J Plant Growth Regul (1989) 8:205–210

Journal of
Plant Growth Regulation

Prevention of Flowering and Increasing Sugar Yield of Sugarcane by Application of Ethephon (2-Chloroethylphosphonic Acid)

P. H. Moore[1] and R. V. Osgood[2]

[1]Department of Plant Physiology, ARS, USDA and [2]Department of Agronomy, Experiment Station, Hawaiian Sugar Planters' Association, 99-193 Aiea Heights Drive, Aiea, Hawaii 96701, USA

Received September 20, 1988; accepted January 4, 1989

Abstract. The inhibition of flowering in sugarcane by ethephon (2-chloroethylphosphonic acid) applied to experimental plots is well-documented; however, verification of its efficacy in large field trials is lacking. Large-scale field trials were established at Mauna Kea Agribusiness Company, Inc., a sugar and macadamia nut plantation located on the island of Hawaii, to determine whether flower inhibition attributed to ethephon would increase sugar yield. Summarization of results from 35 paired block experiments showed an 87% reduction in tasseling in the ethephon-treated blocks. The yield of sugarcane was increased by 7.5%, and the yield of sugar by 10%. The correlation (r^2) between the decrease in flowering and increase in cane and sugar yield was only 0.02 and 0.08%, respectively, indicating that the yield increase attributed to ethephon was not adequately explained by its effect on flowering.

Flowering of commercial sugarcane (*Saccharum* spp. hybrids) is an intermediate daylength response occurring annually during autumn. The sugarcane inflorescence is a determinant panicle, so that following induction of flowering the reproductive culms no longer produce internodes or leaves. Termination of vegetative shoot development can temporarily increase sugar yields by partitioning that part of photosynthates normally used for vegetative growth into additional storage sucrose. However, over the longer interval the flowering culms stop growth, begin to senesce, become diseased, and cause a decrease

Paper No. 665 in the journal series of the Experiment Station, Hawaiian Sugar Planters' Association.

in yield. Both gains and losses in yield of sugarcane are reported as the result of flowering (Hes 1951).

In Hawaii, sugarcane is grown as a two-year crop which may be subjected to flowering twice during a complete crop cycle. If flowering occurs more than six months before harvest, there can be a significant loss in sucrose yields (Coleman 1968, Gosnell and Julien 1976, Hes 1951). Thus, ways to reduce or prevent flowering were tested. The method most amenable to commercial application is the use of plant growth regulators (PGRs).

Many compounds were tested for flower-inhibiting activity (Gosnell and Julien 1976, Moore 1974, Moore 1985, Singh and Reddy 1976). The six PGRs that advanced to field-scale testing were maleic hydrazide (MH-30; 1,2-dihydro-3,6-pyridazinedione), monuron [CMU; 3-(p-chlorophenyl)-1,1-dimethylurea], diuron, [DCMU; 3-(3,4-dichlorophenyl)-1,1-dimethylurea], paraquat (Gramoxone; 1,1′-dimethyl-4,4′-bipyridinium salt), diquat [Reglone; 6,7-dihydrodipyridol (1,2-a:2′,1′-c) pyrazinediium salt], and ethephon (Ethrel; 2-chloroethylphosphonic acid). Diquat was registered by the U.S. Environmental Protection Agency and was used commercially in Hawaii for 15 years, even though it was seldom more than 50% effective in preventing flowering and caused crop damage by desiccating leaves. Ethephon was registered by the EPA in time for the 1988 flower initiation season; diquat is no longer used in Hawaiian sugarcane for control of flowering.

Tests with ethephon initiated in 1981 indicated this substance as a potential flower control agent (Moore and Osgood 1986, Osgood et al. 1983). On the basis of results of two yield trials showing about a 15% reduction in flowering and a sugar gain of 3.7 metric tonnes per hectare (mt ha^{-1}), a decision was made to test further the effect of ethephon on a commercial scale. We present here results from a series of 35 field tests.

Materials and Methods

Experiments were conducted from 1983 through 1987 with the heavy flowering commercial hybrid H70-0144 under production at the Mauna Kea Agribusiness Company, Inc., Papaikou, Hawaii. Ethephon applications were limited to field block experiments 6–14 months of age in September, the time for flower induction. Ethephon applications were generally made in August; however, in two blocks, applications were made in late July.

Adjacent field blocks were used as treatment and control plots and were scheduled for harvest at the same time. Treatment blocks ranged in size from 2–34 ha in area and averaged 13 ha. Test blocks were randomly located on the plantation at elevations ranging from 40–300 m.

Ethephon applications were made by fixed wing aircraft at the rate of 0.56 kg ha^{-1} in a spray volume of 94 L ha^{-1}.

The effect of treatment on flowering was evaluated in January/February, following an August application of ethephon. Ten sampling stations were established within each block. At each station 50 stalks were randomly picked for evaluation. Nontasseled stalks were sliced open to determine if flowering was initiated. Stalks were categorized as vegetative or floral. The effect of treat-

Table 1. Effect of ethephon treatment on flowering, cane tonnage, and sugar yield in 35 paired block experiments at Mauna Kea Agribusiness Company, Inc. (N = 35).

Measurement	Treatment: Ethephon	Treatment: Control	*t* statistic	p > *t*
Flowering (%)	3.1	23.5	9.91	0.0001
Sugarcane yield (tonnes ha^{-1})	234.4	218.0	2.77	0.0091
Sugar yield (tonnes ha^{-1})	27.5	25.0	3.67	0.0008

ment on yield was determined from field harvest data taken when the crops were 23–29 months of age.

Gross sugarcane yield was obtained by weighing the transport trucks as they entered the mill yard. Net yields were obtained by subtracting a visually estimated trash value. Cane quality (tons of cane per ton of sugar) were obtained by core sampling of the cane in the trucks (Payne and Rhodes 1967). Sugar yield for blocks was determined after raw-sugar processing techniques at the Hilo Coast Processing Company (Birkett 1982, Clark 1982, Payne 1963, Richardson et al. 1982, Villageliu 1982).

Each paired field block was considered as one replication of the experiment. The differences between the treatment and control blocks were evaluated by a *t* test at the 95% level of confidence ($p = 0.05$). A regression analysis was used to establish the relationship between tassel control and yield.

Results

Ethephon-treated fields flowered significantly less than the control fields. Flowering in control fields ranged from 3–51%, and averaged 23.5% (Table 1). Treated field plants flowered from 0–21%, and averaged 3.1%. In only two treated fields did more than 9% of the plants flower. These fields were treated in July, prior to the recommended treatment window of August 5 through August 25. Compared with untreated control plots, flowering of plants in ethephon-treated fields was reduced by 87%.

With only seven exceptions in 35 tests, the ethephon-treated fields yielded cane with higher fresh weights and sugar content than the controls. The differences in sugar yield ranged from −2.12 to +9.34 mt ha^{-1}, and averaged +2.5 mt ha^{-1} (a 9.9% increase) (Table 1). The average gain in cane fresh weight of 16.4 mt ha^{-1} (a 7% increase) was less than the relative or present gain in sugar.

After the deletion of seven fields from the data set having excessively large differences between treatment and control, there was poor correlation between the level of tasseling and the yield of sugar ($r^2 = 0.08$) and cane ($r^2 = 0.02$) (Table 2). Thus, it appears that differences in yield between ethephon-treated and untreated plots is not primarily attributable to reduced flowering. This conclusion is supported by the regression equations which predict ($p > 0.14$) an increase in cane of 5.99 tonnes ha^{-1} and an increase in sugar of 0.43 tonnes ha^{-1} when there is no effect of treatment of flowering.

Table 2. Linear regressions between percent reduction of flowering (x) and increase in fresh weight tonnage of cane and sugar of ethephon-treated fields (N = 28).

Yield parameter	Regression eq.	r^2	F (model)
Cane (tonnes ha^{-1})	$Y = 0.121x + 5.99$	0.020	0.53
Sugar (tonnes ha^{-1})	$Y = 0.034x + 0.43$	0.080	2.27

Discussion

The results presented here show that ethephon is very effective in preventing flowering and in increasing cane fresh weight and sugar yields of cv. H70-0144. This cultivar is grown in Hawaii as a two-year crop. In earlier tests involving other cultivars, grown for either one or two years in Hawaii (Moore and Osgood 1986, Osgood et al. 1983), Mauritius (Gosnell and Julien 1976), Sudan (Rostron 1978), Brazil (Deuber and Irvine 1987), and Australia (Anon 1987), ethephon consistently reduced flowering but only sometimes increased sugar yields.

The large number of environmental and crop factors which affect both flowering and yield, and the interaction between these crop characteristics, results in a highly variable relationship between reduced flowering and sugar yield. Thus, a large number of trials is needed to quantitate the degree that flowering is detrimental to yields. In the present 35 field trials conducted over a four-year period, the regression between decreased flowering and increased sugar yields indicated a gain of approximately 0.03 mt ha^{-1} sugar for each 1% reduction in flowering. This compares favorably with the relationship between flowering and yield previously reported. Hes (1951) reported the results of Van Vloten (1910) in Java on the yields of flowering and nonflowering culms and calculated a sugar yield reduction of 0.04–0.05 mt ha^{-1} for each 1% flowering. Similarly, Rao (1977) in Barbados used stools of culms as experimental plots and reported stool yields as a function of percent flowering. Rao calculated a potential sugar loss of 0.05 mt ha^{-1} for each 1% flowering.

Although ethephon significantly decreased flowering and increased cane and sugar yields, the correlation between flower reduction and increased yields was poor. Several obvious reasons for this poor relationship in these field tests are as follows:

1. In 8 of the 35 field trials, the level of flowering in nontreated controls was less than 10%. Elimination of flowering at this low level is not expected to influence yields greatly, so that yield differences in these cases must be because of other variables or inexact pairing of treatment and control field blocks.
2. The high variability in cane and sugar yields shown at less than 10% flower control is also shown at higher control levels. For example, of two fields that had a 20% reduction in flowering, one had a gain in sugar yield of 34.4%, whereas the other had a loss of 3.3%. The regressed data show an expected gain of 4.4%, so that figures above and below this value represent yield variability.
3. The effect of flowering on yield is known to vary with time and environ-

mental conditions between time of flowering and harvest. Generally, the longer the intervening time period and the better the environment for growth, the greater the inhibitory effect of flowering. Both intervening time and environments were variables not subject to control in these experiments.

Ethephon is obviously not a specific flowering-prevention PGR. At low concentrations ethephon has been shown to be both stimulatory and inhibitory to vegetative growth of grasses (Poovaiah and Leopold 1973, Rostron 1978, Van Andel and Vertkerke 1978). In sugarcane, PGRs inhibitory to vegetative growth can bring about an increase in sucrose storage. In these trials, sugar yields were increased more than fresh weight yields. This might indicate that flowering lowered sugar yields primarily by causing a decrease in the percentage of sucrose rather than decreasing the fresh weight yield of the crop; or it might indicate that ethephon causes an increase in the percentage of sucrose of the crop in a way not related to flowering. There is supporting evidence for both possibilities. One of the ways that flowering lowers yields is by initiating senescence which leads to a respiration loss of the sucrose already stored in the stalk parenchyma. On the other hand, ethephon has been used on sugarcane crops near the time of harvest to increase the sugar yield by increasing the sucrose percentage. The sugar producers refer to this process as "ripening." The use of ethephon in attempts to ripen cane in Hawaii has given inconsistent results (Osgood and Teshima 1980). In addition, ethephon applied early in the crop cycle, as in these trials, has never given increased ripening (Osgood et al. 1983). Therefore, the sugar gains in these trials are related to increased cane tonnage at least partially because of the reduction in flowering.

Acknowledgments. The authors wish to thank personnel in the Agronomic Research Department of Mauna Kea Agribusiness Company, Inc., especially John Cross and Iris Iwami for overseeing the data-gathering.

References

Anon (1987) Flower suppression with ethephon 1986 trial. Australian Bureau of Sugarcane Experiment Stations, 87th Annual Report pp 16–17

Birkett HS (1982) Evaporation and sugar boiling. In: Luke DK Jr (ed) Sugar y asucar 1982 yearbook. Palmer Publications, New York, pp 191–199

Clark SJ (1982) Clarification and filtration. In: Luke DK Jr (ed) Sugar y asucar 1982 yearbook. Palmer Publications, New York, pp 132–145

Coleman RE (1968) Physiology of flowering in sugarcane. Proc Int Soc Sugar Cane Technol 14:992–1000

Deuber R, Irvine JE (1987) Controle do florescimento da cana-de-acvcar Com aplicacao de ethephon. Buletin Tecnico Copersucar 36/87:16

Gosnell JM, Julien HR (1976) Variations in the effects of flowering on cane yield and quality. Proceedings 1976. Monsanto Sugar Cane Ripener Sem 1:253–257

Hes JW (1951) The effect of arrowing on the yield of cane. Sugar J 14:10–17

Moore PH (1974) Flowering control with diquat. Hawaii Plant Rec 58:323–329

Moore PH (1985) *Saccharum*. In: Halevy H (ed) Handbook on flowering. Vol. VI. CRC Press Inc., Boca Raton, Florida, pp 243–262

Moore PH, Osgood RV (1986) Use of ethephon to prevent flowering of sugarcane in Hawaii. Proc Int Soc Sugar Cane Technol 9:298–304

Osgood RV, Teshima A (1980) The effect of several growth regulators on dry matter production and partitioning in sugarcane CV. H59-3775. Proc Plant Growth Reg Soc Am 7:150

Osgood RV, Moore PH, Carr JB (1983) Comparison of diquat and ethephon for prevention of flower initiation in sugarcane (*Saccharum* spp. hybrids). Proc Plant Growth Reg Soc Am 10:266–269

Payne JH (1963) The processing of sugar cane into juice and fiber. Proc Int Soc Sugar Cane Technol 11:971–991

Payne JH, Rhodes LJ (1967) Assaying cane deliveries by core sampling and direct analysis. Proc Int Soc Sugar Cane Technol 12:1552–1559

Poovaiah BW, Leopold AC (1973) Effects of ethephon on growth of grass. Crop Sci 13:755–758

Rao PS (1977) Effects of flowering on yield and quality of sugarcane. Exp Agric 13:381–387

Richardson W Jr, Isherwood MO Jr, Sloane G (1982) Sugar cane sampling and analysis. Sugar cane mill yard handling and payment systems. In: Luke DK Jr (ed) Sugar y asucar 1982 yearbook. Palmer Publications, New York, pp 49–63

Rostron H (1978) A review of chemical ripening of sugarcane with Ethrel in southern Africa. Proc Int Soc Sugar Cane Technol 16:1605–1616

Singh S, Reddy MS (1976) Effect of inhibition of flowering on improvement of cane yield and juice quality under Coimbatore conditions. J Agric Sci Comb 87:375–380

Van Andel OM, Vertkerke DR (1978) Stimulation and inhibition by ethephon of stem and leaf growth of some Gramineae at different stages of development. J Exp Bot 29:639–651

Van Vloten JFW (1910) Resultaten van Nashproeven, in 1910 te Sempalwadak geoogst en verdere beschouwingen over de waarnemingen, in den proeftuin Kasembon te Sempalwadak gedaan. Arch vd Suikerrind in Ned Ind 18:276–302

Villageliu AE (1982) State of the art: a review of cane conveying, preparation, milling and diffusion. In: Luke DK Jr (ed) Sugar y asucar 1982 yearbook. Palmer Publications, New York, pp 89–96