Potential Biofuel Crop *Sorghum bicolor* Germination and Growth on Florida Agricultural Soils Previously Treated with the Herbicides Simazine, Norflurazon or Bromacil

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Introduction

The citrus industry has been facing strong economic and cultural challenges over the past few years. As a result, many land owners are searching for alternative crops to citrus, or alternative uses of their land. One potential alternative crop is *Sorghum bicolor*, which can be used as a biofuel. The decision to use citrus production land as a biofuel production site requires evaluation of the potential effects of pesticides (particularly herbicides) commonly used in citrus production. In the absence of available toxicity information, bioassays are required to evaluate the potential phytotoxicity due to residual herbicides in the soil. The three herbicides included in this study are simazine, norflurazon, and bromacil. Product labels for all three of these herbicides recommend performing a field bioassay prior to planting any desired crops in soils previously treated with each.

Simazine is a non-selective preemergent or post emergent herbicide used to control annual grasses and broadleaf weeds. The mode of action for simazine is inhibition of photosystem II electron transport in chlorophyll, inhibiting photosynthesis (Gunasekara et al, 2007). Simazine is mobile, with a relatively low sorption coefficient for soil organic matter and clay particles (Gunasekara et al, 2007). Simazine leaches in organic rich sandy soils (Reddy, et al. 1992). The product label for simazine warns of potential rotational crop injury

Norflurazon is a selective preemergence herbicide used to control annual grasses and broad leaf weeds. Due to the recalcitrant nature of norflurazon there is an expected impact for rotational crops. The primary symptom of phytotoxicity for norflurazon is chlorosis, or whitening of the leaves. Norflurazon inhibits carotenoid biosynthesis. Without carotenoids, chlorophyll pigment is susceptible to photodegradation (Bartels and Watson, 1978). Norflurazon becomes more mobile and more active in soils as clay and organic matter content decrease (Singh et al, 1985).

Bromacil is a broad spectrum preemergent herbicide used for selective control of perennial grasses in citrus croplands. Bromacil is also known to be a recalcitrant herbicide. The mode of action for bromacil is inhibition of electron transport (Pallett and Dodge, 1980). Given its' high water solubility and low sorption coefficient, bromacil is

expected to be mobile. It is moderately sorbed by organic matter and weakly by clay and metal oxides (Reddy, et al. 1992).

The focus of this study was to identify the effect of each herbicide on sweet sorghum (*Sorghum bicolor*), which is a drought tolerant species known for lignocelluloses, sugar and starch production. Sweet sorghum is expected to be a bioenergy crop (Rooney et al, 2007). There are many varieties of sorghum with sufficient cellulose and starch content to make these varieties an attractive bioenergy crop. High-biomass sorghum varieties have an ethanol yield similar to corn stover. Sorghum is among the list of crops to be studied further for feasibility of biofuel production (NREL, 2011).

Sorghum is a rotational crop outside of Florida, and potential crop injury from norflurazon has been well documented. Studies performed in Georgia found significant injury to grain sorghum in all locations that were treated with norflurazon for the previous two seasons using application rates recommended by the herbicide labels. One year following annual applications of 3.4 kg/ ha, significant crop injury was seen in all five soils in the study (12%-81% injury). One year following annual applications of 1.7 kg/ha, injury to sorghum grown on two of five soils tested (25% and 30% injury) was observed; with injured crops growing on soils with lower soil organic matter content (Schroeder and Banks, 1986). Studies performed in Texas found that norflurazon persistence in soils is increased with increased application rates, tilling and repeated applications. Applications 2x the labeled rate for pre-plant incorporated herbicide resulted in 77% plant injury 2 years after the application. When applied at 1x the labeled rate for 3 consecutive annual applications, 100% injury occurred after 1 year and 68% injury occurred after 2 years (Keeling et al, 1989). When sorghum was rotated with cotton in Arkansas, norflurazon concentration in soil above 450-500 ng/g resulted in sorghum injury and yield reductions (Barnes and Lavy, 1991).

No reports characterizing toxic concentrations of bromacil or simazine are available for sorghum. However, toxic effects are expected due to the product labels warning of potential crop injury due to residual herbicide, especially in soils with low organic matter content.

If sorghum is adopted as a rotational crop in south Florida, it would likely be planted on former sugar cane cropland or citrus cropland. The soil orders for these croplands are histosol and spodosol, respectively (see Figure 1). The soils chosen are important to Florida agriculture. Spodosols are dominant Florida soils formed in the flat woods under coniferous species. This soil type is known to be acidic, and is defined by a horizon with high organic matter content that was stripped from upper soil layers (Brady and Weil, 2008). The Spodosol is a common soil used in citrus production. There

is a need to identify alternative profitable crops (such as bioenergy crops) for citrus producers impacted by presently incurable citrus diseases. The histosol is another very important soil for Florida agriculture. Histosols are highly productive land, extensively used for sugar cane and row crop production. Due to the high organic matter content, this soil type is also an important option for biofuel crop production.

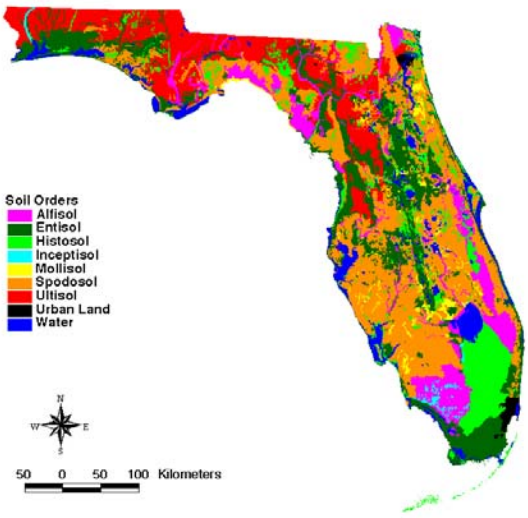


Figure 1: Florida Soil Order Map

The first objective of this research project was to identify concentrations of three persistent herbicides that are toxic to sorghum, thus allowing assessment of risks and potential success in fields with a history of use of these herbicides. The three herbicides evaluated include bromacil, norflurazon, and simazine. The second objective was to determine if a seed germination bioassay using sorghum grown on filter paper in the lab can be correlated to a bioassay of sorghum seed germinated and grown in the greenhouse on each soil.

Materials & Methods:

A herbicide range-finding bioassay was performed in August 2013 at the University of Florida/IFAS Indian River Research and Education Center (Fort Pierce). Range-finding assays are used to identify where effects occur, and are usually followed by a definitive study evaluating concentrations between the highest no observable effects concentration (NOEC) and the lowest observable effects concentration (LOEC). Soils for these studies were obtained from the IFAS facilities located in Belle Glade and Ft. Pierce, and represent two prominent Florida soil types found in agricultural areas - histosol (Belle Glade) and spodosol (Ft. Pierce).

Herbicide concentrations evaluated for each soil followed a log series of 0.01, 0.1, 1, 10, and 100 mg/kg. The concentration of active ingredient (AI) in the pure product varies. This study included the commercially available herbicides: Simazine 4L (42.1% simazine, 6-chloro-N-N diethyl-1,3,5-triazine-2,4-diamine; Drexel Chemical Company, Memphis TN), Solicam DF (78.6% norflurazon, 4-chloro-5-(methylamino-2-[3(trifluoromethyl)-phenyl]—3-(2H)-pyridazione, Syngenta, Greensboro, NC), and Hyvar X (80% bromacil, 5-bromo-6-methyl-3-(1-methylproply)-2,4-(1H,3H)pyrimidinedione; DuPont, Wilmington, DE). Initial stock solutions of 1000 mg active ingredient and deionized water were made. The 1000 mg/l stock solution was further diluted to make individual 100 ml stock solutions for the log series, ranging from 0.01 mg/l – 100 mg/l. These six stock solutions were used to spike the petri dishes for the lab study and the soils for the greenhouse study.

Sorghum seed was obtained through the University of Florida's Department of Agronomy. The study used technical grade Sweet Sorghum, variety (Topper 76'6), having a reported germination rate of 87%.

Germination and growth- Lab Studies

Three replicates of each pesticide concentration were evaluated. Two layers of lab filter paper (90 mm circles, Watman grade #1) were placed in sterile polystyrene petri dishes (90 mm diameter); to which 10 ml of each herbicide spiking solution was added. Five replicate controls were included, receiving only 10 ml of deionized water. Ten sorghum seeds were placed on the filter paper within each Petri dish; which was then closed and sealed with paraffin tape. The Petri dishes were labeled and randomly distributed on the lab countertop. Seed germination was evaluated daily for 1 week. At the end of one week sorghum growth data was collected. The parameters measured included shoot length, root length, total biomass and fraction of plants showing discoloration.

Germination and growth-Greenhouse studies

These studies were conducted using the histosol and spodosol. Soils were moistened then sieved through a #10 sieve to homogenize before spiking with the herbicides. For each herbicide treatment concentration, aliquots of the stock solution were spiked into 810 kg batches of the spodosol and 480 kg batches of the histosol. The soil and pesticide solution was homogenized. The soil bioassay was performed in 7 cm square seed pots, which were filled within 2 cm of the top. Each pot was filled with 270 g of the spodosol and 160 g of the histosol after spiking the herbicides. Three replicate pots were included for each herbicide concentration. Ten seeds were counted on sterile Petri dishes for each pot. The seeds were uniformly distributed on the soil surface in each pot, then pushed 1 cm below the surface. The pots were labeled and placed randomly in a

temperature controlled (36.1°C max) greenhouse in August 2013. Ten ml of tap water was added to each pot every two days.

Germination observations were made daily until the seedlings reached the third leaf stage. Plant growth data was collected after 2 weeks, when the third leaf development was observed. The plants were evaluated for individual shoot length, individual shoot biomass, fraction of plants discolored, and function of photosystem II electron transport processes measured as Fv/Fm (chlorophyll fluorescence) on five randomly selected leaves. Chlorophyll fluorescence measurements provide a quantitative assessment of the efficiency at which photosystem II (PSII) converts light energy into chemical energy by photochemistry. PSII is responsible for electron movement to NADP to be used to move the proton pump and ultimately drive ATP production (Baker, 2004). As mentioned before, the mode of action for two of the herbicides is PSII electron transport inhibition. Herbicide effect on PSII electron transport is detected by analyzing light re-emitted after being absorbed by chlorophyll molecules. Interruption to PSII electron transport and subsequent plant stress is an indication of herbicidal effects, especially if the mode of action is PSII electron transport inhibition (Baker, 2008). The measure of chlorophyll fluorescence is a function of the maximum fluorescence (Fm) and minimum fluorescence (Fo), and is reported as the ratio of (Fm-Fo)/Fm or Fv/Fm (Desk Top Plant Stress Guide, 2013). For most plants, leaves analyzed for Fv/Fm will have values between 0.79 and 0.83, if the plant is healthy; values below this indicate plant stress (Desk Top Plant Stress Guide, 2013).

Statistical analysis

This study used a randomized complete block statistical design with 3 replications of each herbicide concentration in a log series (0.01, 0.1, 1, 10, and 100). The blocks for greenhouse germinated sorghum included soil type (spodosol and histosol) and herbicide (simazine, norflurazon, and bromacil). The lab germinated sorghum seed studies were blocked by herbicide.

Observed germination count and growth measurements were analyzed using JMP version 10 (SAS, Cary, NC). An analysis of variance (ANOVA) was performed to determine significant differences in germination or growth among pesticide concentrations, soil types or herbicide types. The ANOVA null hypothesis states that there will be no difference in germination or growth between pesticide concentrations, herbicide types or soil types. Data found to be significantly different by ANOVA, was further analyzed using the Student's t test for means comparison between herbicide treatments and the non-treated control. Significant differences can be determined by JMP means comparison for unbalanced data for the non-treated sorghum (control) and

herbicide treated sorghum. The means comparison in JMP is a graphical technique to identify significant separation of means by intersection of comparison circles. The center of the circle is the group mean and the radius of the circle is the 95% confidence interval of the group mean. Non-overlapping confidence intervals are significantly different. For overlapping comparison circles, the angle of intersection of the circles is >90 degrees if there is a significant difference. JMP also generates an ordered differences report, which provides a means comparison using the Student's t test and the corresponding *p*-value.

Results and Discussion:

Seedling germination- Lab Studies

Analysis of seed germination data showed no significant differences between the control and the herbicide treatment concentrations. The ANOVA for the 48 hour lab germination count with simazine, norflurazon, and bromacil resulted in p-values of 0.99, 0.67 and 0.46 respectively. The ANOVA for the 1 week germination count had p values of 0.99, 0.63, and 0.70 respectively. Likewise, no significant differences between the control and any of the herbicide treatments were seen for seedling growth in the filter paper bioassay. ANOVA was performed for seedling growth measurements taken from seedlings grown on the filter paper assays with simazine, norflurazon and bromacil. No significant differences were found for individual shoot height (p=0.37, 0.24, and 0.81), individual root length (p=0.08, 0.08, 0.16), or total biomass (p=0.12, 0.31, 0.84).

The most likely explanation for the lack of any effects using these assays is a mismatch between the mode-of-action and the light conditions. The mode of action for these three herbicides is related to light. However, the tests were conducted under ambient light conditions in the lab. Ambient light conditions contain very little photosynthetically active radiation, thus limiting the impacts on the germinating seedlings. These herbicides are not expected to inhibit germination, but to assert their impacts on actively photosynthesizing plants.

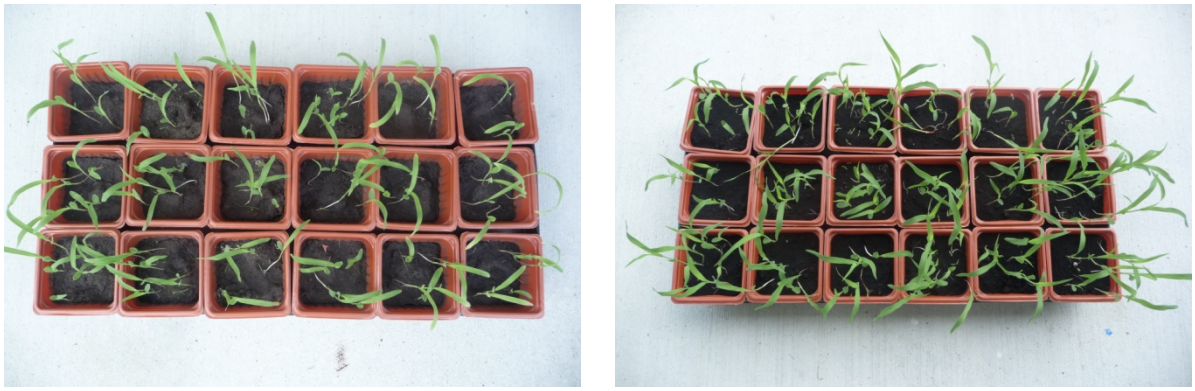
Seedling germination-Greenhouse studies

Analysis of seed germination in each of the soil types showed no significant difference between the control and herbicide-treated soils. The ANOVA for the 48 hour soil germination on spodosol with simazine, norflurazon, and bromacil resulted in *p*-values of 0.67, 0.77, and 0.85 respectively. The ANOVA for germination following 1 week in herbicide treated spodosol also showed no significant difference (*p*=0.25, 0.08, 0.61). No significant difference was found for germination in herbicide treated histosol, 48 hour

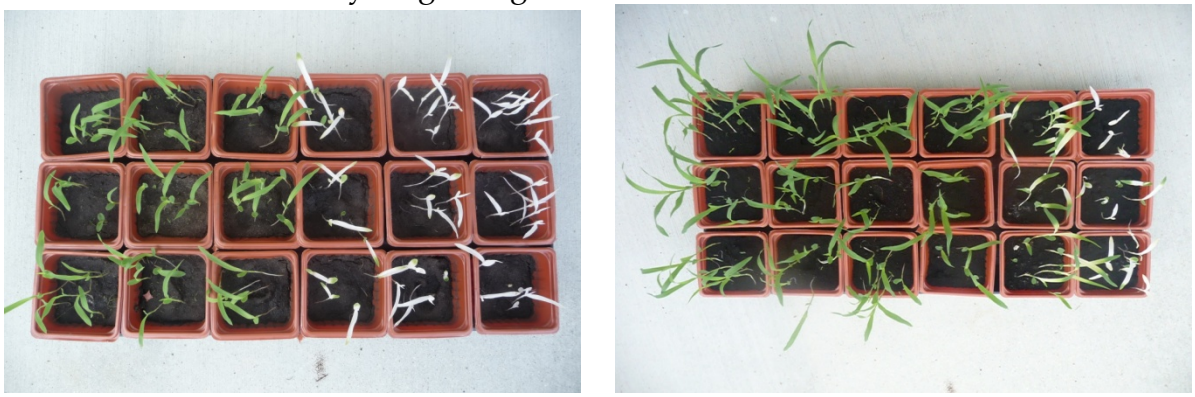
germination (p=0.19, 0.77, 0.93) and 1 week (p=0.70, 0.59, 0.08). As found in the seedling germination lab study, the mode of action does not affect seedling germination.

Seedling growth on soils - Greenhouse studies

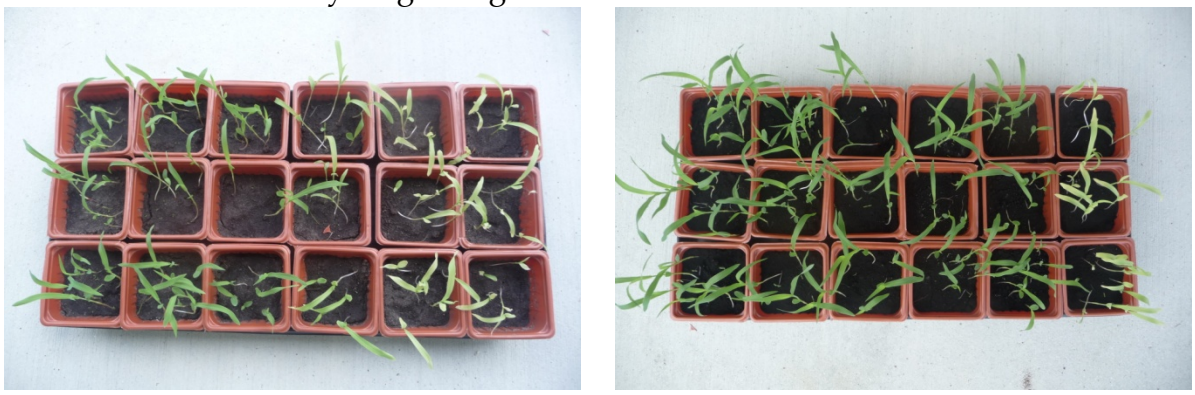
Sorghum Grown on Spodosol **Sorghum Grown on Histosol**



Seven day sorghum growth on simazine treated soils



Seven day sorghum growth on norflurazon treated soils



Seven day sorghum growth on bromacil treated soils

Seedling growth on spodosol

Significant differences between controls and some treatment concentrations were seen for seedling growth in the spodosol (Table 1).

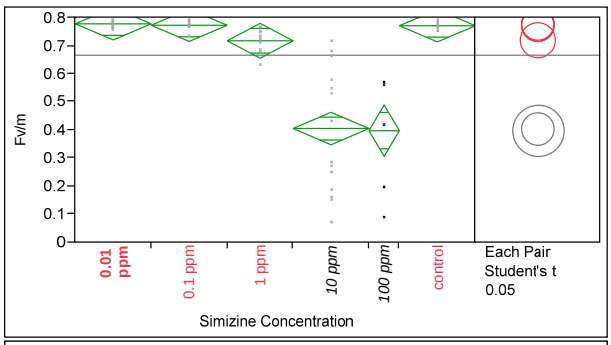
Table 1: Bioassay of Sorghum Grown on Spodosol Spiked with Log Series Concentration of Herbicide

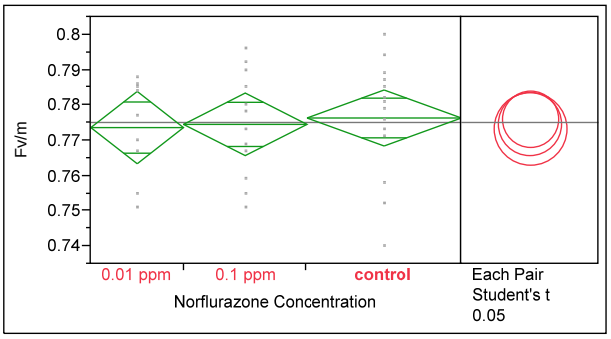
	Height (mm)						Weight (mg)					Fv/m				
	Pesticide Conc.	Mean	SD	Difference from control	Standard Error	p-value	Mean	SD	Difference from control	Standard Error	p-value	Mean	SD	Difference from control	Standard Error	p-value
Simazine	Control	118.85	22.97				83.47	24.07				0.7716	0.0096			
	0.01 mg/kg	106.13	30.91	12.73	8.67	0.1511	66.75	23.98	16.72	8.59	0.0545	0.7782	0.0111	0.0066	0.0409	0.8722
	0.1 mg/kg	112.16	37.66	6.69	9.31	0.474	77.63	36.09	5.85	9.07	0.5207	0.7731	0.0143	0.0015	0.0409	0.9702
	1 mg/kg	103.67	32.43	15.18	9.08	0.0975	60.58	28.59	22.89	8.69	0.0099	0.7178	0.0367	0.0538	0.0424	0.2092
	10 mg/kg	103.06	19.3	15.79	9.75	0.1083	59	19.5	24.47	9.59	0.0124	0.4059	0.2197	0.3657	0.0409	<.0001
	100 mg/kg	92.27	23.84	26.58	9.92	0.0086	40.92	16.65	42.55	9.59	<.0001	0.3985	0.2085	0.3731	0.0541	<.0001
Norflurazon	Control	115.56	26.87				79.21	26.12				0.7764	0.016			
	0.01 mg/kg	108.55	22.79	7.01	6.11	0.2542	63.71	22.5	15.51	8.64	0.0794	0.7737	0.0138	0.0027	0.0064	0.6705
	0.1 mg/kg	108.4	23.2	7.16	6.25	0.2549	77.18	23.48	2.04	8.64	0.81	0.7746	0.0148	0.0018	0.0058	0.758
	1 mg/kg	79.15	10.5	36.4	6.7	<.0001	*25.11	9.7	54.11	6.95	<.0001	*				
	10 mg/kg	68.86	6.31	46.7	6.85	<.0001	*11.93	10.26	67.93	6.43	<.0001	*				
	100 mg/kg	68.73	4.18	46.82	6.72	<.0001	*11.68	4.24	67.83	6.6	<.0001	*				
Bromacil	Control	117.95	49.16				86.72	51.31				0.774	0.0086			
	0.01 mg/kg	135.05	28.59	17.09	11.34	0.1346	107.95	30.66	21.23	15.58	0.1794	0.7732	0.0081	0.0006	0.0291	0.9836
	0.1 mg/kg	135.2	58.01	17.25	12.56	0.1727	98.08	61.39	11.35	17.24	0.5133	0.7717	0.0072	0.0023	0.0296	0.9388
	1 mg/kg	87.17	30.2	30.79	11.94	0.0113	*18.78	28.37	70.88	12.73	<.0001	0.4247	0.2404	0.3493	0.0385	<.0001
	10 mg/kg	83.33	21.35	34.62	34.62	0.0045	*9.68	6.32	77.04	11.91	<.0001	*				
	100 mg/kg	73.12	23.9	44.84	44.84	0.0003	*15.84	10.54	67.97	11.91	<.0001	*				

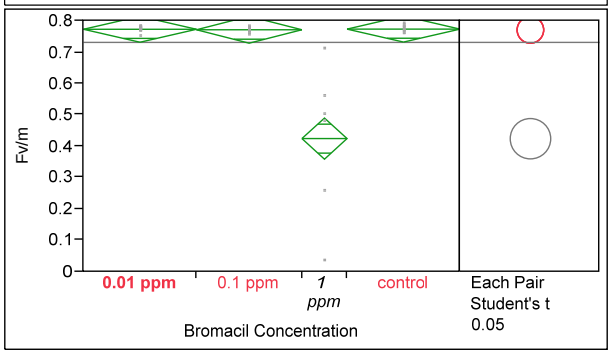
Notes:
NOEC - No observable effect level (Italicized)
LOEC - Lowest observable effect level (Bold)
* Desiccated plants, weight not normally distributed and Fv/m measurements not possible

The analysis with the easiest data to discern was the chlorophyll fluorescence with ANOVA having p-values of <0.0001 for simazine and bromacil. ANOVA for norflurazon could only be conducted with concentrations 0.1 mg/kg, 0.01mg/kg, and control due bleaching (i.e. destruction of chlorophyll) of leaves of plants exposed to concentrations above 1 mg/kg. The ANOVA for norflurazon concentrations 0.1, 0.01, and control had a p-value of 0.90 indicating no significant differences. The Fv/m for simazine concentrations ≤ 1 mg/kg had a range of 0.7782 to 0.7178; stressed plants were significantly different ranging from 0.4247 to 0.3985. The Fv/m for bromacil concentrations ≤ 0.1 mg/kg were in the range of 0.774 to 0.7717, while Fv/m for 1 mg/kg bromacil was 0.4247. There was a significant difference between the control and stressed plants. The small standard deviation and drastic difference in healthy and stressed plant Fv/m ratios made it easy to distinguish the LOEC based on chlorophyll fluorescence.

Measurements of chlorophyll fluorescence (Fv/Fm) for sorghum grown on herbicide-spiked spodosol – 7 days



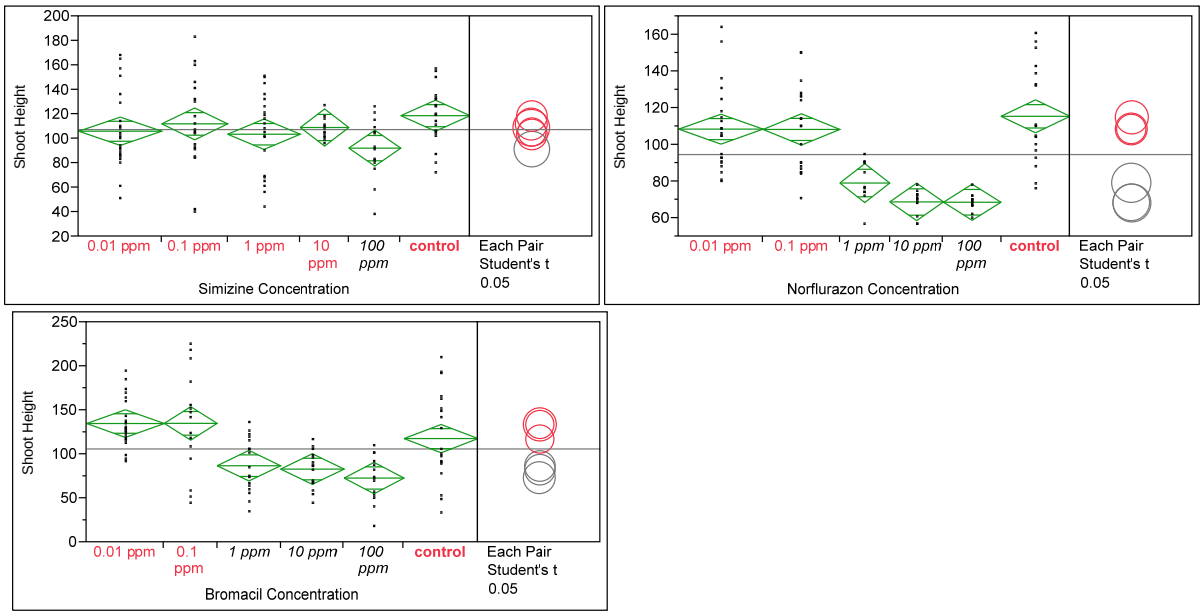




ANOVA of individual seedling height measurements for sorghum grown in the simazine treated spodosol showed little difference among herbicide treated soils (p = 0.15). The only significant difference in comparison to the control was at 100 mg/kg (p = 0.01). A significant difference was observed between controls and treatments for

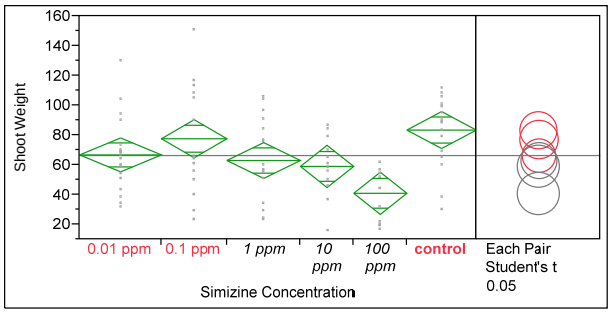
seedlings grown in some of the norflurazon and bromacil treated spodosol. Individual seedling heights for norflurazon treated soils were different from the control at treatment concentrations ≥0.1 mg/kg with *p*-values all <0.0001. Seedling heights for bromacil treated soils were also different from the control at concentrations ≥0.1 mg/kg (*p*=0.01 at 0.01 mg/kg)

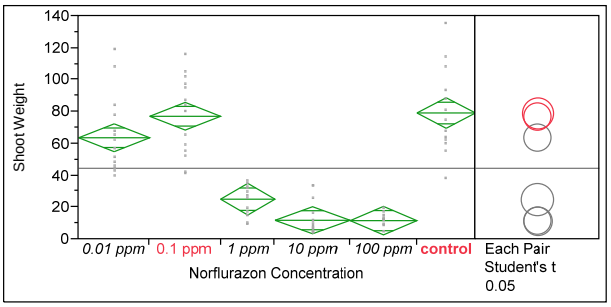
Sorghum bioassay of herbicide spiked spodosol –Shoot height at seven days

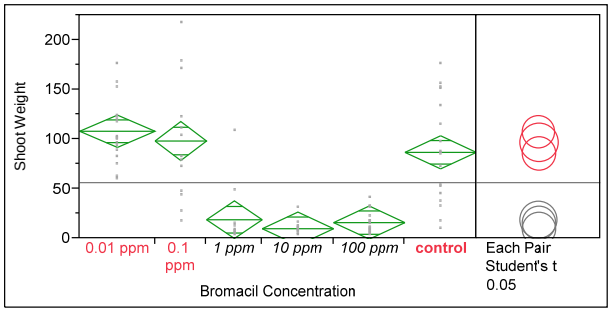


Individual plant shoot weights were also significantly different from the controls for some treatment concentrations, primarily due to the desiccation of plants exposed to norflurazon and bromacil concentrations ≥ 1 mg/kg. The ANOVA for both of these bioassays resulted in p-values <0.0001. The ANOVA for simazine exposed plants was significant (p= 0.0005), however individual Student's t test comparing control to herbicide concentrations ≤ 1 mg/kg did not show a strong association as shoot weights of plants exposed to low herbicide concentrations were highly variable.

Sorghum bioassay of herbicide spiked spodosol – Shoot biomass at seven days







Based on the strong statistical significance of individual plant height and random leaf chlorophyll fluoroscopy, the NOEC for norflurazon and bromacil is 0.1 mg/kg. The NOEC for simazine is also 0.1 mg/kg based on individual biomass. The LOEC for seedling growth in the spodosol containing norflurazon, simazine and bromacil is 1 mg/kg.

Seven- day bioassay of sorghum grown on herbicide spiked histosol

Analysis of the bioassay performed on the histosol soil was more difficult to interpret than for the spodosol. This may be the result of background concentrations of the herbicides being present in the soil from the Belle Glade collection site. All of the plants analyzed for chlorophyll fluorescence showed stress, with the non-treated controls having a mean values ranging from 0.3968 to 0.4694. There were significant differences in chlorophyll fluorescence values based on ANOVA, but this was due to high variability among treatment groups, with irregular peaks of plants with higher Fv/m ratios in treated soils compared to the control. Nearly all sorghum seedlings indicated plant stress. The few exceptions of plants showing less stress may have been subjected to less of the background herbicide contamination.

Individual seedling height measurements for sorghum grown in simazine treated histosol were statistically significant (ANOVA p=0.002), but all of the means for treated soils were higher than the control. Individual height measurements for norflurazon-exposed seedlings were statistically different (ANOVA *p*-values of <0.0001), with all treated soils being lower than the control. ANOVA for sorghum grown on the bromacil

treated histosol had a *p*-value of <0.001; with seedlings grown in soils below 1 mg/kg bromacil showing better growth compared to higher bromacil concentrations. This high variability is further evidence of background pesticide contamination overshadowing the effects of the herbicide treatments in the experimental design.

Individual weight measurements for seedlings grown on the simazine treated histosol were not statistically significant based on ANOVA (p=0.56). Weight measurements for norflurazon-exposed seedlings were statistically different with all treated soils being significantly lower than the control (ANOVA *p*-values of <0.0001). ANOVA of sorghum grown on bromacil treated histosol resulted in a *p*- value of <0.001. Seedlings grown in soils with less than 1 mg/kg bromacil had more biomass in comparison to soils with higher bromacil concentrations. This variability is additional evidence of background pesticide contamination.

Due to observed plant stress from soil contamination in the controls and inconsistent means comparison for physical parameters, estimation of NOECs and LOECs were not conducted.

Lab Germination and Growth compared to Greenhouse Germination and Growth

There are no possible connections between the lab analysis and greenhouse analysis since the lab germination and growth data did not show statistical differences and the greenhouse studies did in many cases. This is likely related to the mode of action for all three of the pesticides being inhibition of photosynthesis. Photosynthetically active light intensities were not likely present in the lab studies (ambient fluorescent lights), thus not invoking toxicity mechanisms. The lab germination and growth on filter paper bioassay cannot be performed in place of bioassays performed in the greenhouse for simazine, norflurazon or bromacil.

Endpoints of Herbicide Treatment – Spodosol

The most sensitive endpoint for sorghum growth on simazine treated spodosol soil is biomass production (0.1 mg/kg). Less sensitive endpoints for simazine toxicity is PSII electron transport inhibition (1 mg/kg) and individual shoot height (10 mg/kg).

The endpoints for Sorghum growth on norflurazon treated spodosol shared the same sensitivity. Soil with norflurazon concentrations above 0.1 mg/kg negatively impacted sorghum growth based on Fv/m ratio reduction from inhibition of carotenoid biosynthesis and chlorophyll destruction, total biomass production or , individual shoot height.

The most sensitive endpoints for sorghum growth on bromacil treated spodosol soil are PSII electron transport inhibition and biomass production (0.1 mg/kg). Individual shoot height was the least sensitive endpoint (10 mg/kg).

Expected Crop Damage or Yield Reduction from Herbicide Application

Sorghum crop damage is expected, if grown on citrus crop soils previously treated with simazine, norflurazon or bromacil, until herbicide concentration falls below the LOEC identified in this study. The half-life of a pesticide is defined as the amount of time required for the active ingredient to become ineffective as a result of detoxification by biodegradation, photo degradation, or hydrolysis, or loss from the treatment site through leaching, runoff or volatilization.

The labeled application rates for each herbicide converted to kg active ingredient per acre are: simazine (1.8 kg/acre), norflurazon (2.3 kg/ acre), and bromacil (1.8 kg/acre). Herbicides applied at the label rate and homogenized in the upper 10 cm of soil due to land management practices such as tilling or by natural processes such as leaching can have the expected concentrations in the rhizosphere of: simazine (3.7 mg/kg), norflurazon (4.6 mg/kg) and bromacil (6.0 mg/kg).

Table 2: Endpoint for Potential Damage to Sorghum as a Rotational Crop to Citrus

Pesticide	Tilled Soil conc. (mg/kg)	LOEC (mg/kg)	Half-Life (days)	Days until lowest endpoint reached
Simazine	3.7	0.1	45 – 100 (EPA, 2009)	90 – 200
Norflurazon	4.6	0.1	130 (EPA, 1996)	780
Bromacil	6.0	0.1	124 – 255 (EPA, 1996)	744 - 1530

The product label for simazine warns of crop injury if rotating crops; stating to only plant corn one year from last application of the product, or if planning to rotate crops, to not apply product in the preceding year (Simazine Product Label, 2013).

Similar results were found during studies of norflurazon injury to sorghum on Georgia soils, with 8.4 kg/acre causing injury in all soils tested (Schroeder and Banks, 1986). The study on Georgia soils found an application rate of as low as 4.2 kg/acre resulted in sorghum injury. The variation in plant injury among soil types treated with norflurazon is attributable to soil characteristics (soil organic matter content, CEC, soil texture, and pH) (Schroeder and Banks, 1986). In general, norflurazon persisted up to 365 days after

treatment in soils (Schroeder and Banks, 1986). The chemical label offers a broader range of half-lives: 38 days to 731 days (Solicam Product Label, 2013).

The product label for bromacil recommends performing a field bioassay prior to planting any desired crops in soils previously treated with the herbicide. For Florida soils, the label recommends not replanting any area that was treated with bromacil within the last 2 years or plant injury may result. According to the chemical label, the half-life for bromacil to break down by natural process is greater than 100 days. Field dissipation studies have shown that the phytotoxic residues of bromacil have persisted in both sand and clay soils for longer than 2 years following a single application of 2.6 lb. bromacil/acre (EPA, 1996).

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Literature Cited:

1. Gunasekara, A., Troiano J., Goh K. Tjeerdema R., 2007. Chemistry and Fate of Simazine. Reviews of Environmental Contamination and Toxicology 189: 1-23
2. Reddy, K. N., Singh, M., and Alvia, A. K. 1992. Sorption and leaching of bromacil and simazine in Florida Flatwoods soils. Bulletin of Environmental Contamination and Toxicology. 48: pages 662-670
3. National Renewable Energy Laboratory, Sorghum to Ethanol Research Initiative 2011. US Department of Energy, Office of Energy Efficiency & Renewable Energy. Oak Ridge Tennessee
4. Barnes C.J., Lavy T.L., Injury and Yield of Selected Crops to Imazaquin and Norflurazon Residues 1991. Weed Technology 5 (3): 598-606.
5. Brady, N., Weil, R., (2008). The Nature and Properties of Soils: Fourteenth Edition. Upper Saddle River, NJ: Pearson Prentice Hall.
6. Bartels, P.G., and C.W. Watson 1978. Inhibition of carotenoid synthesis by fluridone and norflurazon. Weed Science 26: 198-203
7. Singh, M., Castle W., Achhireddy N., 1985. Movement of Bromacil and Norflurazon in a Sandy Soil in Florida. Bulletin of Environmental Contamination and Toxicology. 35: 279-284
8. Pallett K.E., Dodge A.D., Studies Into the Action of Some Photosynthetic Inhibitor Herbicides 1980, Journal of Experimental Botany 31 (123): 1051-1066
9. Keeling J.W., Lloyd R.W., Abernathy J.R., Rotational Crop Response to Repeated Applicatrions of Norflurazon 1989, Weed Technology 3 (1): 12-125.
10. Schroeder J., Banks P., Persistence of Norflurazon in Five Georgia Soils 1986. Weed Science 34 (4): 599-606
11. Rooney W., Blumenthal J., Bean B., Mullet J., 2007. Designing sorghum as a dedicated bioenergy feedstock. Biofuels, Bioproducts and Biorefining. Volume 1, Issue 2. Pages 147-157.
12. Baker N.R. (2008) Chlorophyll Florescence: A Probe of Photosynthesis In Vivo, Annual Review of Plant Biology, Volume 59, Pages 89-113.
13. Baker N.R., Oxborough K, Chlorophyll fluorescence as a probe of photosynthetic productivity. Dordecht, the Netherlands: Springer, 2004. Print

14. Opti-Sciences, 2013. Desktop Plant Stress Guide. Edition 2.3. Hudson, New Hampshire
15. Drexel Chemical Company (2013), Simazine 4L Product Label. Memphis, Tennessee
16. Syngenta Chemical Company (2013), Solicam DF Herbicide Product Label. Greensboro, North Carolina
17. Du Pont Chemical Company Agricultural Products (2013). Hyvar X Herbicide Product Label. Wilmington, Delaware
18. EPA National Primary Drinking Water Regulations, Drinking Water and Health Pages. Technical Factsheet on: Simazine. US EPA, Washington, DC.
19. EPA Reregistration Eligibilty Decision R.E.D. Technical Factsheet on: Norflurazon EPA-738-F-012. 1996 (July). Office of Pesticide Programs. US EPA, Washington, DC.
20. EPA Reregistration Eligibilty Decision R.E.D. Technical Factsheet: Bromacil 738-96-013. 1996 (August). Office of Pesticide Programs. US EPA, Washington, DC.
21. U.S. Environmental Protection Agency. 1989 (January). Heath Advisory Summary: Bromacil. US EPA, Washington, DC.
22. Figure 1: Florida Soil Order Map Credit: Sabine Grunewald, University of Florida. Soil and Water Science Department http://soils.ifas.ufl.edu/faculty/grunwald/research/projects/NRC_2001/NRC.shtml