NOTAS CIENTÍFICAS

Quinoa (*Chenopodium quinoa*) reaction to herbicide residue in a Brazilian Savannah soil[1]

Roberto Lorena de Barros Santos[2], Carlos Roberto Spehar[3] and Lucio Vivaldi[4]

Abstract – The quinoa (*Chenopodium quinoa* Willd.) cultivation, one of the most promising in double cropping with soybeans or maize, depends on weed control. The objective of this work was to evaluate quinoa reaction to herbicide residue in a savannah soil. Six herbicide treatments, trifluralin, pendimethalin, clomazone, imazaquin, trifluralin + imazaquin and control, were applied, prior to summer cultivation of soybean, in a Dark-Red Latosol (typic Haplustox). Soybean cultivar BR 9 Savana was grown and soil samples were collected at 15, 38, 100, 145 and 206 days after treatment and stored at -5ºC. Bioassays were conducted in greenhouse, using quinoa, cultivar Q18. Imazaquin was the most harmful to quinoa seedlings, up to 206 days after application, followed by clomazone 15-38 days after application; trifluralin and pendimethalin had no residual effect. These results suggest that a broad-base screening should be conducted.

Index terms: chenopod, weed control, toxicity, yields.

Reação de quinoa (*Chenopodium quinoa*) a resíduos de herbicida em um solo de cerrado

Resumo – O cultivo da quinoa (*Chenopodium quinoa* Willd.), um dos mais promissores em sucessão à soja ou ao milho, depende do controle de plantas daninhas. O objetivo deste trabalho foi estudar a reação da quinoa a resíduos de herbicidas num solo de cerrado. Seis tratamentos com herbicidas, trifluralin, pendimethalin, clomazone, imazaquin, trifluralin + imazaquin e testemunha, foram aplicados, antes da semeadura de soja, cultivar BR 9 Savana, em um Latossolo Vermelho-Escuro. Amostras de solo foram coletadas aos 15, 38, 100, 145 e 206 dias após a aplicação e armazenadas sob temperatura de -5ºC. Bioensaios foram conduzidos em casa de vegetação, usando a quinoa, cultivar Q18. Imazaquin mostrou-se o mais prejudicial à quinoa até os 206 dias, seguido por clomazone entre 15 e 38 dias após a aplicação; trifluralin e pendimethalin não mostraram efeito residual. Estes resultados sugerem ampliar a triagem, com a inclusão de novos produtos.

Termos para indexação: quenopódio, controle de planta daninha, toxicidade, rendimento.

Cropping systems in the Brazilian Savannah, for the past 20 years, were based on soybean and maize cultivation in the rainy season, with little

[1] Accepted for publication on March 13, 2003.

[2] Esplanada dos Ministérios, Bloco D, Edifício Anexo A, Térreo, sala 7, CEP 70043-900 Brasília, DF. E-mail: robertolbs@agricultura.gov.br

[3] Embrapa-Centro de Pesquisa Agropecuária dos Cerrados, Caixa Postal 08223, CEP 73301-970 Planaltina, DF, Brazil. E-mail: spehar@cpac.embrapa.br

[4] Universidade de Brasília, Dep. de Estatística, Caixa Postal 4481, CEP 70910-900 Brasília, DF. E-mail: vivaldi@unb.br

agricultural activity during the long dry period. The monocrop systems have caused problems such as pests, diseases, weeds and organic matter loss due to tillage, soil exposition to solar radiation, nutrient loss, high soil density, erosion, increased production cost due to unbalanced use of fertilizers and pesticides, yield reduction, and negative environmental impacts (Spehar, 1998).

Farming in the savannahs has evolved to direct drilling or zero-tillage, in more recent times. This system requires the cultivation of cover crops for soil protection and efficient weed control (Spehar & Landers, 1997). Mulching, although necessary, has come from a small number of species of only two botanical families, Gramineae (maize, millet and sorghum) and Leguminosae (soybean and common bean). Introduction of new crops is based on drought resistance, rapid growth, soil improvement and diversified utilization (Spehar & Cabezas, 2001; Spehar & Santos, 2002).

The Andean grain crop quinoa (*Chenopodium quinoa* Willd., Chenopodiaceae) has been introduced for autumn cultivation, after the main crop, using residual moisture at the end of the rainy season (Spehar & Souza, 1993; Santos, 1996; Spehar, 1998). A major concern for successive cropping is the need of suitable weed control and the effect of herbicide residue on the following crop.

Quinoa, although an ancient crop, is new in modern agriculture. Little study has been conducted on its reaction to herbicides (Carbone, 1986; Alvarez, 1990). It belongs to the same genus as *Chenopodium album* and may be susceptible to some chemicals developed for weed control in soybean, common beans, maize and rice. Herbicides developed for sugar beet and spinach, such as alachlor and tribunil, have shown negligible damage on quinoa (Alvarez, 1990). Their effectiveness on prevalent weeds in the savannahs has not been determined.

Trifluralin, pendimethalin, clomazone, imazaquin and mixtures of them have been recommended for soybean cultivation. Trifluralin residues have shown intermediate persistence in savannah oxisols. Concentration of 1.8 mg kg^{-1} in the soil was still found 150 days after application (Almeida & Rodrigues, 1995). Carbone (1986) verified that trifluralin severely damaged quinoa when the crop was sown 24 hours after application.

Pendimethalin is highly absorbed by soil clay particles. When used in recommended dosage, it does not affect the subsequent crops (Ahrens, 1994). Persistence of its residues in savannah soil is not known; although the clay fraction has reduced chemical activity, the cation-exchange capacity depends on soil organic matter.

Clomazone, used for soybeans in summer, has affected successive cereal crops (wheat, oats and barley). Chlorosis has been observed when high dosage is used. These species, however, recover from herbicide injury and their grain yield is not affected (Ahrens, 1994). Usually, a minimum of 150 days after application is required for subsequent crop.

Imazaquin, used in soybeans and highly persistent in soil, can affect successive maize; its degradation depends on temperature and soil organic matter (Ahrens, 1994). Imazapyr, of a similar radical group and long lasting

residue, has shown to be more affected by temperature and moved down by leaching, under high rainfall on a Udic Ustochrept, USDA, soil (McDowell et al., 1997).

The objective of this work was to evaluate quinoa reaction to herbicide residue in savannah soil (oxisol).

The field experiment was carried out at Embrapa-Centro de Pesquisa Agropecuária dos Cerrados, Planaltina, DF, Brazil (15º36' S and 47º12' W, at an elevation of 1,000 m.a.s.l.), in a Dark-Red Latosol (Typic Haplustox). Soil physical characteristics are sand, 5 g kg^{-1}; loam, 190 g kg^{-1} and clay 460 g kg^{-1}; organic matter, 28 g kg^{-1}. The soil chemical analysis indicated pH (H_2O), 5.6; Al, 0.0 $cmol_c$ kg^{-1}; Ca+Mg, 2.8 $cmol_c$ kg^{-1}; P, 8.9 mg kg^{-1} and K, 0.2 $cmol_c$ kg^{-1}. Dolomitic lime (4 ton ha^{-1}, 100 g 100 g^{-1} $CaCO_3$ equivalent), P (105 kg ha^{-1}, in the form of single superphosphate), K (68 kg ha^{-1}, in the form of KCl), Fritted Trace Elements (micronutrients source, at the rate of 40 kg ha^{-1}) were applied and the area was cultivated for three successive seasons, prior to this experiment.

The experiment was arranged in a randomized complete block design, with three replications. The herbicide treatments with respective rates were clomazone (500 g ha^{-1} of a.i.), trifluralin (376 g ha^{-1} of a.i.), and imazaquin (22.5 g ha^{-1} of a.i.), pendimethalin (615 g ha^{-1} of a.i.) and trifluralin + imazaquin (376 and 22.5 g ha^{-1} of a.i., respectively). These levels were chosen based on recommendation obtained by testing the herbicides in savannah soils (Gazziero & Souza, 1993). The plots had 9 m^2 and soybean, cultivar BR 9 Savana, was sown after herbicide application. The rainfall during the experiment was 1,252 mm, distributed between December and May. There was no precipitation in June.

All chemicals and mixture were pre-plant applied; only trifluralin and trifluralin + imazaquin were incorporated into the soil. Soybeans were hand sown in rows 45 cm apart, after herbicide application. During and after soybean growth, ten soil samples per replication were collected in the depth of 0 to 15 cm, at 15, 38, 100, 145 and 206 days after application, to make a composite sample. These were immediately taken from the field and stored in a freezer at a temperature of -5°C, to stop herbicide degradation.

In September 1995, the samples were removed from freezer and left at 25°C for one day. From every composite sample, three subsamples (replications) of 200 mL were taken and transferred to plastic cups with no holes. Twenty viable quinoa seeds of cultivar Q18, previously selected for adaptability to the savannahs (Santos, 1996), were sown in each cup, at 1 cm depth, and periodically watered to reach field moisture capacity. The experiment was carried out in a greenhouse, set to 25±2ºC. The quinoa seeds were harvested in the previous crop season and stored in a cold-dry room at 5°C temperature.

A completely randomized design in a factorial scheme 5×5+1 (five sampling dates × five herbicides + control), with nine replications, was used. Observations were made at 7, 8, 9, 10, 12, 13, 14 and 16 days after sowing and compared to no-herbicide treatment (control). Herbicide injury, i.e., cotyledonary leaves in upright position (imazaquin) and chlorosis (clomazone) were observed. At the end of the bioassay, above ground plant parts were measured and harvested; data on plant height, number of individuals and dry weight were collected. Dry weight was obtained by placing the plants in a muffle, set to 40ºC, until they reached constant weight.

Analysis of variance was performed and the means were compared by the Tukey test at 5% of probability. The coefficient of variation (CV %) for plant height, number of plants and dry weight were, respectively, 12, 50 and 43 (Table 1). These values suggest that plant height is more consistent than the other two factors; number of plants was, probably, affected by a combination of treatment and undetected seed vigour, leading to increased statistical error, reflected by the high CV values.

Trifluralin is basically a germination inhibitor whose effect has shown to quickly reduce in the soil (Ahrens, 1994). It had no effect on quinoa plant height 15 days after application, contrasting to calcareous sandy-clay loam soil, in which it caused complete death (Carbone, 1986). It may be effectively used for narrow leaf weed control on quinoa grown in savannah soil.

Plant height was significantly affected in quinoa for the imazaquin and trifluralin + imazaquin herbicide residue treatments, for the first three sampling dates, meaning that imazaquin residues, between 100 and 145 days of application, can strongly affect the initial growth of quinoa.

Pendimethalin, trifluralin and control did not show statistical differences for plant height in the sampling dates. These results indicated no synergistic effect by mixing trifluralin to imazaquin. Pendimethalin is a herbicide that acts mainly in the stem and, as one could expect, it had no residual effect on quinoa.

Clomazone treatment caused effect on plant height which, however, disappeared between 15 and 38 days after application. There were statistical differences for dry weight for both imazaquin, and clomazone, thus confirming the observations on plant height.

Table 1. Reaction of quinoa, cultivar Q18 to herbicide treatment, at five sampling times (ST), in a savannah soil[(1)].

ST (daa)	CT	CL	PE	IM	TI	TR
			Plant height (mm)			
15	58.33ab	39.00bcdef	60.00ab	27.67ef	20.00f	56.67abc
38	55.00abc	67.50a	51.67abcd	32.50def	25.00f	55.00abc
100	52.50abcd	60.00ab	50.00abcd	48.33bcde	36.00cdef	56.67ac
145	63.33a	56.67abc	60.00ab	56.67abc	40.00bcdef	56.67abc
206	55.00abc	54.33abcd	60.00ab	56.00abc	50.00abcd	60.00ab
Mean	57.14	55.85	56.82	45.07	31.77	57.00
			Number of plants			
15	12.00	10.50	10.67	8.00	7.00	11.33
38	12.00	11.33	11.00	6.33	9.67	17.00
100	13.00	6.33	8.00	14.67	8.33	9.67
145	12.67	11.00	13.00	9.67	13.33	9.33
206	15.33	13.33	10.33	14.67	8.00	8.67
Mean	11.71	10.50	10.83	10.67	9.46	11.20
			Dry weight (mg)			
15	116.00	176.50	68.03	0.04	133.00	234.30
28	170.70	91.70	106.00	0.06	182.30	196.00
100	199.30	183.00	154.30	43.70	171.00	103.30
145	138.30	210.50	129.70	144.00	241.00	197.00
206	206.00	210.70	225.30	220.00	176.70	189.00
Mean	169.60	169.50	141.40	60.30	181.50	183.90

[(1)]Values followed by the same letter do not differ at 5% probability by the Tukey test; CT: control; CL: clomazone; PE: pendimethalin; IM: imazaquin; TI: trifluralin+imazaquin; TR: trifluralin; daa: days after aplication.

The significant values for plant height and dry matter show that effects of imazaquin residue in soil can be detected by these characters (Table 2). The low relationship between number of plants and the treatments containing imazaquin can be attributed to the mode of action of this herbicide, i.e., absorption by the root system. In low concentrations it does not kill the plant, although may be confounded with seed vigour. Emergence rate was 64%, on average, for control. It is possible that the plot, 20 seeds in 200 mL cup, was not appropriate to isolate the treatment effect when measured by number of plants, fresh weight and dry weight. In this experiment, plant height was the character that best expressed treatment effect and should be used in short-term testing.

On the ninth day, the treatments with imazaquin had plants with modified cotyledonary leaves. From horizontal position in normal seedlings (control) they moved to almost upright position. This symptom was followed by curving down of seedlings; some recovered from injury whereas others died. The symptom of toxicity for the treatments containing imazaquin was observed up to the last sampling date, although not detected by plant parameters. The symptoms, lasting 7, 5, 4, 3 and 1 day in relation to respective 15, 38, 100, 145 and 206 sampling dates, were inversely proportional.

The observations were made only up to 16 days after the start of the bioassay. This does not necessarily mean that, seven months after imazaquin application, its residue will not cause harmful effects on quinoa. The high sensitivity of quinoa to reduced levels of imazaquin residue, however, suggests it can be efficiently used in bioassays to detect the presence of that herbicide in soil.

The chlorosis symptom caused by clomazone in quinoa has been verified in other species as typical of this herbicide (Ahrens, 1994). The symptom evolved from chlorotic patch in the leaf blade, while xylem and phloem maintained green, to complete chlorosis of leaves and subsequent plant death. To avoid negative effect of pre-plant herbicide residue on quinoa cultivation in savannah soils, for successful double cropping, it may be advantageous to use non-residual herbicides on the main crop, depending on suitable application and weed infestation.

The results showed that quinoa seedlings are highly susceptible to imazaquin residue up to 206 days after application; clomazone has little residual effect on quinoa, causing damage between 15 and 38 days after application; trifluralin and pendimethalin have no residual effect and can be

Table 2. Correlation coefficients among herbicide treatments and plant characters.

Treatment	Plant character		
	Height	Number	Dry matter
Trifluralin + imazaquin	-0.8978*	-0.1388	-0.8722*
Imazaquin	-0.7395*	-0.4843	-0.7856*
Trifluralin	+0.1346	+0.0005	+0.0049
Clomazone	-0.0729	-0.2943	-0.3215
Pendimethalin	-0.0013	-0.0104	+0.2175
Control	+0.0009	-0.0295	-0.0025

*Significant at 5% probability.

used on weed control for quinoa; the high sensitivity of quinoa to imazaquin herbicide makes it a good indicator of the presence of this chemical in soils.

Acknowledgements

To Empresa Brasileira de Pesquisa Agropecuária, Conselho Nacional de Desenvolvimento Científico e Tecnológico and Universidade de Brasília, for technical and financial support.

References

AHRENS, W. H. **Herbicide handbook**. Champaign: Weed Science Society of America, 1994. 393 p.

ALMEIDA, F. S.; RODRIGUES, B. N. **Guia de herbicidas**: contribuição para o uso adequado em plantio direto e convencional. 3. ed. Londrina: Iapar, 1995. 675 p.

ALVARES, M. Herbicidas. In: WAHLI, C. (Ed.). **Quinua**: hacia su cultivo comercial. Quito: Latinreco, 1990. p. 61-68.

CARBONE, J. J. M. R. **Adaptation of the Andean grain crop quinoa for cultivation in Britain**. 1986. 338 leaves. Thesis (Ph.D. in Plant Genetics and Breeding) - University of Cambridge, Cambridge, England, 1986.

GAZZIERO, D. L. P.; SOUZA, I. F. Integrated weed management. In: ARANTES, N. E.; SOUZA, P. I. M. (Ed.). **Cultura da soja nos cerrados**. Piracicaba: Potafos,1993. p. 183-298.

McDOWELL, R. W.; CONDRON, L. M.; MAIN, B. E.; DASTGHEIB, F. Dissipation of imazapyr, flumetsulam and thifensulfuron in soil. **Weed Research**, Oxford, England, v. 37, p. 381-389, 1997.

SANTOS, R. L. B. **Estudos iniciais para o cultivo de quinoa (*Chenopodium quinoa* Willd.) nos cerrados**. 1996. 135 f. Dissertação (Mestrado em Ciências Agrárias) - Universidade de Brasília, Brasília. 1996.

SPEHAR, C. R. Production systems in the savannas of Brazil: key factors to sustainability. In: LAL, R. (Ed.). **Soil quality and agricultural sustainability**. Chelsea: Ann Arbor, 1998. p. 301-318.

SPEHAR, C. R.; CABEZAS, W. A. R. L. Introdução e seleção de espécies para a diversificação do sistema produtivo nos cerrados. In: CABEZAS, W. A. R. L.; FREITAS, P. L. (Ed.). **Plantio direto na integração lavoura pecuária**. Uberlândia: UFU, 2001. p. 179-188.

SPEHAR, C. R.; LANDERS, J. Características, limitações e potencial do plantio direto nos cerrados. In: SEMINÁRIO INTERNACIONAL SOBRE O SISTEMA PLANTIO DIRETO, 2., 1997, Passo Fundo. **Proceedings**... Passo Fundo: Embrapa-CNPT. 1997. p. 127-131.

SPEHAR, C. R.; SANTOS, R. L. B. Quinoa BRS Piabiru: alternativa para diversificar os sistemas de produção de grãos. **Pesquisa Agropecuária Brasileira**, Brasília, v. 37, n. 6, p. 889-893, jun. 2002.

SPEHAR, C. R.; SOUZA, P. I. M. Adaptation of quinoa (*Chenopodium quinoa* Willd.) to cultivation in the Brazilian savannahs: preliminary results. **Pesquisa Agropecuária Brasileira**, Brasília, v. 28, n. 5, p. 635-639, maio 1993.