Pelargonic acid – a potential organic aquatic herbicide for duckweed management

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ABSTRACT

Duckweeds (*Lemna spp*.) are small, free-floating, aquatic plants that flourish on stagnant or slow moving water surfaces throughout the continental U.S. Members of the genus are among the smallest flowering plants, and they provide food for fish and fowl. However, their aggressive growth and invasive tendencies make them formidable aquatic weeds; and, when uncontrolled, their presence can result in oxygen depletion, fish kills, and death of submerged aquatic plants. Greenhouse research was conducted at Lane, OK, to determine the feasibility of using pelargonic acid to control duckweed. Pelargonic acid is a fatty acid naturally occurring in many plants and animals and present in many foods. AU720 (65% pelargonic acid, BioSafe Systems LLC) is a potential organic herbicide under development for aquatic weed control. Research treatments included 4 dilutions of the product (0.0006%, 0.0015%, 0.006%, and 0.015% v/v) and a control (0% v/v) with 8 replications, and the experiment was repeated twice. Duckweed (7.5 g) was added to 400 mL beakers containing 250 mL of the solutions, and the beakers were placed in a greenhouse. Visual ratings were collected 1, 3, and 5 days after treatment. Pelargonic acid was phytotoxic at all dilutions. Duckweed control was less than acceptable (< 10% control) at 0.0006% and 0.0015%, inconsistent at 0.006% (3 to 99% control), but very effective (96 to 100% control) at 0.015%. If used at 0.015% v/v, pelargonic acid (AU720) has potential as a duckweed management tool.

Keywords: Lemna minor, aquatic weed control, pelargonic acid, organic

INTRODUCTION

Duckweeds (*Lemna spp*. L.) are small, free-floating, aquatic plants that flourish on stagnant or slow moving water surfaces throughout the continental U.S. Members of the genus are among the smallest flowering plants with a prolific growth rate that can be a blessing or a curse, depending one's perspective. Duckweed is a natural food source for fish and fowl; however, it is invasive because it is easily transported by fish and water foul to new locations where it quickly exploits suitable environments. Rapid vegetative reproduction allows duckweed to double in mass in less than two days, and it is capable of producing up to 10 generations from a single frond during a 10 day to 14 day period (Skillicorn et al., 1993).

In addition to its rapid growth, duckweed contains a high quality and quantity of proteins, amino acids, minerals, and nutrients (Skillicorn et al., 1993). Researchers have demonstrated the beneficial aspects of using duckweed for domestic fish production (Arrivillage, 1994; Essa, 1997; Fasakin et al., 1999; Leng et al., 1995; Robinette et al., 1980; Skillicorn et al., 1993; Van Dyke and Sutton, 1977), including catfish, tilapia and carp; for domestic birds, including ducks (Hossain, 1998; Khanum et al., 2005; Leng et al., 1995;

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Muztar et al., 1979) and chickens (Abdulayef, 1969; Haustein et al., 1988, 1992, 1994; Lautner and Mueller, 1954; Muzaffarov et al., 1968**;** Muztar et al., 1979; Truax et al., 1972;); for pigs (Landolt and R. Kandeler, 1987; Leng et al., 1995); and for ruminants (Leng et al., 1995; Smith and Leng, 1993), including cattle (Rusoff et al., 1978, 1980), sheep (Porath et al., 1986), and goats (Reid, 2003). These studies have shown that duckweed can provide a large portion or even all of the for certain animals. The extent at which duckweed can provide the nutritional needs of animals depends on the specific animal's growth stage and nutritional requirements and the conditions under which the duckweed is produced (Culley et al., 1981; Leng et al., 1995; Skillicorn et al., 1993).

One method of obtaining large quantities of nutrient-rich duckweed biomass is a systemic duckweed production system based on waste water, either animal or human (Körner et al., 2003). Duckweed is ideally suited to clean waste water (Alaerts et al., 1996; Hammouda et al., 1995; Körner et al., 1998, 2003; Mandi, 1994; Skillicorn et al., 1993) because of its efficient nutrient absorption (Ice and Couch, 1987), its rapid growth rate (Skillicorn et al., 1993), and its ease of harvest (Körner et al., 2003).It provides not only a nutrient-rich duckweed biomass for animal feeds but also an alternative feed source for biofuels (Cheng and Stomp, 2009). Use of duckweed biomass for biofuel production also avoids safety concerns about the direct human consumption of animals raised on waste water grown duckweed (Cheng and Stomp, 2009).

Unfortunately, duckweed's aggressive growth, ability to compete, and invasive tendencies make it a formidable aquatic weed which, uncontrolled, can result in oxygen depletion, decreased fish production, fish kills, reduced plant diversity, and decreases in aesthetics and navigation (Parr et al., 2002; Meijer and Sutton, 1987). Diquat (1,1'-ethylene-2,2'-dipyridylium) and fluridone [(1-methyl-3-phenyl-5-[3-trifluoromethyl) phenyl]-4(1*H*)-pyridinone)] are two highly recommended synthetic (non-organic) aquatic herbicides for control of duckweed (Arnold, 1979; Blackburn and Weldon, 1965; Cheshier et al., 2008; Langeland et al., 2002; McCowen et al., 1979; Wells et al., 1986). Diquat and fluridone, like the other synthetic herbicides, have their advantages and disadvantages when attempting to control duckweed; but all of the synthetic herbicides have a common disadvantage¯ they are not cleared for use in conjunction with certified organic crop production.

Organic certification was developed in recognition of the necessity for consistent standards across the U.S. to benefit producers, processors, wholesalers, retailers, and consumers. Prior to establishment of federal guidelines (National Organic Program, 7 CFR Part 205, 7 U.S.C. 6501–6522) for organic certification in 2002, a multitude of agencies and associations throughout the U.S. maintained a diverse list of acceptable inputs, production methods, and policies to determine organic certification. Differences in certification standards invited marketing inconsistencies, misunderstandings, and misrepresentations concerning organic products. Certified organic crop production is more than a list of *do's* and *don'ts* of acceptable and prohibited inputs or practices; rather, it is a holistic approach to sustainable and healthy food production that enhances the well-being of the consumer and protects natural resources. One important aspect of certified organic crop production is the prevention of non-organic substances from intentionally, or inadvertently, being brought into the production area. This would include the intentional application of irrigation water, or natural water flow containing disallowed material, from a pond or lake onto a certified organic production area.

Pelargonic acid is a fatty acid naturally occurring in many plants and animals and present in many foods (EPA, 2004). Pelargonic acid injures and kills plants by destroying the cell membranes, causing rapid desiccation of plant tissues. Chloroplast bleaching is seen within a short time after application (Senseman, 2007). Although the

exact mode of action is not yet known, the primary impact is the immediate decrease in intercellular pH with a resulting loss of cell membrane integrity (Senseman, 2007). Pelargonic acid has potential as an organic non-selective postemergent contact herbicide for terrestrial weeds (Webber et al., 2005; Webber and Shrefler, 2007). Pelargonic acid provides excellent weed control at low application rates and volumes in the terrestrial environment. In addition to pelargonic acid, other fatty acids are under consideration and development as potential organic herbicides. Greenhouse research was conducted at Lane, OK, to determine the feasibility of using pelargonic acid as a potential aquatic herbicide to control duckweed.

METHODS AND MATERIALS

Duckweed (*Lemna minor* L.) was grown in 9 L aquatic growth chambers in a greenhouse at Lane, OK. AU720 (65% pelargonic acid, BioSafe Systems LLC[1,2]) is a potential organic herbicide under development for aquatic weed control. Treatments included 4 dilutions of the product (0.0006%, 0.0015%, 0.006%, and 0.015% v/v) and a control (0% v/v) with 8 replications and the experiment was repeated twice. Duckweed (7.5 g) was added to 400 mL beakers containing 250 mL of the diluted solutions and the beakers placed in a greenhouse. The plant material uniformly covered the water surface of each beaker.

Visual ratings were collected at 1, 3, and 5 days after treatment (DAT). Visual ratings at 1 DAT measured the percentage of duckweed discoloration. The visual ratings at 3 and 5 DAT measured the percentage duckweed control (percentage dead). All data were subjected to ANOVA and mean separation using LSD with P=0.05 (SAS Inc., SAS, Ver. 9.0, Cary, NC). The percentage of duckweed discoloration and loss were prepared for analyses using a square root arcsine transformation to normalize the data. Mean differences were determined using the transformed data and the non-transformed data values are reported using the mean differences determined with the transformed data.

RESULTS AND DISCUSSIONS

Discoloration

Discoloration data (1 DAT) was consistent across experiments with no interaction between treatment solutions and experiments. Discoloration data is presented averaged across the 2 experiments (Table 1). There were significant differences in plant discoloration as a result of pelargonic acid applications; an increased discoloration from 0 to 98.94% (0 to 0.015%).

Although none of the plants appeared to be dead at 1 DAT, a large percentage were discolored and no longer green. The 0.006% and 0.015% solutions produced at least 90% discoloration and was significantly greater than the lower 2 AU720 solutions and the 0% control. Discoloration was not a clear predictor of plant mortality, even though discoloration followed the general trend seen in duckweed control at 3 and 5 DAT where the percentage of dead duckweed was measured (Table 2 and 3).

Duckweed Control

Statistical analysis determined that there was a significant interaction between the solution concentrations and each experiment for data collected at 3 and 5 DAT. The interaction was a result of the inconsistent results for the 0.0060% treatment. As a result of the treatment by experiment interaction, the data is reported

[1] The mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

[2] AU720 (65% pelargonic acid), BioSafe Systems LLC, Meadow Street East Hartford, CT 06108, Phone: 860.290.8890, Fax: 860.290.8802, Website Address: www.biosafesystems.com

Table 1. Impact of AU720 solutions on duckweed discoloration at 1 DAT averaged across 2 experiments with 8 replications per experiment.

AU720 Solutions	1 DAT Discoloring %
0%	0.00 e[1]
0.0006%	2.56 d
0.0015%	6.50 c
0.006%	90.31 b
0.015%	98.94 a

[1]Values in columns followed by the same letter are not significantly different at P≤0.05.

separately for the two experiments (Table 2 and 3).

Percentage duckweed control, death of individual plants, was significantly affected by treatment solutions (Table 2 and 3). In both experiments, duckweed control for AU720 solutions of 0.0006 and 0.0015% resulted in less than 5% control. Duckweed control was significantly greater for the 0.006% treatment for both experiments, although control remained poor (59.88 and 56.75%) at 3 and 5 DAT for experiment 1 and good (88.75 and 88.13%) for 3 and 5 DAT for experiment 2. Consistent duckweed discoloration between experiments, and inconsistent duckweed control, between experiments for the 0.006% treatment is an indication of the precarious expectations of controlling duckweed at the intermediate application rate of 0.006%. The 0.015% rate provided consistently high (>99%) duckweed control for both experiments (Table 2 and 3).

CONCLUSIONS

It was determined that pelargonic acid (AU720) has potential to significantly impact duckweed at application rates of 0.006 and 0.015% AU720. If approved as an organic herbicide, pelargonic acid could be a valuable tool in certified organic production systems involving ponds and lakes. Preliminary results with AU720 at 0.006% showed promising, but inconsistent outcomes. The 0.006% rate may have potential use depending on duckweed management goals, cost of the material, application timing and methods. Duckweed control was consistently excellent at the 0.015% AU720; but because of duckweed's prolific growth and rate of reproduction, AU720 should be considered as a management tool for duckweed rather than a method to achieve 100%

Table 2. Impact of AU720 solutions on duckweed control (death) at 3 and 5 DAT for experiment 1.

AU720 Solutions	3 DAT Control %	5 DAT Control %
0%	2.00 c[1]	2.00 c
0.0006%	2.00 c	2.00 c
0.0015%	3.00 c	3.00 c
0.006%	59.88 b	56.75 b
0.015%	99.13 a	99.00 a

[1]Values in columns followed by the same letter are not significantly different at P≤0.05.

Table 3. Impact of AU720 solutions on duckweed control at 3 and 5 DAT for experiment 2.

AU720 Solutions	3 DAT Control %	5 DAT Control %
0%	0.00 d[1]	0.00 d
0.0006%	0.38 d	0.38 d
0.0015%	4.88 c	4.00 c
0.006%	88.75 b	88.13 b
0.015%	100.00 a	99.88 a

[1]Values in columns followed by the same letter are not significantly different at P≤0.05.

control in a pond or lake. Future research should investigate additional application rates and delivery systems, along with large scale evaluations.

REFERENCES

Abdulayef, D.A. 1969. The use of common duckweed as green feed for chickens. Uzbekskii Biologicheskii Zournal (USSR) 13(3):42-43.

Alaerts, G.J., M. M. Rahman, and P. Kelderman. 1996. Performance analysis of a full-scale duckweed covered lagoon. Water Res. 30:843-852.

Arnold, W. 1979. Fluridone - A new aquatic herbicide. J. Aquat. Plant Manage. 17:30-33.

Arrivillage, A. 1994. Effect of substituting prepared feed by the aquatic plant *Wolffia* sp. (Lemnaceae) on the growth response of tilapia (*Oreochromis niloticus*) and mojarra paleta (*Cichlasoma synspillum*) fry. World Aquaculture Soc. Ann. Meeting, Jan. 14-18, 1994. New Orleans, LA, USA.

Blackburn, R.D. and L.W. Weldon. 1965. The sensitivity of duckweeds (Lemnaceae) and azolla to diquat and paraquat. Weeds 13:147-149.

Cheng, J.J. and A.M. Stomp. 2009. Growing duckweed to recover nutrients from wastewaters and for production of fuel ethanol and animal feed. Clean Soil Air Water. 37(1):17-26.

Cheshier, J.C., R.M. Wersal, and J.D. Madsen. 2008. Duckweed control using Fluridone in sequential treatments. Mississippi State Univ.: GeoResources Institute Report 4005. p. 1-6.

Culley, Jr., D.D., E. Rejmankova, J. Kvet, and J.B. Frye. 1981. Production, chemical quality, and use of duckweed (Lemnaceae) in aquaculture, waste management, and animal feeds. J. World Maric. Soc. 12:27-49.

EPA. Pesticides: Regulating Pesticides. Pelargonic Acid (217500). U.S. Environmental Protection Agency. Retrieved September 30, 2009. www.epa.gov/pesticides/ biopesticides/ ingredients/factsheets/factsheet_217500.htm

Essa, M.A. 1997. Utilization of some aquatic plants in diets for Nile tilapia, *Oreochromis niloticus*, fingerlings. Egyp. J. Aquat. Bio. Fish. 1(2):19-34.

Fasakin, E.A., A.M. Balogun, and B.E. Fasuru. 1999. Use of duckweed, *Spirodela polyrrhiza* L. Schleiden, as a protein feedstuff in practical diets for tilapia, *Oreochromis niloticus* L. Aguacult. Res. 30:313-318.

Haustein A.T., R.H.Gillman, P.W. Skillicorn, V. Vergara, V. Guevara, and A. Gastanaduy. 1988. Duckweed, a useful strategy for feeding chickens: Performance of layers fed with sewage-grown Lemnaceae species. Poultry Sci. 69:1835-1844.

Haustein A.T., R.H. Gillman, P.W. Skillicorn, V. Guevara, F. Dias, V. Vergara, A. Gastanaduy, and J.B. Gillman. 1992. Compensatory growth in broiler chicks fed on *Lemna gibba*. British J. of Nutrition. 68(2):329-335.

Haustein A.T, R.H. Gillman, P.W. Skillicorn, H. Hannan, F. Dias, V. Guevana, V. Vergara, A. Gastanaduy, and J.B. Gillman. 1994. Performance of broiler chickens fed diets containing duckweed (*Lemna gibba*). J. of Agric. Sci. 122(2):288-289.

Hammouda, O., A. Gaber, and M.S. Abdel-Hameed. 1995. Assessment of the effectiveness of treatment of waste water-contaminated aquatic systems with *Lemna gibba*. Enzyme Microb. Technol. 17:317-323.

Hossain M.J. 1998. Use of duckweed as a feed for ducks. Duckweed production by using integrated farm waste and its utilization as animal feed. A publication of Duckweed Research Project, Ministry of Fisheries and Livestock and BLRI, Bangladesh. p. 21-23.

Ice, J. and R. Couch. 1987. Nutrient absorption by duckweed. J. Aquat. Plant Manage. 25:30-31.

Khanum, J., A. Chwalibog, and K.S. Huque. 2005. Study on digestibility and feeding systems of duckweed in growing ducks. *Livestock Research for Rural Development. 17:1-10.*

Körner, S., G.B. Lyatuu, and J.E. Vermaat. 1998. The influence of *Lemna gibba* L. on the degradation of organic material in duck-weed covered domestic waste water.
Water Res. 32:3092-3098.

Körner, S., J.E. Vermaat, and S. Veenstra. 2003. The capacity of duckweed to treat wastewater. J. Environ. Qual. 32:1583-1590.

Landolt, E. and R. Kandeler. 1987. The family of Lemnaceae – a monographic study.Vol. 2. Phytochemistry, physiology; application; bibliography, Ver_ffentlichungen des Geobotanischen Institutes ETH, Stiftung Rubel, Zurich, Switzerland.

Langeland, K.A., O.N. Hill, T.J. Koschnick, and W.T. Haller. 2002. Evaluation of a new formulation of Reward Landscape and Aquatic Herbicide for control of duckweed, waterhyacinth, waterlettuce, and hydrilla. J. Aquat. Plant Manage. 40:51-53.

Lautner V. and Z. Mueller. 1954. Feeding value of some water plants I. Abornik Cesk.Akad.Zemedl.Vol. 27(A):333-354

Leng, R.A., J.H. Stanbolie, and R. Bell. 1995. Duckweed - a potential high-protein feed resource for domestic animals and fish. Livestock Research for Rural Development 7(1).
11 p. Retrieved September 30, 2009. http://www.lrrd.org/lrrd7/1/3.htm

Mandi, L. 1994. Marrakesh waste water purification experiment using vascular aquatic plants *Eichhornia crassipes* and *Lemna gibba*. Water Sci. Technol. 29:283-287.

McCowen, M.C., C.L. Young, S.D. West, S.J. Parka, and W.R. Arnold. 1979. Fluridone, a new herbicide for aquatic plant management. J. of Aquat. Plant Manage. 17:27-30.

Meijer, L.E. and D.L. Sutton. 1987. Influence of plant position on growth of duckweed. J. Aquat. Plant Manage. 25:28-30.

Muztar, A.J., S.J. Slinger, and J.H. Burton. 1979. Metabolizable energy content of freshwater plants in chicken and ducks. Poult. Sci. 56:1893-1899.

Muzaffarov A.M., T. Taubayev, and M. Abdiyev. 1968. The use of *Lemna minor* L. for poultry feeding. Usbekskii Biologia Cheskii Zournal (USSR). 12(3):44-46.

Parr, L.B., R.G. Perkins and C.F. Mason. 2002. Reduction in photosynthetic efficiency of *Cladophora glomerata*, induced by overlying canopies of *Lemna* spp. Water Res. 36:1735-1742.

Porath, D., G. Oron, and G. Granoth. 1986. Duckweed as an aquatic crop: Edible protein recovery, production and utilization. Proc. Fifth Int. Symp. Agric. Waste, Amer. Soc. of Agric. Engineers. St. Joseph, MI, USA. p. 680-687.

Reid, W.S. 2003. Exploring duckweed (*Lemna gibba*) as a protein supplement for ruminants using the Boer goat (*Capra hircus*) as a model, Masters of Science Thesis, North Carolina State Univ., Raleigh, N.C., USA.

Robinette H.R., M.W., Brunson, and E.J. Day. 1980. Use of duckweed in diets of channel catfish. Proc.13th Ann. Conf. SE Assoc. Fish Wildlife Age. p. 108-114.

Rusoff, L.L., S.P. Zeringgue, A.S. Achacoso, and D.D. Culley. 1978. Feeding value of duckweed (an aquatic plant, family Lemnaceae) for ruminants. J. Dairy Sci. 61(1):186.

Rusoff, L.L., E.W. Blakeney, and D.D. Culley. 1980. Duckweeds (Lemnaceae family) – a potential source of protein and amino acids. J. Agric. Food Chem. 28:848-850.

Senseman, S.A. (Ed.) 2007. Herbicide Handbook, Ninth Ed. Weed Science Society of America. Lawrence, KS.

Skillicorn, P., W. Spira, and W. Journey. 1993. Duckweed aquaculture. A New Aquatic Farming System for Developing Countries. The World Bank, Washington, DC., USA. pp. 76. (http://www.p2pays.org/ref/09/08875.htm)

Smith P. and R.A. Leng. 1993. Rural Science Honours thesis "Bypassing Duckweed Protein" UNE, Armidale, NSW, Australia.

Truax, R.E., D.D. Culley, M. Griffith, W.A. Johnson, and J.P. Wood. 1972. Duckweed for chick feed? Louisiana Agric. 16(1):8-9.

Van Dyke, J.M. and D.L. Sutton. 1977. Digestion of duckweed (*Lemna spp*.) by the grass carp (*Ctenopharyngolon edella*). J. of Fish Bio. 11:273-278.

Webber, C.L. III, J.W. Shrefler, and V.B. Langston. 2005. Weed control with pelargonic acid (2004) Lane, Oklahoma. *In*: Brandenberger, L. and Wells, L. (eds.). 2004 Vegetable Weed Control Studies. Oklahoma State Univ., Div. of Agric. Sci. and Natural Resources, Depart. of Hort. & Landscape Architecture. Stillwater, OK. MP-162. p. 32-33.

Webber, C.L. III and J.W. Shrefler. 2007. Pelargonic acid weed control: Concentrations, adjuvants, and application timing. Proc. 26th Hort. Industries Show. Ft. Smith, AR. Jan. 5-6, 2007. p. 145-148.

Wells, R., B. Coffey, and D. Lauren. 1986. Evaluation of Fluridone for weed control in New Zealand. J. Aquat. Plant Manage. 24:39-42.