mg/kg resulted in a maize leaf area comparable to the indaziflam-free treatment, while 0.75 mg/kg led to a reduction in the maize leaf area. The fresh and dry weights of the maize plants experienced a significant increase due to the residue from 0.15 mg of indaziflam per kg of soil. Residues from 0.3 and 0.45 mg/kg soil yielded maize plant fresh and dry weights comparable to the indaziflam-free treatment. Conversely, residues from 0.6 and 0.75 mg of indaziflam per kg soil resulted in a notable reduction ($p \leq 0.05$) in the fresh and dry weights of the maize plants.

Table 5. Symbolic depictition of the effect of indaziflam and its residue on growth of maize

Maize	8 weeks after treatment						16 weeks after treatment					
	Indaziflam dose (mg/kg)											
	0	0.15	0.3	0.45	0.6	0.75	0	0.15	0.3	0.45	0.6	0.75
Plant height (cm)	29.85	-	-	-	-	-	19.50	*	*	*	-	-
Number of leaves	7.00	*	*	-	-	-	7.00	*	*	*	*	-
Leaf Area (cm^2)	98.70	-	-	-	-	-	26.70	+	+	*	*	-
Fresh plant weight (g)	30.04	-	-	-	-	-	12.60	+	*	*	-	-
Dry plant weight (g)	10.49	*	-	-	-	-	4.40	+	*	*	-	-

Symbols: + indicates a value significantly higher than the control, * indicates no significant difference from the control, and - indicates a value significantly lower than the control, based on Duncan's New Multiple Range Test (DNMRT) at the p = 0.05 significance level.

Effects of indaziflam and its residues on the growth of melon.

Eight weeks after treatment application, the growth of melon showed a significant reduction ($p \leq 0.05$) as a result of applying 0.15 and 0.3 mg indaziflam per kg soil during sowing (Tables 6, 7). Notably, plant height, leaf count, leaf area, and the fresh and dry weights of melon plants decreased in correspondence with the increasing concentration of the indaziflam herbicide. Indaziflam concentrations greater than 0.3 mg/kg of soil resulted in no emergence of melon seedlings.

Eight weeks after re-sowing, which aligns with 16 weeks after treatment application, the presence of residues from 0.15, 0.3 and 0.45 mg indaziflam per kg soil did not yield a significant impact on the plant height and leaf count per melon plant in comparison to the indaziflam-free treatment. However, residues from 0.6 mg indaziflam per kg soil significantly reduced melon plant height. Additionally, residues from 0.75 mg indaziflam per kg soil resulted in no emergence of melonseedling. Residues from concentrations of indaziflam greater than 0.15 mg/kg significantly decreased ($p \leq 0.05$) the leaf area of melon. The dry and fresh weights of the melon plant exhibited a significant increase ($p \leq 0.05$) due to the presence of residues from low concentrations of indaziflam (0.15 and 0.3 mg/kg). Residues from 0.45 mg indaziflam per kg soil did not yield a significant impact ($p \leq 0.05$) on the dry and fresh weights of the melon plant. However, residues from 0.6 mg/kg significantly reduced ($p \leq 0.05$) both the dry and fresh weights of the melon plant.

Table 6. Effect of indaziflam and its residue on growth of melon

Indaziflam dose (mg/kg)	Plant height (cm)	Number of leaves	Leaf Area (cm^2)	Fresh plant weight (g)	Dry plant weight (g)
	8 weeks after treatment				
0	84.50a	21.00a	44.62a	5.60a	1.98a
0.15	7.00b	3.00b	4.01b	0.00b	0.00b
0.3	6.00b	2.00b	3.58b	0.00b	0.00b
0.45	0.00b	0.00b	0.00b	0.00b	0.00b
0.6	0.00b	0.00b	0.00b	0.00b	0.00b
0.75	0.00b	0.00b	0.00b	0.00b	0.00b
SE±	7.45	1.76	1.91	0.23	0.78
16 weeks after treatment					
0	28.20a	7.00a	63.00a	5.50b	1.30b
0.15	24.00a	8.00a	61.00a	7.70a	1.50a
0.3	23.00a	8.00a	31.00b	8.90a	1.80a
0.45	22.00ab	8.00a	22.50bc	5.70b	1.30b
0.6	14.20b	5.00a	14.40c	4.30c	0.90c
0.75	0.00c	0.00b	0.00d	0.00d	0.00d
SE±	2.81	0.94	3.84	1.89	0.13

Means in a column followed by similar letters are not significantly different at 5% level of probability by Duncan's New Multiple Range Test (DNMRT).

Table 7. Symbolic depictition of the effect of indaziflam and its residue on growth of melon

Melon	8 weeks after treatment						16 weeks after treatment					
	Indaziflam dose (mg/kg)											
	0	0.15	0.3	0.45	0.6	0.75	0	0.15	0.3	0.45	0.6	0.75
Plant height	84.50	-	-	-	-	-	28.20	*	*	*	-	-
Number of leaves	21.00	-	-	-	-	-	7.00	*	*	*	*	-
Leaf Area (cm^2)	44.62	-	-	-	-	-	63.00	*	-	-	-	-
Fresh plant weight (g)	5.60	-	-	-	-	-	5.50	+	+	*	-	-
Dry plant weight (g)	1.98	-	-	-	-	-	1.30	+	+	*	-	-

Symbols: + indicates a value significantly higher than the control, * indicates no significant difference from the control, and - indicates a value significantly lower than the control, based on Duncan's New Multiple Range Test (DNMRT) at the p = 0.05 significance level.

Effects of indaziflam and its residues on the growth of tomato.

At 8 weeks after sowing and treatment application, the application of indaziflam at concentrations of 0.15, 0.3, 0.45, 0.6 and 0.75 mg/kg resulted in no emergence of tomato plants (Tables 8, 9). This outcome unequivocally indicates that indaziflam significantly impeded ($p \leq 0.05$) the growth of tomato plants in contrast to the indaziflam-free treatment. Consequently, no observable plant height, leaf count, leaf area, or dry and fresh weights were recorded due to the indaziflam treatment.

Eight weeks postre-sowing, corresponding to 16 weeks post-treatment application, residues of 0.15 and 0.3 mg of indaziflam per kg of soil did not significantly impact the height of tomato plants. In contrast, residues from higher concentrations of indaziflam resulted in a notable reduction in the height of tomato plants. Residues from 0.15, 0.3, 0.45 and 0.6 mg indaziflam per kg soil did not significantly impact the leaf count and leaf area of tomato plants. However, the presence of residues from 0.75 mg indaziflam per kg soil significantly decreased both the leaf count and the leaf area of tomato plants. The presence of residues from 0.15 and 0.3 mg indaziflam per kg soil resulted in a notable increase in both tomato plant fresh and dry weights. In contrast, residue from 0.45 mg indaziflam per kg soil did not significantly impact the fresh and dry weights of tomato plants. However, residue from 0.75 mg indaziflam per kg soil substantially reduced the fresh and dry weights of tomato plants.

Table 8. Effect of indaziflam and its residue on growth of tomato

Indaziflam dose (mg/kg)	Plant height (cm)	Number of leaves	Leaf Area (cm^2)	Fresh plant weight (g)	Dry plant weight (g)
	8 weeks after treatment				
0	22.25a	31.00a	9.54a	16.83a	3.06a
0.15	0.00b	0.00b	0.00b	0.00b	0.00b
0.3	0.00b	0.00b	0.00b	0.00b	0.00b
0.45	0.00b	0.00b	0.00b	0.00b	0.00b
0.6	0.00b	0.00b	0.00b	0.00b	0.00b
0.75	0.00b	0.00b	0.00b	0.00b	0.00b
SE±	0	1.09	0.3	0.67	0.12
	16 weeks after treatment				
0	14.75a	20.00a	2.80b	4.40c	0.80b
0.15	16.50a	21.00a	6.82a	10.40a	1.60a
0.3	12.00ab	19.20a	4.04b	6.60b	1.20a
0.45	10.25b	18.20a	2.68b	4.00c	0.80b
0.6	7.75b	14.00a	1.82bc	2.40d	0.50b
0.75	1.12c	2.00b	0.35c	0.00e	0.00c
SE±	1.5	2.89	0.65	1.91	0.42

Means in a column followed by similar letters are not significantly different at 5% level of probability by DNMRT.

Table 9. Symbolic depictition of the effect of indaziflam and its residue on growth of tomato

Tomato	8 weeks after treatment						16 weeks after treatment					
	Indaziflam dose (mg/kg)											
	0	**0.15**	**0.3**	**0.45**	**0.6**	**0.75**	**0**	**0.15**	**0.3**	**0.45**	**0.6**	**0.75**
Plant height (cm)	22.25	-	-	-	-	-	14.75	*	*	-	-	-
Number of leaves	31	-	-	-	-	-	20	*	*	*	*	-
Leaf Area (cm^2)	9.54	-	-	-	-	-	2.8	*	*	*	*	-
Fresh plant weight (g)	16.83	-	-	-	-	-	4.4	+	+	*	-	-
Dry plant weight (g)	3.06	-	-	-	-	-	0.8	+	+	*	*	-

Symbols: + indicates a value significantly higher than the control, * indicates no significant difference from the control, and - indicates a value significantly lower than the control, based on Duncan's New Multiple Range Test (DNMRT) at the $p = 0.05$ significance level.

DISCUSSION

The phytotoxicity of indaziflam, which was observed as its negative impact on plant growth, seemed to vary as the time after application progressed. While phytotoxic effects were evident shortly after application, its prevalence over time depends on the crop and the concentration of indaziflam. Some crops and indaziflam concentrations showed reduced phytotoxicity at 16 weeks after treatment, while others continued to experience negative impacts. This variation underscores the complexity of the interaction between indaziflam, plant species, and the duration after application.

At 8 weeks after treatment, the application of indaziflam at sowing reduced significantly various growth parameters of amaranthus, including plant height, leaf number, leaf area, and fresh/dry weights. This initial phytotoxicity was evident shortly after application. Interestingly, at 16 weeks after treatment, the residues of indaziflam from concentrations greater than 0.15 mg/kg continued to negatively impact amaranthus growth by reducing plant height, leaf number, leaf area, and fresh/dry weights. This persistence of phytotoxic effects indicates that indaziflam residues remained biologically active in the soil and continued to hinder amaranthus growth over an extended period. The reduction in the amaranthus growth parameters, which showed an upward trend as the concentrations of indaziflam increased, corroborates the findings of Sebastian et al. (2017), who reported that indaziflam reduced the growth of susceptible crops in a dose-dependent manner.

The phytotoxicity of indaziflam on maize was evident 8 weeks after treatment, where different concentrations reduced plant height, leaf count, leaf area, and fresh/dry weights. This impact suggests that maize is sensitive to indaziflam when planting is done shortly after indaziflam application. The response was more complex at 16 weeks after treatment. For low concentrations of indaziflam, the growth parameters showed comparability to the control treatment, indicating a reduction in phytotoxicity. This observation could be attributed to the breakdown of the low concentration of indaziflam and its decreasing concentration over time. This result corroborates the findings of Guerra et al. (2014) where maize has intermediate tolerance to indaziflam. In this study, maize exhibited higher tolerance to indaziflam when compared to amaranthus and tomato. Similarly, Braga et al. (2020) reported superior tolerance of maize over sorghum, wheat, and oats towards indaziflam. However, residues from high indaziflam concentrations (0.6 and 0.75 mg/kg) still negatively impact maize growth, suggesting that the phytotoxic effects persist for high concentrations even at 16 weeks after application.

Melon plants showed significant reductions in growth parameters at 8 weeks after treatment, indicating strong phytotoxicity shortly after indaziflam application. At 16 weeks after treatment, the effects of indaziflam residues were mixed. Residues from lower concentrations (0.15 and 0.3 mg/kg) increased dry and fresh weights, suggesting a reduction in phytotoxicity. However, residues from higher concentrations (0.6 and 0.75 mg/kg) continue to negatively affect growth, underscoring persistent phytotoxicity for high residue concentrations.

On the other hand, the most severe phytotoxicity was observed in tomato plants. At 8 weeks after treatment, all concentrations of indaziflam led to no emergence of tomato plants, indicating strong and immediate phytotoxic effects.

The impact remained consistent at 16 weeks after treatment, as residues from all concentrations continued to impede tomato growth. This indicates that indaziflam, even at lower concentrations, has a prolonged and detrimental impact on tomato plants.

Among the effects observed due to indaziflam, a noteworthy phenomenon was the emergence of increased growth of maize and melon at low concentrations. This observed increase in growth aligns with hormetic effect, where low doses of stressors or toxins stimulate beneficial effects or growth, while high doses are inhibitory (Pincelli-Souza et al. 2020). This finding agrees with the report of da Costa et al. (2020) where indaziflam is capable of stimulating plant growth. This implies that indaziflam at low concentration is beneficial to some intercrops in plantations. The stimulatory effect seen at lower indaziflam concentrations on maize and melon challenges the traditional linear dose-response model, where exposure to a toxin is deemed harmful. These findings emphasize the need for a nuanced understanding of dose-response relationships and the potential benefits of low-level stressors.

Considering the diverse susceptibility levels of amaranthus, maize, melon, and tomato to different indaziflam concentrations, it is crucial to customize the application of indaziflam by considering the individual tolerances of each crop in intercropping system. This could entail modifying the concentrations utilized or adopting alternative cultivation strategies to mitigate any potential detrimental effects on the growth of these crops. The study implies the importance of managing the persistence of indaziflam in soil to facilitate intercropping of the test crops in plantations treated with this herbicide. This supports the report of Melo et al. (2016) where persistent herbicides often pose risks to susceptible crops in rotation and intercropping systems.

Furthermore, this study suggests that maintaining a sufficient pre-plant interval between the application of indaziflam and the sowing of crops can prevent adverse effects on crop growth. This inference is drawn from the observed negative impact of indaziflam when applied at sowing and the absence of such effects when an eight-week pre-plant application interval was observed. These findings corroborate the conclusions of Soltani et al. (2011), who reported that increasing the pre-plant herbicide application interval can mitigate crop injury.

In alignment with the findings of Mendes et al. (2021), who examined the effect of cow bonechar on the herbicidal activity of indaziflam in tropical soil, it is suggested that the incorporation of cow bonechar into soil at a rate of 2 t/ha could be explored as a strategy to manage the persistence of indaziflam. This approach should be investigated further to evaluate the responses of the test crops.

In conclusion, this study showed that the use of indaziflam in intercropping system involving amaranthus, maize, melon, and tomato could negatively impact the growth of these crops.

RESUME

Imomoh I.J., Ayodele O.P. et Ikuenobe C.E. 2024. Amélioration de la productivité des plantations: Une étude sous-serre sur l'impact de l'indaziflam sur l'amarante, le maïs, le melon et la tomate dans les systèmes de cultures intercalaires. Tunisian Journal of Plant Protection 19 (2): 87-100.

L'impact potentiel du nouvel herbicide de pré-levée indaziflam sur les cultures intercalaires courantes de plantation d'amaranthe, maïs, melon et tomate, a été évalué dans une étude sous-serre. Les traitements expérimentaux comprenaient l'application suivante d'indaziflam dans le sol au semis : 0, 0,15, 0,30, 0,45, 0,60 et 0,75 mg/kg. Ces traitements ont été mis en place selon un plan complètement randomisé avec quatre répétitions. L'effet de l'indaziflam a été évalué par échantillonnage destructif après 8 semaines de croissance, et son effet résiduel a été examiné après le re-semis après la même période, plus précisément 16 semaines après l'application d'indaziflam. Les données sur la hauteur de la plante, le nombre de feuilles, la surface foliaire, le poids frais de la plante et le poids sec de la plante ont été enregistrés dans chaque cas de traitement. Les données recueillies ont été soumises à une analyse de variance et les moyennes des traitements ont été séparées à l'aide du *Duncan's New Multiple Range Test* à un niveau de signification de 5 %. L'étude a révélé des réductions significatives ($p \leq 0{,}05$) de la croissance des cultures d'essai en raison de l'application d'indaziflame, les effets les plus prononcés correspondaient aux concentrations les plus élevées. Les semis d'amarante et de tomate n'ont pas émergé à des concentrations > 0,15 mg/kg et ≥ 0,15 mg/kg, respectivement. Le maïs et le melon ont présenté une croissance réduite à des concentrations > 0,3 mg/kg. Les effets résiduels étaient significatifs, réduisant notamment les paramètres de croissance des plantes à des concentrations d'indaziflame plus élevées, en particulier à 0,6 et 0,75 mg/kg. En conclusion, l'indaziflame à des concentrations supérieures à 0,15 mg/kg inhibe significativement la croissance des cultures intercalaires des plantations courantes, avec des effets résiduels persistants, ce qui suggère son adéquation limitée à son utilisation dans de tels contextes.

Mots clés: Herbicide de pre-levée, indaziflam, intercalaire, persistance d'herbicide, semis

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ملخص

إيموموه، إيسيسيلي دجون وأولاتوندي فيليب أيوديلي وسيليستين إيبيهايريكهي إيكونوبي. 2024. تحسين إنتاجية المَزارع: دراسة في البيوت المحمية حول تأثير المبيد العشبي إندازيفلام على القطيفة والذرة والبطيخ والطماطم في أنظمة الزراعة البينية. Tunisian Journal of Plant Protection 19 (2): 87-100.

تم تقييم التأثير المحتمل للمبيد العشبي الجديد قبل البزوغ إندازيفلام على المحاصيل البينية المزروعة بشكل شائع من القطيفة والذرة والبطيخ والطماطم في دراسة تحت البيوت المحمية. تضمنت المعاملات التجريبية إضافة مبيد إندازيفلام إلى التربة عند البذر بنسب 0، 0.15، 0.30، 0.45، 0.60 و 0.75 ملغم/كغم. تم تنفيذ هذه المعاملات وفق التصميم العشوائي الكامل بأربعة مكررات. تم تقييم تأثير مبيد إندازيفلام عن طريق أخذ العينات التدميرية بعد 8 أسابيع من النمو، وتم فحص تأثيره المتبقي بعد إعادة البذر بنفس الفترة، أي 16 أسبوع بعد تطبيق المبيد. تم تسجيل بيانات عن ارتفاع النباتات وعدد الأوراق ومساحة الأوراق والوزن الطازج للنباتات والوزن الجاف للنباتات في كل حالة معاملة. تم إخضاع البيانات المجمعة لتحليل التباين وتم فصل معدلات المعاملات باستخدام اختبار دنكان الجديد متعدد المدى عند مستوى دلالة 5%. بينت الدراسة انخفاضات كبيرة ($p \geq 0.05$) في نمو نباتات الاختبار بسبب تطبيق المبيد، مع التأثيرات الأكثر وضوحًا مقابلة لأعلى التركيزات. لم تبزغ بادرات القطيفة والطماطم بتركيزات > 0.15 مجم/كجم و ≤ 0.15 مجم/كجم، على التوالي. أظهرت الذرة والبطيخ انخفاضا في النمو عند التركيزات > 0.3 ملغم/كغم. وكانت تأثيرات متبقيات المبيد كبيرة، لا سيما انخفاض مؤشرات نمو النباتات عند التركيزات الأعلى من المبيد، خاصة عند 0.6 و0.75 ملجم/كجم. في الخلاصة، أدى مبيد إندازيفلام بتركيزات أعلى من 0.15 ملغم/كغم إلى تثبيط نمو المحاصيل الزراعية الشائعة بشكل كبير، مع استمرار تأثيرات متبقياته، مما يشير إلى ملاءمته المحدودة للاستخدام في مثل هذه الحالات.

كلمات مفتاحية: مبيد عشبي قبل البزوغ، إندازيفلام، زراعات بينية، ثبات المبيد العشبي، بذر

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