Persistence and mobility of imazaquin in a humid tropical soil

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Summary
The field persistence and mobility of imazaquin in the late and early cropping seasons of a humid tropical environment was studied using corn seedling growth bioassay.

The results showed that imazaquin at the recommended field rate of 150 g a.i. ha^{-1} persisted for only eight weeks after treatment (WAT) in the late season and 10 WAT in the early season, a period of persistence that approximates the growing period of most tropical arable crops. This implies that effective weed control may be expected throughout the critical period of weed competition for most arable tropical crops. Susceptible crops such as corn and sorghum can therefore be safely planted from 10 weeks after a pre-emergence spray application of imazaquin on this tropical soil. Doubling the field recommended rate from 150 g a.i. ha^{-1} to 300 g a.i. ha^{-1} increased the persistence of imazaquin by two weeks, implying that caution must be exercised on the rate of imazaquin applied for weed control in order to avoid a carry over problem. Imazaquin did not leach beyond 15 cm depth when 150 g a.i. ha^{-1} or 300 g a.i. ha^{-1} was applied in both seasons, hence contamination of underground water is not likely to occur following the application of imazaquin.

Introduction
The duration for which effective weed control is expected after herbicide application depends partly on the persistence of the herbicide. Information on the persistence of a herbicide is also important in order to know when a susceptible follow-up crop can be planted in a field which had earlier received some herbicide treatment. Imazaquin is registered for use in soybean but recent research has indicated that it can be used also in cowpea (Poku and Akobundu 1985). The persistence of imazaquin in soil would therefore be of importance to a grower applying imazaquin to soybean or cowpea with a plan to rotate the following year to corn.

There have been several reports on the persistence of herbicides on temperate soils (Walker and Bond 1977, Zimdahl and Gwynn 1977, Williams and Eagle 1979). Very little information is available on this subject in the humid and sub-humid tropics (Akinyemiju *et al.* 1986, Utulu *et al.* 1986). It is expected that the persistence of herbicides in temperate soil will differ from that of tropical soil, due to differences in climatic and soil factors, as well as differences in soil management and cultural practices. Imazaquin is a relatively new compound, therefore its persistence needs to be investigated. Information on the lateral and downward leaching of imazaquin is also important in order to know the potential for ground water contamination.

The objectives of this study are to determine the length of time that imazaquin remains active in the soil after application and to monitor the downward movement of imazaquin in a humid tropical soil.

Materials and methods
The experiment was conducted at the University Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife in the late (September – December) and early (April – July) cropping seasons of 1990 and 1991 respectively. The weather conditions at the farm (latitude 7°28‘N, longditude 4°33‘E and altitude 244 m) during the periods of the experiment is presented in Table 1. Generally, temperature was higher in the late season than in the early season, and in the early season there was a greater amount of rainfall and a higher percentage relative humidity than in the late season. The weather conditions of both seasons is typical of the pattern in the tropical rainforest belt of the humid tropics. The experimental field had not been cropped in the previous eight years. Prior to this study, the land was cleared, ploughed twice and harrowed with a tractor mounted disc plough or harrow. The soil (Alfisol) has the same physical and chemical properties as the soil used for an earlier bioassay study (Evbuomwan *et al.* 1993). The late season trial contained three replicates of 15 m × 11 m, each being separated by 2 m buffers. Each replicate was further divided into four plots of 11 m × 3 m corresponding to three herbicide treatments and a control. Bonds were then manually constructed around each herbicide treated plot and the control. In addition to the choice of relatively flat piece of land, the bonds further ensures that lateral movement of herbicide from one plot to the other is prevented. Three rates of

Table 1. Mean monthly weather data at the University Teaching and Research Farm during the period of the experiment (September – December 1990, January – July 1991).

Month	Solar radiation (watts/m^2/day)	Temperature (10.00 hrs)	Temperature soil at 10 cm depth	Relative Humidity (%) (10.00 hrs)	Relative Humidity (%) (16.00 hrs)	Sunshine (hours)	Total rainfall (mm)	Rainy days
September	3561	23.6	26.8	86	72.6	3.3	17.6	20
October	4207.4	29.5	28.6	81.5	72.1	5.7	10.3	8
November	4684	32.6	29.9	60.6	62.1	7.7	0	0
December	4904	34.7	27.4	74.4	47.6	6.5	2.7	2
January	4128	33	27.5	63.6	41.7	5.4	0	0
February	4576	34.1	28.8	79.1	44.4	6.4	12.95	4
March	4036	32	29.2	84.7	57.2	4.8	11.23	6
April	3656	30.2	29.1	74.6	59.6	6.5	20.4	9
May	2560	28.5	28.8	88.5	78.3	6.2	11.2	10
June	3870	26.8	27.8	86	72.2	4.5	22.4	12
July	*	28.5	28.5	83.4	71.5	4.6	13.6	21

* not determined

imazaquin viz.: 100, 150 and 300 g a.i ha^{-1} and a control (0.0 g a.i ha^{-1}) were randomized among the four plots of each replicate. The experiment was a split-split plot with treatments arranged in a randomized complete block. The main plot was imazaquin rate, the sub-plot was the depth of sampling, while the sub-sub-plot was time after application. The layout and design was identical for the early season trial which was located on a similar, but adjacent piece of land. In each trial imazaquin representing 100, 150 and 300 g a.i ha^{-1} respectively was mixed with water and sprayed on the 11 m × 3 m strip in each replicate using a portable pressurized sprayer previously calibrated to deliver 200 litres of spray solution per hectare at a pressure of 2–3 kg/cm^2. The spraying was done on 20 September 1990 and 15 April 1991 for the late and early season trials respectively. Soil samples were collected from a randomly selected 1 m × 1 m of each 1 m × 3 m herbicide treated strips and the control in the three replicates for a total of 36 samples on each sampling date. Each soil sample was scooped with a hand trowel to a depth of 7.5 cm in the first 1 m × 1 m plot, 7.5–15.0 cm in the second plot and 15.0–22.5 cm in the third plot. The soil samples for each depth were thoroughly mixed and separately put in cellophane bags for the screenhouse bioassay. In the screenhouse, each bag was emptied into plastic pots measuring 5 cm in diameter and 7 cm in depth.

In both seasons, the first soil sample was collected immediately after imazaquin application, then three days after treatment (DAT), seven DAT and 14 DAT after which subsequent samples were collected at two weekly intervals until no phytotoxic symptoms were observed at two consecutive sampling dates. In order to eliminate plant uptake as a factor in the dissipation of imazaquin in the field, no crop was planted on the experimental plots.

Screenhouse bioassay

The choice of corn as the bioassay plant and the procedure of the screenhouse bioassay was based on the bioassay developed for imazaquin by Evbuomwan *et al.* (1993). Corn (*Zea mays* L. var. Western Yellow) seeds were first sown at 100 per wooden tray (45 cm × 35 cm × 7.5 cm) filled with steam pasteurized saw-dust. Watering was done regularly every other day for six days, a period found by an earlier bioassay study to be sufficient to produce suitable corn seedlings for the bioassay. Consequently, corn seedlings were produced for each bioassay by seeding corn six days before a set of soil samples were collected. This approach ensured that there was a measurable amount of height growth before growth inhibition commenced due to the herbicide. Seedlings for each bioassay were selected for uniformity in stem diameter, height and number of leaves. Two corn seedlings were then carefully transplanted into each pot containing treated soil samples or the control. Shoot length of the bioassay seedlings were determined at the end of two weeks after transplanting when a consistency was observed across the herbicide rates. At the end of the two weeks, the plants were harvested by scooping each from the pots and the soil attached to the roots was removed by washing. The plants were then separated into shoot and root. The shoot dry weight was determined after oven-drying at 80°C for 48 hours. Subsequent sampling and transplanting were carried out until no injury symptoms were observed at two consecutive sampling periods.

The data collected was analysed statistically and the means compared using the least significant difference (Lsd) test at the 5% and 1% levels of probability (Steel and Torrie 1980). Data on shoot length and shoot dry weight were expressed as percentage of control. These values were used to estimate the residue of imazaquin from a standard curve developed from an earlier bioassay experiment conducted with the soil of the experimental site (Evbuomwan *et al.* 1993). Stepwise multiple regression was carried out on the residue level and the time of sampling for each sampling depth.

Table 2. Analysis of variance of imazaquin residue levels obtained by corn shoot length and shoot dry weight bioassays in the late and early seasons at different times after a soil application.

		Late season		Early season	
Sources of variation	DF	shoot length (F values)	shoot dry weight (F values)	shoot length (F values)	shoot dry weight (F values)
Replication	2	3.26NS	3.56NS	3.19NS	3.42NS
Rate of imazaquin (ROH)	3	4.13*	2.22NS	6.77**	2.13NS
Error A	6				
Depth of sampling (DEPTH)	2	2.95*	1.66*	3.74*	2.19*
DEPTH × ROH	6	6.18**	5.91*	3.79*	3.21*
Error B	16				
Time of sampling (TAP)	10	6.92**	5.20*	6.72**	4.70*
DEPTH × TAP	20	4.36*	2.22NS	5.02*	2.80*
ROH × TAP	30	2.34*	2.01*	2.52*	1.05NS
TAP × ROH × DEPTH	60	2.17*	2.72*	2.13	3.82*
Error C	240				
Total	395				

* significant at 5% level of probability
** significant at 1% level of probability
NS not significant at 5% level of probability

Results

The analysis of variance of imazaquin residue over the sampling period and depth is presented in Table 2. From this table, it could be observed that imazaquin residue estimated by corn shoot length was more consistently significant than the residue estimated by corn shoot dry weight, hence only the data from corn shoot length is presented.

Late Season

Imazaquin residue detected at different times and depth after application in the late season is presented in Table 3. Sampling immediately after application showed that in the 7.5 cm soil depth only 90, 93 and 95% were found where 100 g, 150 g and 300 g a.i ha^{-1} respectively had been applied. No residue was detected beyond 7.5 cm soil depth throughout the first week after application irrespective of the rate of application although imazaquin concentration in this top soil continued to decrease. At the end of the second week after application, concentration of imazaquin left in the top 7.5 cm was only 35, 40 and 38% where 100 g, 150 g and 300 g a.i ha^{-1} respectively had been applied. At this time also 36 and 31% were detected in the 7.5–15.0 cm soil depth where 150 g and 300 g a.i ha^{-1} respectively had been applied. No detection was observed beyond the 15 cm depth irrespective of the rate. Also, for the rest of the sampling period imazaquin concentration in both the top 7.5 cm and the 7.5–15.0 cm were similar and imazaquin did not leach beyond the 15 cm soil depth although the amount distributed in the top 7.5 and the 7.5–15.0 cm continued to decline (Table 3). By 70 days after application no imazaquin residues were found in the 0–7.5 and 7.5–15.0 cm samples although some traces at the 0–7.5 cm depth were found where 300 g a.i ha^{-1} was applied.

A regression curve of the disappearance and downward movement of imazaquin in the late season is presented

Table 3. Field dissipation and mobility of imazaquin in the late cropping season as evaluated by corn shoot length expressed as percentage of control.

Time after application (days)	Depth of sampling (cm)	Rate applied (g a.i. ha^{-1})	Shoot length reduction (%)	Residue level (g a.i. ha^{-1})	Residue level (% of initial rate)	Disappearance (%)
0	0–7.5	100	34	90	90	10
		150	54	140	93	7
		300	63	285	95	5
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	0	0	0	0
3	0–7.5	100	29	75	75	25
		150	47	125	83	17
		300	60	215	71	29
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	0	0	0	0
7	0–7.5	100	27	70	70	30
		150	36	95	63	37
		300	56	150	50	50
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	0	0	0	0
14	0–7.5	100	16	35	35	65
		150	24	60	40	60
		300	44	115	38	62
	7.5–15	100	0	0	0	0
		150	23	55	36	64
		300	36	95	31	69
28	0–7.5	100	14	30	30	70
		150	22	55	36	64
		300	36	95	31	69
	7.5–15	100	0	0	0	0
		150	18	40	26	74
		300	28	70	23	77
42	0–7.5	100	0	0	0	0
		150	20	30	30	70
		300	30	80	26	74
	7.5–15	100	0	0	0	0
		150	16	35	23	77
		300	25	65	21	79
56	0–7.5	100	0	0	0	0
		150	16	35	23	77
		300	25	65	21	79
	7.5–15	100	0	0	0	0
		150	14	30	20	80
		300	20	45	15	85
70	0–7.5	100	0	0	0	0
		150	0	0	0	0
		300	14	13	10	90
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	0	0	0	0

Lsd (0.05) = 50 for means of residue level over the sampling dates.
Lsd (0.05) = 30 for means of residue level over the rates of imazaquin.
Lsd (0.05) = 49 for means of residue level over the sampling depth.

in Figure 1. The prediction equation for the disappearance of the different rates at the 0–7.5 cm and 7.5–15.0 cm are significantly different and their R^2 are very high, above 95% generally. The prediction curves confirm the biphasic nature of the disappearance of imazaquin from the soil, an initial rapid dissipation within the first 14 days, followed by a gradual but steady disappearance from the 14th through to the 70th or 84th day after application depending on the rate (Figure 1).

Early Season

Imazaquin residue in soil at different times after a pre-emergence application in the early season is presented in Table 4. As in the late season 85, 83 and 92% of 100 g, 150 g and 300 g a.i ha^{-1} respectively were detected within 24 hours of imazaquin application. Dissipation and downward movement of imazaquin began from the first week of application. For example, at the seventh day after application 40 and 32% of the initial application of 150 g and 300 g a.i ha^{-1} respectively were now found in the 7.5 – 15 cm soil depth. Also, at the end of the first week after application imazaquin residue has decreased generally to about 70% or less of initial application in the top 7.5 cm soil. Imazaquin dissipation in the two soil depths continued until the 12th week after application when only traces of initial 300 g a.i ha^{-1} application were found in the top 7.5 cm soil depth. The 100 g a.i ha^{-1} application did not leach beyond the 7.5 cm top soil, nor was any imazaquin residue observed in the 15.0–22.5 cm soil profile throughout the early season trial.

Figure 2 shows the disappearance curve of imazaquin in the early season. As in the late season trial, the prediction equations were significant and their R^2 values were very high. Similarly, the prediction curves confirmed the bi-phasic pattern of imazaquin disappearance in the soil. Between 0 and 14 days after application there was a rapid disappearance of imazaquin followed by a steady but gradual disappearance, at the different rates and soil depth, from the 14th until the 98th day after application. In contrast to the actual data in Table 4, the regression curve showed that traces of imazaquin were detectable up to 98 days after application of 300 g a.i ha^{-1}. In general the prediction curves in both seasons showed a two-week longer persistence than actually detected.

Discussion

The more significant imazaquin residue estimated by corn shoot length as compared to the shoot dry weight may have been due to the fact that shoot length is more sensitive to imazaquin residue than the shoot dry weight. Corn shoot length was found in an earlier bioassay to be more correlated to imazaquin residue than the shoot dry weight. Basham *et al.* (1987) corroborates the better correlation of corn shoot length to imazaquin residue.

In both the early and late seasons, there was a proportion of imazaquin that could not be detected in the soil after application irrespective of the rate. For example, in the late season 7% could not be detected in the top 7.5 cm soil depth where the recommended rate of 150 g a.i ha^{-1} imazaquin was applied. This short-fall in the amount of imazaquin detected may be the limit of detection of the bioassay procedure used in this study. The 7–17% may also have been lost through leaching, chemical drift, photolysis, hydrolysis, volatilization or due to some adsorption of imazaquin molecules to soil colloids and was therefore not available for the bioassay plant. The influence of these

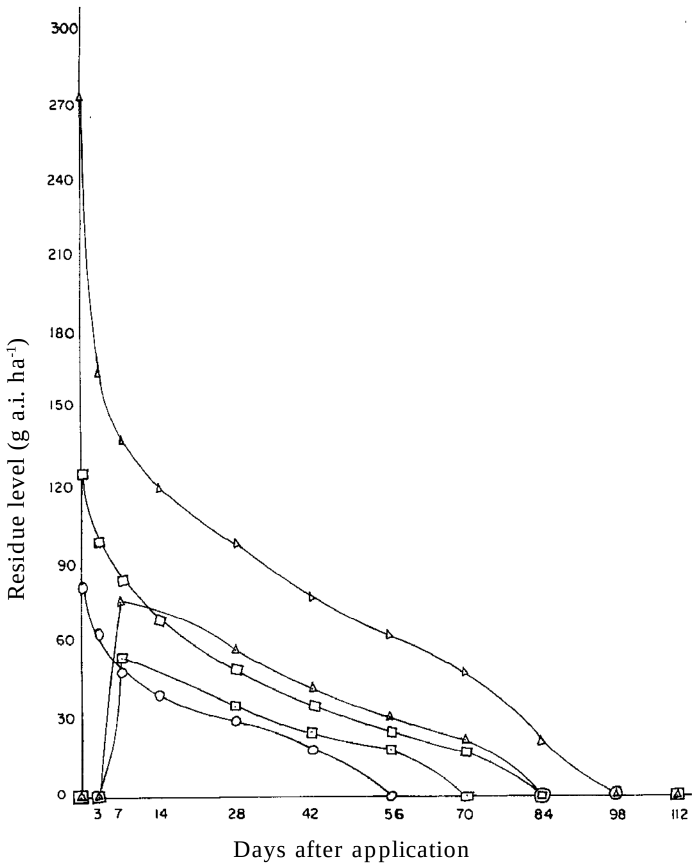

Figure 1. Disappearance and downward movement of imazaquin in a tropical alfisol in the late cropping season.

	Δ = 300 g a.i. ha^{-1}	**$\hat{Y}$=286.5-4.9x+1.3x^2 R^2=0.97****
0–7.5 cm	**□ = 150 g a.i. ha^{-1}**	**$\hat{Y}$=124.2+35.97x-11.8x^2 R^2=0.98****
	○ = 100 g a.i. ha^{-1}	**$\hat{Y}$=105.96-8.79x+1.02x^2 R^2=0.98****
7.5–15 cm	**Δ = 300 g a.i. ha^{-1}**	**$\hat{Y}$=-15.2+18.94x-6.12x^2 R^2=0.98***
	⊡ = 150 g a.i. ha^{-1}	**$\hat{Y}$=3.873+15.74x-1.80x^2 R^2=0.95***

(significant at 1% level of probability)**
(* significant at 5% level of probability)

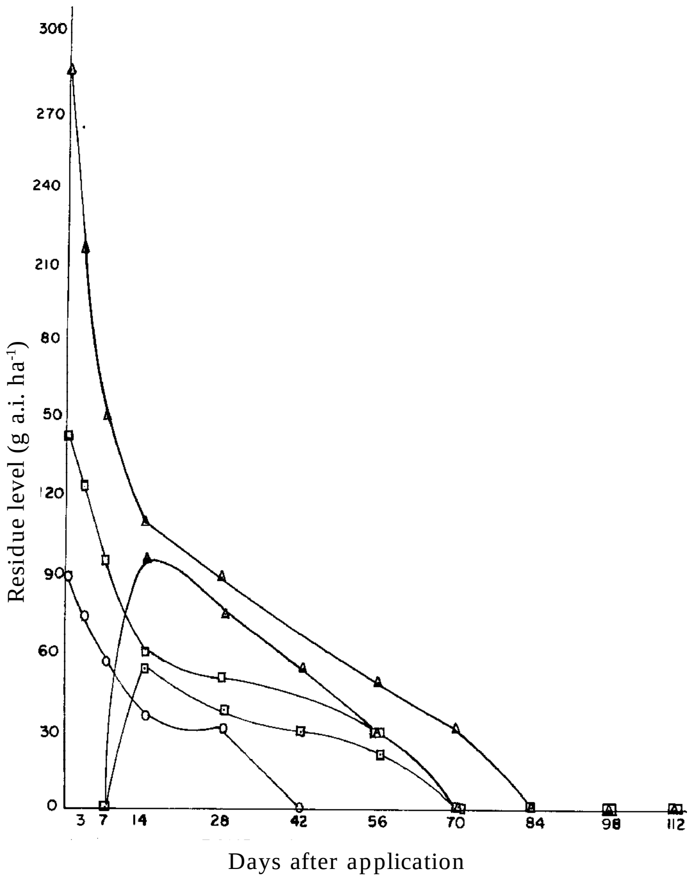

Figure 2. Disappearance and downward movement of imazaquin in a tropical alfisol in the early cropping season.

	Δ = 300 g a.i. ha^{-1}	**$\hat{Y}$=292.9-27.1x+0.4x^2 R^2=0.98****
0–7.5 cm	**□ = 150 g a.i. ha^{-1}**	**$\hat{Y}$=147.5-20.7x+0.02x^2 R^2=0.94****
	○ = 100 g a.i. ha^{-1}	**$\hat{Y}$=109.6-20.4x+0.9x^2 R^2=0.97****
7.5–15 cm	**Δ = 300 g a.i. ha^{-1}**	**$\hat{Y}$=-13.3+28.2x-2.7x^2 R^2=0.86***
	⊡ = 150 g a.i. ha^{-1}	**$\hat{Y}$=-3.3+15.2x-1.5x^2 R^2=0.77***

(significant at 1% level of probability)**
(* significant at 5% level of probability)

factors on imazaquin dissipation in the field has been noted by Basham *et al.* (1987) and Renner *et al.* (1988).

Imazaquin at the recommended rate of 150 g a.i ha^{-1} persisted for eight weeks after treatment (WAT) in the late season and 10 WAT in the early season in the top 7.5 cm of the soil, a period that approximates the growing period of most arable tropical crops. This indicates that effective weed control following imazaquin application may be expected throughout the critical period of weed competition for most arable tropical crops. It also indicates that sensitive crops can safely be planted after 10 weeks following imazaquin application. Utulu *et al.* (1986) and Akinyemiju *et al.* (1986) have reported similar short persistence of several herbicides in the humid tropical soil.

The persistence of imazaquin in the top 7.5 cm of the soil in the early season was two weeks longer than that of the late season irrespective of the rate. This increase in persistence may have been due to differences in the climatic factors between the early and late season, indicating that the length of time that imazaquin remains active in the soil depends in part on the season in which it is applied. Rainfall and temperature, which separate these seasons, are the most important factors and will therefore be expected to have direct influence on imazaquin dissipation in the humid tropical soil.

Similarly, the observed higher residue of imazaquin at the 7.5–15.0 cm soil depth in the early season as compared to the late season was probably due to the influence of rainfall, which was greater in the early than late season, and this would have increased the downward movement of imazaquin. The influence of soil moisture on herbicide movement has been reported by Marriage *et al.* (1977), Mulder and Nalewaja (1979), Goetz *et al.* (1986) and Basham *et al.* (1987) who found that increasing the moisture content of the soil increased the mobility of several herbicides, including imazaquin, in the soil. The restricted mobility of imazaquin within the 15 cm soil zone may have been due to its polarity and increased adsorption with depth. Renner *et al.* (1988) reported that imazaquin adsorption onto soil colloids increase with depth. Mobility of most herbicides does not exceed 10–15 cm in the soil profile, due to cationic or anionic binding onto soil colloids (Adams 1973, Khan *et al.* 1976). The restricted movement of imazaquin in the soil indicates that contamination of underground water is unlikely to occur following imazaquin application on alfisol.

Doubling the recommended rate of imazaquin prolonged the persistence in both the late and early seasons. This suggests that great caution should be taken in the application of imazaquin in order to avoid a carry over problem. This observation is consistent with Basham *et al.* (1987) and Renner *et al.* (1988), who observed that increasing the rate of imazaquin in temperate soils above 140 g a.i ha^{-1} tends to increase its duration of activity.

Table 4. Field dissipation and mobility of imazaquin in the early cropping season as evaluated by corn shoot length expressed as percentage of control.

Time after application (days)	Depth of sampling (cm)	Rate applied (g a.i. ha^{-1})	Shoot length reduction (%)	Residue level (g a.i. ha^{-1})	Residue level (% of initial rate)	Disappearance (%)
0	0–7.5	100	32	85	85	15
		150	50	125	83	17
		300	63	275	92	8
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	0	0	0	0
3	0–7.5	100	28	70	70	30
		150	42	115	77	23
		300	58	165	55	45
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	0	0	0	0
7	0–7.5	100	25	60	60	40
		150	39	105	70	30
		300	55	140	47	53
	7.5–15	100	0	0	0	0
		150	25	60	40	60
		300	35	95	32	68
14	0–7.5	100	21	45	45	55
		150	35	90	60	40
		300	52	130	43	57
	7.5–15	100	0	0	0	0
		150	23	50	33	67
		300	30	75	25	75
28	0–7.5	100	19	35	35	65
		150	32	85	57	43
		300	50	125	42	58
	7.5–15	100	0	0	0	0
		150	20	40	27	73
		300	27	65	22	78
42	0–7.5	100	15	25	25	75
		150	30	75	50	50
		300	45	115	38	62
	7.5–15	100	0	0	0	0
		150	18	30	20	80
		300	25	60	20	80
56	0–7.5	100	12	0	0	0
		150	22	45	30	70
		300	40	110	37	63
	7.5–15	100	0	0	0	0
		150	15	25	17	83
		300	20	40	13	87
70	0–7.5	100	10	0	0	0
		150	15	25	17	83
		300	35	95	32	68
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	15	25	8	92
84	0–7.5	100	0	0	0	0
		150	0	0	0	0
		300	15	25	8	92
	7.5–15	100	0	0	0	0
		150	0	0	0	0
		300	0	0	0	0

Lsd (0.05) = 50 for means of residue level over the sampling dates.
Lsd (0.05) = 30 for means of residue level over the rates of imazaquin.
Lsd (0.05) = 49 for means of residue level over the sampling depth.

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