Potassium Fertilization of Bluegill Ponds

by

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Abstract

Bluegill ponds at Auburn University, Alabama were treated with potassium (K) fertilizer at rates of 0, 0.125, 0.5, 1, 2, 4, and 8 Kg/ha with either one or two ponds per rate. Concentrations of potassium in pond water ranged from 2.34 to 38.9 mg/L by the end of the study and were correlated with potassium input. Chlorophyll *a* concentration and gross photosynthesis rate were not related to potassium input or concentration. Thus, it is not surprising that bluegill production, although highly variable among ponds (mean 416 ± 106 kg/ha; range 243 to 570 kg/ha) was not correlated with potassium application rate or concentration. The large degree of variation in bluegill production among ponds apparently was caused by differential survival of the initial fish stock and incomplete removal of small fish entangled in masses of filamentous algae during harvest.

This study suggests that potassium fertilization is unnecessary in bluegill ponds with potassium concentration above 2.3 mg/L; the concentration in the control pond. Likewise, it should be unnecessary to use potassium fertilizer in sportfish ponds in the southern United States that contain more than 2.3 mg/L potassium. If potassium concentration in pond water is less than 2.3 mg/L or unknown, potassium fertilizer should be applied at 1 kg K/ha; equal to about 2 kg/ha of muriate of potash fertilizer. Pond bottom soil adsorbs potassium on cation exchange sites and serves as a source of this nutrient to the water column. In potassium deficient ponds, application of potassium for a

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few years should increase the concentration of this nutrient in bottom soil making further potassium fertilization unnecessary.

Acknowledgments

 The author would like to thank his family for their support. He also extends a special thanks to Dr. Claude E. Boyd for giving him an opportunity to study in the Unites States and to gain experience and knowledge about water quality analysis.

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INTRODUCTION

Ponds are built for purposes such as irrigation, livestock watering, sportfishing, and landscaping. There is about 1.2 million hectares of ponds in the southeastern United States, and one of the most important uses of these ponds is to culture sportfish for recreational fishing. Sportfish ponds are often managed to enhance fish production, and about 15% (180,000 ha) of pond in the Southeast are likely fertilized (Boyd, Querioz, and Wright 2002).

Ponds are usually fertilized by adding inorganic nutrients to the water to promote phytoplankton growth and enhance the food base for sportfish(Boyd 1990). Organic fertilizers derived from a wide variety of sources such as manures, leaves, grass, weeds, and other agricultural wastes or by-products are useful as pond fertilizatiers (Hickling 1962). However, manures and other organic fertilizers seldom are used in sportfish ponds in the Southeast. This is mainly because most sportfish pond owners are no longer farmers, and they do not have a ready supply of organic fertilizers from farm activities. It is much more convenient for them to purchase common inorganic commercial fertilizers. Small amounts of these relatively inexpensive fertilizers have the same benefit to fish production as much larger amounts of manures or other organic fertilizers.

Fertilizers with many different analyses ($\%N$-$\%P_2O_5\%$-$\%K_2O$) have been used in the Southeast, e.g., 20-20-5, 16-20-5, 16-20-5, 18-46-0, 0-46-0, 13-38-0 and 10-34-0 (Masser undated). These ratios have resulted from results of experiments, different

interpretation of results of experiments, and experience. Fertilizer price is also a reason for the different analyses. The example, the cost of 0-46-0 fertilizer is much less than that of on 20-20-5 fertilizer. Unless the nitrogen and potassium in the 20-20-5 fertilizer is needed, pond owners should use the 0-46-0 fertilizer to reduce cost, minimize nutrient use and pollution potential, and conserve resources (Boyd 2003)

Much of the research on sportfish pond fertilization has been done by scientists at Auburn University. It has been well established that nearly all sportfish ponds in the Southeast benefit from phosphorous fertilization, and new ponds (less than 5 to 10 years old) also need nitrogen fertilizers. The latest research-based recommendation for fertilization of new ponds to apply 6 kg N and 3 kg P_2O_5 at intervals sufficient to maintain a secchi disk visibility of 30 to 45 cm (Boyd, Pengseng, and Boyd 2008)

The aim of this study was to re-evaluate potassium fertilization requirement of bluegill *Lepomis microchirus* ponds by using a wide range of potassium fertilization rates (0 to 8 kg K/ha).

LITERATURE REVIEW

Most of the research on pond fertilization has focused on nitrogen and phosphorous. These two nutrients are considered more likely than other essential plant nutrients to limit phytoplankton productivity (Wetzel 2001). Phosphorous fertilization will stimulate plant growth in nearly all ponds (Swingle 1947), but additions of nitrogen also may be necessary in some ponds, and especially in new ponds (Swingle et al 1963).

Early work at Auburn University suggested that fertilization of ponds with 9 kg/ha N and 9 kg/ha P_2O_5 (N:P ratio of 1:0.437) was ideal for sportfish ponds (Swingle 1947). However, later work revealed that the phosphorous application rate could be reduced to 4.5 kg P_2O_5 by using liquid fertilizers or pre-dissolving granular fertilizers in water before applying them (Metzger and Boyd 1980).

Some workers have recommended using N:P ratio of 7:1 to 15:1 in pond fertilizers because phytoplankton cells often have N:P ratios within this range (Das and Jana 1996). However, Boyd and Tucker (1998) pointed out that even though there was a rather wide N:P ratio in phytoplankton cells, a much more narrow ratio was needed in fertilizers because phosphorous was rapidly adsorbed by bottom soils. In order to achieved the desired N:P ratio in the pond water, a rather narrow N:P ratio was needed in the fertilizer.

Nitrogen accumulates in bottom soil organic matter and is recycled through decomposition by microorganisms (Swingle et al. 1963; Boyd and Tucker 1998). Blue-

green algae in fish ponds also fix nitrogen (Swingle et al. 1963; Lin et al. 1988). Thus, after 5 years or more of fertilization with both nitrogen and phosphorous, the nitrogen available from microbial recycling of organic matter will support a high level of fish production in pond fertilized only with phosphorous (Swingle et al. 1963; Murad and Boyd 1987).

Wudtisin and Boyd (2005) recently demonstrated that phosphorous fertilization rate could be reduced to 3 kg/ha of P_2O_5 per application in ponds from which sediment had been removed a few months before. Yuvanatemiya and Boyd (2006) demonstrated that bottom soil fertility was similar to that of new ponds following sediment removal. Boyd et al. (2008) found that 6 kg/ha nitrogen per application gave optimum sunfish production in ponds that also were fertilized at 3 kg/ha of P_2O_5 per application. These ponds also had been subject to sediment removal the year before the experiment was conducted. Thus, Boyd et al. (2008) made the recommendation that ponds on the Auburn University E.W. Shell (EWS) Fisheries Center should be fertilized at the rate of 6 kg/ha of N and 3 kg/ha of P_2O_5 per application following sediment removal. They further suggested that new ponds should also be fertilized at the same rate, but that nitrogen fertilization could be discontinued in older ponds. They felt that this fertilization schedule would be effective in most areas in the Southeastern United States where soils are acidic and strongly absorb phosphorous from the water. In areas with high total calcium concentrations in pond waters, the phosphorous rate may need to be increased because phosphorous will precipitate directly from the pond water even though bottom soils are not acidic (Boyd and Tucker 1998).

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The experiment by Wudtisin and Boyd (2005) and Boyd et al. (2008) did not follow the traditional method of replicating two or three fertilization rates in each of three or four ponds (Boyd 1990). Instead, They used a wide range of un-replicated nitrogen and phosphorous treatments and evaluated the effect of fertilizer application rate on fish production by regression analysis. This proved to be a highly effective way of conducting fertilizer experiments.

Mortimer (1954) reviewed the early literature on pond fertilization and reported several instances where potassium was included in pond fertilizers. However, he reported that potassium did seem to be necessary to increase fish production in ponds. The early work on pond fertilization at Auburn University was included by Mortimer (1954) in his assessment. Hickling (1962) conducted experiments on pond fertilization in Malaysia and found no increase in fish production attributable to potassium. Hepher (1962, 1963) reported that pond waters in Israel were high in potassium concentration and concluded that potassium fertilization was unnecessary. Nevertheless, in a study conducted at Auburn University (Dobbins and Boyd 1976), there was a modest increase in fish production (although not significant at the 0.05 probably level) in ponds treated with potassium fertilizer. Water in these ponds contained about 1.3 mg/L potassium before fertilization, and the researchers concluded that in water of very low potassium concentration, fertilization with this nutrient might be beneficial. Moreover, Saha (1979) observed a positive response in phytoplankton productivity to application of potassium fertilizer to a newly constructed pond.

Potassium fertilizers are widely used in low-salinity inland water for marine shrimp culture. These waters often have low potassium concentrations that lead to stress

and mortality of shrimp postlarvae soon after stocking (McNevin et al. 2004). The potassium fertilizers, muriate of potash (potassium chloride) and Kmag (potassium magnesium sulfate) are applied to increase potassium concentration to 50 mg/L in waters of inland shrimp ponds in Alabama (Boyd et al. 2007).

Some workers have suggested that potassium fertilization of ponds may be counterproductive. Potassium reportedly increased the growth of submergent aquatic plants that are undesirable in ponds (Das and Jana, 1996). Jaworski et al. (2003) found that very low concentrations of potassium (0.3 to 0.8 mg/L) were adequate for growth of the diatoms *Asterionella formosa* and *Diatoma elonatum*. It was concluded that natural potassium concentrations in ponds would be adequate, and potassium was not needed in pond fertilizers despite being important in fertilization of terrestrial crops. A study by Bideh and Rai (2006) showed that potassium reduced the growth of the blue-green alga *Microcystis.* They claimed that at a concentration of 240 mg/L potassium, the internal pH of cells increased from 7.2 to 9.8 in comparison to the control. The effect was to reduce protein concentration, increase sodium loss from cells, and lessen growth and survival of *Microcystis.* Bideh and Rai (2006) even suggested that potassium fertilization could be used to control *Microcystis* blooms in ponds. However, they did not indicate if high potassium concentration might be toxic to other types of algae.

Although Hickling (1962), Boyd and Dobbins (1978), and several other investigators made cursory evaluations of potassium fertilization effects on fish production, no single study has focused on a detailed analysis of potassium fertilization of fish ponds. The only potassium fertilization study found was on the fate of potassium applied to inland ponds for culture of marine shrimp in Alabama (Boyd et al. 2007). This

study showed that potassium additions enhanced shrimp survival and production. The investigation also revealed that pond bottom soils with a high content of 2:1 layered clays (smectite clays) rapidly removed potassium from water by cation exchange. They found these soils also removed potassium from water by fixation within the inter-layers of the clay. Thus, pond bottoms do not saturate rapidly with potassium and fertilization must be repeated one or more times per growing season. The role of potassium fertilization in shrimp ponds is to raise potassium concentrations in the water and improve the physiological status of shrimp. There was no effort in these studies to determine if potassium addition influenced primary productivity. In sportfish ponds, the role of fertilizer nutrients is to enhance primary productivity that serves as the base of the food web for fish production (Swingle and Smith 1938; Mortimer 1954; Boyd and Tucker 1998).

MATERIALS AND METHODS

This experiment was conducted in 400 m^2 earthen ponds each approximately 1 m in average depth and located in the E series at the Lower Station of the EWS Fisheries center. This research station is about 10 km north of Auburn, Alabama and is situated at 32.5°N latitude. The mean annual temperature is 17.2°C (mean minimum = 11.1°C; mean maximum = 23.3°C). The ponds were constructed in 1971 on acidic, fine-loamy, kaolinitic, thermic Typic Kanhapludults. The water source is a reservoir filled by runoff from a wooded watershed. This water has total alkalinity and total hardness concentrations of 8 to 12 mg/L as CaCO$_3$, nutrients and organic matter concentrations are low (Boyd 1990).

Total alkalinity concentration in pond waters was measured in March 2008. Ponds with concentration below 25 mg/L were treated in mid March with agricultural limestone at 2,000 kg/ha (Boyd 1990). Bluegill *Lepomis macrochirus* (0.70 g/fish) were purchased from American Sportfish, Montgomery, Alabama, and 2,000 bluegill fingerlings and four grass carp *Ctenopharynodon idella* (88 g/fish) were placed in each pond on 28 March 2008.

The technique of using a wide range of un-replicated fertilizer treatments and analyzing the results by regression analysis to obtain the optimum fertilizer application rate (Wudtisin and Boyd 2005) was used in this study. The experiment consisted of eight different potassium chloride treatments (Table 1) ranging from 0 to 3.86 kg/pond (0 to

8 kg K/ha). On each fertilization date, all ponds received diammonium phosphate and urea-ammonium sulfate at rate equal to 6 kg N/ha and 3 kg P_2O_5/ha per application. The fertilization rates provide the optimum inputs of nitrogen (Wudtisin and Boyd 2005) and phosphorus (Boyd, Pengseng, and C. Boyd 2008) for sportfish ponds. Fertilizers were weighed and transferred to 20 L of pond water in a plastic bucket. The water was stirred to dissolve the fertilizer, and the resulting slurry was splashed over pond surfaces. Fertilizers were applied three times at 2-week intervals and afterward for eight times at 3-week intervals between 30 March and 26 October.

Water samples were collected with a 90-cm water column sampler (Boyd and Tucker 1992). Samples were taken between 06:00 and 08:00 am and midway between fertilization dates. They were transported to the laboratory where analyses were initiated at once. Chlorophyll *a* concentration was determined by spectroscopy of acetone-methanol extracts of phytoplankton removed from samples by membrane filtration; total alkalinity was estimated by acidimetry; total hardness was determined titration with EDTA; soluble reactive phosphorus was determined by filtering sample and measured with ascorbic acid method; total ammonia nitrogen by phenate method; turbidity was determined by nepthelometry and expressed in nephelometer turbidity units(NTU) (Cleceri et al. 1998). Potassium ion was determined by flame spectrometry. In additional, water samples were dipped from pond surfaces on several occasions and water temperature, pH and conductance measured with portable meters.

Secchi disk visibility was determined on each sampling date. At monthly intervals, net and gross photosynthesis were measured by the oxygen light-dark bottle

procedure (Boyd and Tucker 1992). One light bottle and one dark bottle were incubated at 25 cm depth in each pond from dawn to noon for about 4 hours.

The abundance of filamentous algae and other aquatic weeds was assessed at monthly intervals. Each pond was visually divided down the middle of its long dimension and each of the two halves were visually divided into three single sections. The approximate area in each of the six sections that was covered by underwater or floating aquatic weeds was estimated and the coverage of the sections with weeds was sketched on an outline map of each pond.

Soil samples were taken at the beginning of the experiment before fertilization begins and after harvest of fish. Each time, samples were collected to depth of 5-cm from ten places in each pond using a 5-cm diameter plastic core sample tube as described by Wudtisin and Boyd (2006). The samples were dried at 60°C in a mechanical convection oven (Boyd and Tucker 1998). Afterward, they were extracted by ammonium acetate and determined potassium ion by frame spectrometry.

Ponds were drained and fish were harvested from 4 to 5 November 2008. Weights of bluegill and grass carp in each pond were recorded. Data were analyzed by linear regression using SigmaPlot (version 8.0) statistical software.

Table 1 Potassium fertilizer treatments; all ponds also received 6 kg N and 3 kg P$_2$O$_5$/ha per application.

Pond No.	Potassium input per application	
	(g/pond)	(kg/ha equivalent)
E 26	0	0
E 28	0	0
E 32	60	0.125
E 31	120	0.25
E 64	120	0.25
E 29	241	0.5
E 66	241	0.5
E 25	482	1.0
E 27	482	1.0
E 65	964	2.0
E 63	1.928	4.0
E 30	3,855	8.0

RESULT AND DISCUSSION

The potassium concentration in water from the pipeline supplying the ponds averaged 2.55 mg/L (range for six samples was 2.3 to 2.8 mg/L). The potassium concentration in the control ponds averaged 2.34 mg/L, and the slight increase in concentration during the study (Fig. 1) probably resulted from evaporation exceeding precipitation. Class A pan evaporation was 142.8 cm, and evaporation from pond surfaces as estimated by multiplying 0.81 by pan evaporation (Boyd 1985) was 115.7 cm. Rainfall was 78.8 cm during the study. Thus, pond evaporation was 36.9 cm greater than the amount of rainfall onto the pond surfaces during the study. Bottom soil in the ponds was not considered an important source of potassium, because the ponds had been renovated in 2006 and 2007 with removal of sediment. A study by Yuvanatemiya and Boyd (2006) revealed that sediment removal greatly reduced bottom soil potassium concentration.

Potassium concentration in waters of ponds fertilized with potassium increased steadily in response to repeated fertilizer application during the study (Fig. 2). Although there was a high correlation ($R^2 = 0.988$) between potassium fertilization rate and potassium concentration in the water, the final potassium concentrations were less than should result if all added potassium had remained in the water. For example, the total input of potassium in ponds treated at 1.0 kg/ha per application was equal to 11 mg/L, while in ponds treated with 8.0 kg/ha potassium per application, the total input was 88
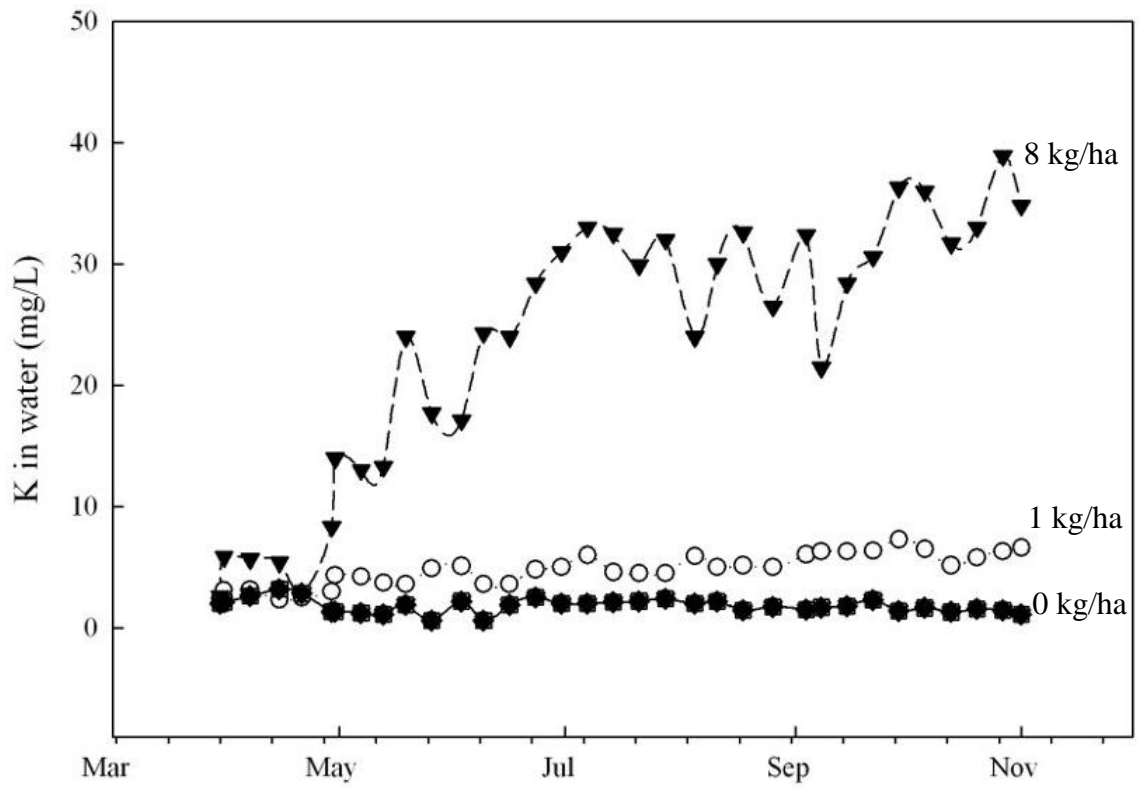
Figure 1 Potassium concentration in pond water treated at 0, 1, and 8 kg/ha per application with potassium fertilizer
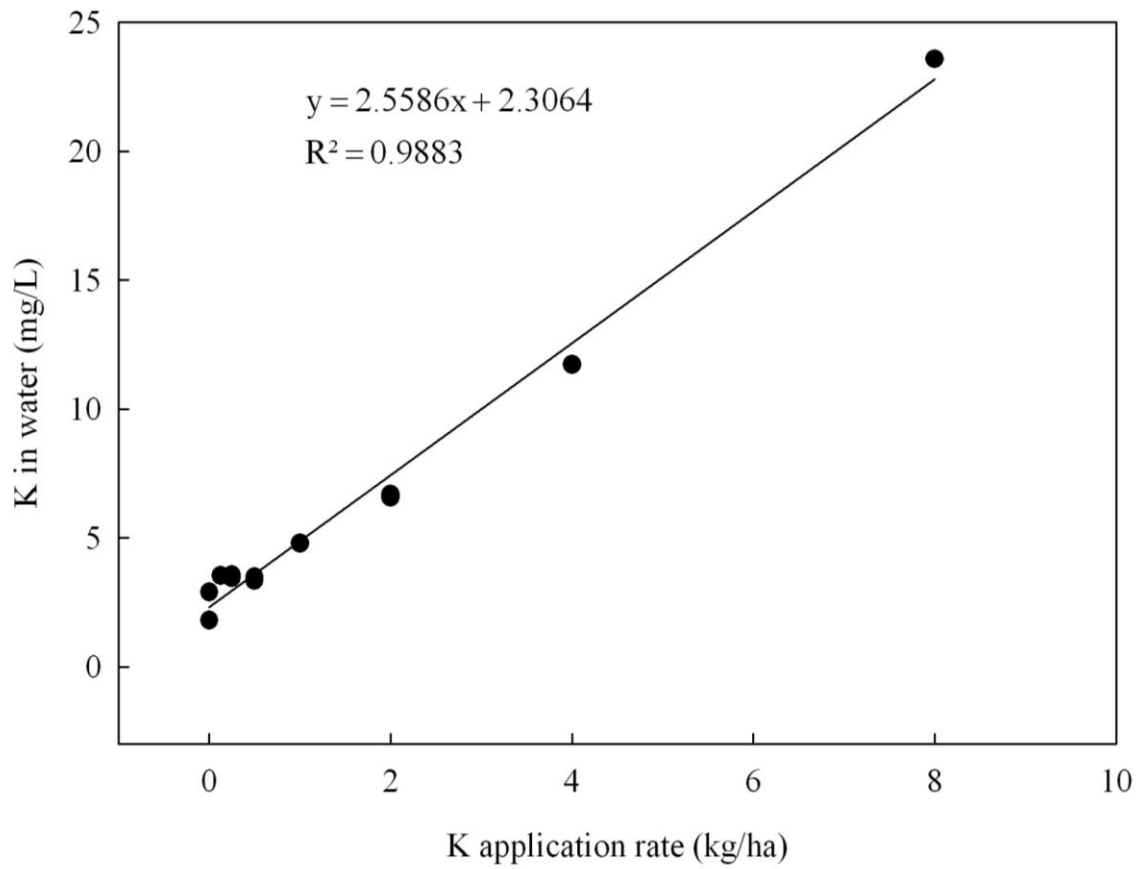
Figure 2 Relationship between potassium fertilization rate and average potassium
concentration in pond water

mg/L. The final potassium concentrations in these two treatments were equal to 6.3 mg/L

and 38.9 mg/L, respectively.

Storage capacity for direct rainfall was maintained in the ponds, and overflow

through the drain pipe did not occur during the study. Thus, potassium added to ponds in

fertilizer and not present in the water at the end of the crop was mainly adsorbed by

bottom soil or lost from ponds in seepage.

There was no way to collect seepage and measure potassium concentration in it,

but seepage from the pond has been measured at about 0.5 cm/day. Ponds had similar

soil potassium concentrations before treatment (70 to 126 mg/kg). However, at the end

of the study, soil potassium tended to increase in relation to greater potassium

fertilization rate (Fig. 3). This suggests that much of the added potassium was absorbed

by bottom soil.

The fact that potassium is absorbed by bottom soil suggests that potassium

concentration in the water should increase over time in ponds that receive regular

additions of potassium. Exchangeable potassium in bottom soil maintains an equilibrium

with potassium in overlaying water (Boyd et al. 2007), and potassium adsorbed by

bottom soil is a possible source of potassium to the water column. Thus, potassium

concentration in water is more likely to be low in new ponds or in recently-renovated

ponds from which sediment was removed than in older ponds that have received inputs of

potassium for several years.

Concentrations of other water quality variables are summarized in Table 2. Total

alkalinity concentrations exceeded 40 mg/L in all ponds and total hardness concentration

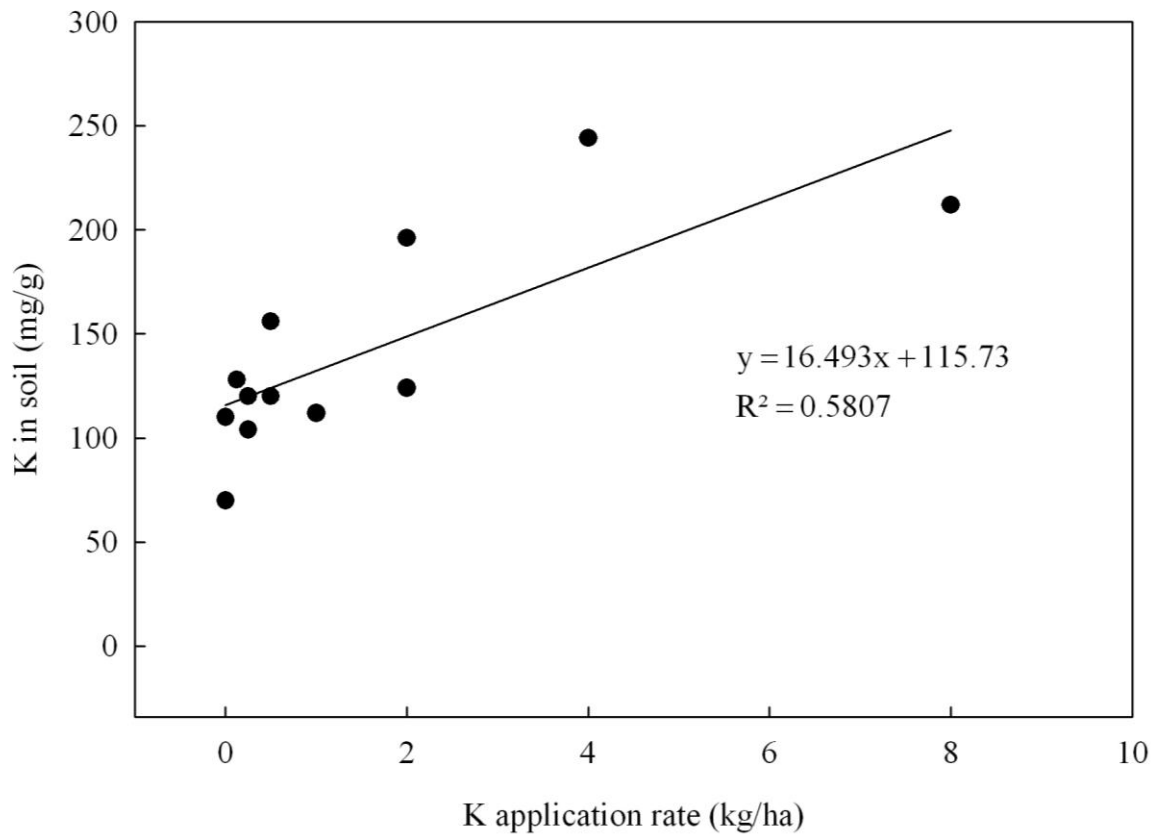was less than 40 mg/L in only one pond. Total alkalinity concentration averaged slightly

Figure 3. Relationship between potassium fertilization rate and potassium

concentration in pond bottom soil at harvest

Table 2 Average concentration of water quality analyses.

Variable	Mean ± standard deviation	Range
Total alkalinity (mg/L)	51.3 ± 6.76	$40.6 - 64.5$
Total hardness (mg/L)	46.0 ± 6.57	$37.8 - 61.9$
Soluble reactive phosphorus (mg/L)	0.10 ± 0.032	$0.06 - 0.19$
Total ammonia nitrogen (mg/L)	0.15 ± 0.052	$0.10 - 0.27$
Turbidity (NTU)	8.4 ± 2.63	$5.4 - 14.2$
Chlorophyll *a* (µg/L)	22 ± 11.5	$8.3 - 46.5$
Gross primary productivity (mg O_2 /L/4 hr)	1.33 ± 0.475	$0.77 - 2.55$
Weed cover (% bottom)	49 ± 22.8	$5.0 - 75.0$

greater (5.3 mg/L) than total hardness concentration. Boyd and Tucker (1998) suggested

that total alkalinity and total hardness should be above 20 mg/L and that alkalinity

concentration should not greatly exceed hardness. Soluble reactive phosphorus and total

ammonia nitrogen concentration were similar to those usually reported in pond

fertilization experiments at Auburn University. There was no correlation ($p<0.05$)

between potassium application rate and concentrations of total alkalinity, total hardness,

soluble reactive phosphorus, and total ammonia nitrogen.

Average turbidity in ponds was 8.4 NTU with a range of 5.4 to 14.2 NTU for

individual ponds. Chlorophyll a concentration averaged 22 µg/L (range = 8.3 to 46.5

µg/L). Phytoplankton was a major source of turbidity in ponds as evident from the

positive correlation ($R^2 = 0.336$) between chlorophyll a concentration and turbidity (Fig.

4). Grass carp stocked in ponds for weed control prevented extensive infestations of

vascular plants, but they did not control macrophytic algae such as *Spirogyra* spp. and

Rhizoclonium spp. effectively.

Phytoplankton blooms did not develop in most ponds until late June, and the

bottoms of most ponds had extensive cover by macrophytic algae. Although bottom

cover by macrophytic algae declined during summer apparently as a result of greater

turbidity from phytoplankton, average coverage of all ponds was 49% for the entire study

(range = 5 to 75%).

Gross photosynthesis also was correlated with chlorophyll a concentration ($R^2 =$

0.310), but there was no correlation between potassium concentration and either

chlorophyll a concentration or rate of gross photosynthesis, $R^2 = 0.0264$ and 0.0768,

respectively (Fig. 5).

There was no correlation between either potassium treatment rate or average potassium

concentration in pond water and sunfish production (Fig. 6) for which $R^2 = 0.039$ and

0.071, respectively. Fish production was variable among ponds (range = 243 to 570

kg/ha), and the mean and standard deviation for the 12 ponds was 416 ± 106 kg/ha. The

coefficient of variation of 25.48% is similar to the coefficient of variation of 27%

reported for nitrogen plus phosphorus fertilization trials over 8 years at Auburn

University (Doyle and Boyd 1984).

The fish production data were separated into control (0 kg/ha of K), low

potassium (0.125 to 1.0 kg/ha), and high potassium (2 to 8 kg/ha); the resulting means

and standard deviations were 380 ± 193, 426 ± 114, and 420 ± 80 kg/ha, respectively.

Data also were separated into low potassium (0 to 1 kg/ha) versus high potassium (2 to 8

kg/ha), and the means and standard deviations were 415 ± 123 and 420 ± 80 kg/ha,

respectively. Sunfish productions in the ponds fertilized with potassium were similar to

production obtained in ponds for which fertilizer contained nitrogen and phosphorus but

no potassium. Sunfish production in ponds at Auburn University treated with similar

amounts of nitrogen and phosphorus ranged from 270 to 418 kg/ha per year over an 8-

year period (Doyle and Boyd 1984). Fish production for the 8-year period averaged 359

± 54 kg/ha. An equation presented by Boyd et al. (2008) predicted that sunfish

production in ponds fertilized with nitrogen and phosphorus at rates used in this study

would produce 481 kg/ha of sunfish. The findings reveal that potassium fertilization of

ponds at Auburn University did not increase production above that achieved with

nitrogen and phosphorus fertilization alone. However, potassium concentration in the

control ponds with less potassium in the water might possibly respond positively to potassium fertilization.

Sunfish production in fertilized ponds usually is positively-correlated with increasing chlorophyll a concentration and gross photosynthesis (Swingle and Smith 1938; Boyd and Tucker 1998). In this study, neither chlorophyll *a* concentration or gross photosynthesis was correlated with sunfish production ($R^2 = 0.188$ and 0.070, respectively) if all ponds are included in the analysis. However, if the two ponds with the lowest fish production (243 and 272 kg/ha) are omitted, fish production increased with increasing chlorophyll a and gross photosynthesis were correlated ($R^2 = 0.540$ and 0.2867, respectively (Fig. 7). The most likely causes of variation in fish production in this experiment were differential survival and reproductive success of the initial fish stock, loss of small fish through the drain pipe during draining for harvest, and incomplete removal of small fish entangled in macrophytic algae during harvest.

It is interesting to note that there were positive correlations of $R^2 = 0.358$ and 0.392 between fish production and greater concentrations of total alkalinity and total hardness, respectively (Fig. 8). This suggests that the common recommendation of maintaining concentrations of alkalinity and hardness above 20 mg/L in fertilized sportfish ponds should be reassessed. (Boyd and Tucker 1998)

$$y = 0.1333x + 5.4984$$
$$R^2 = 0.3355$$

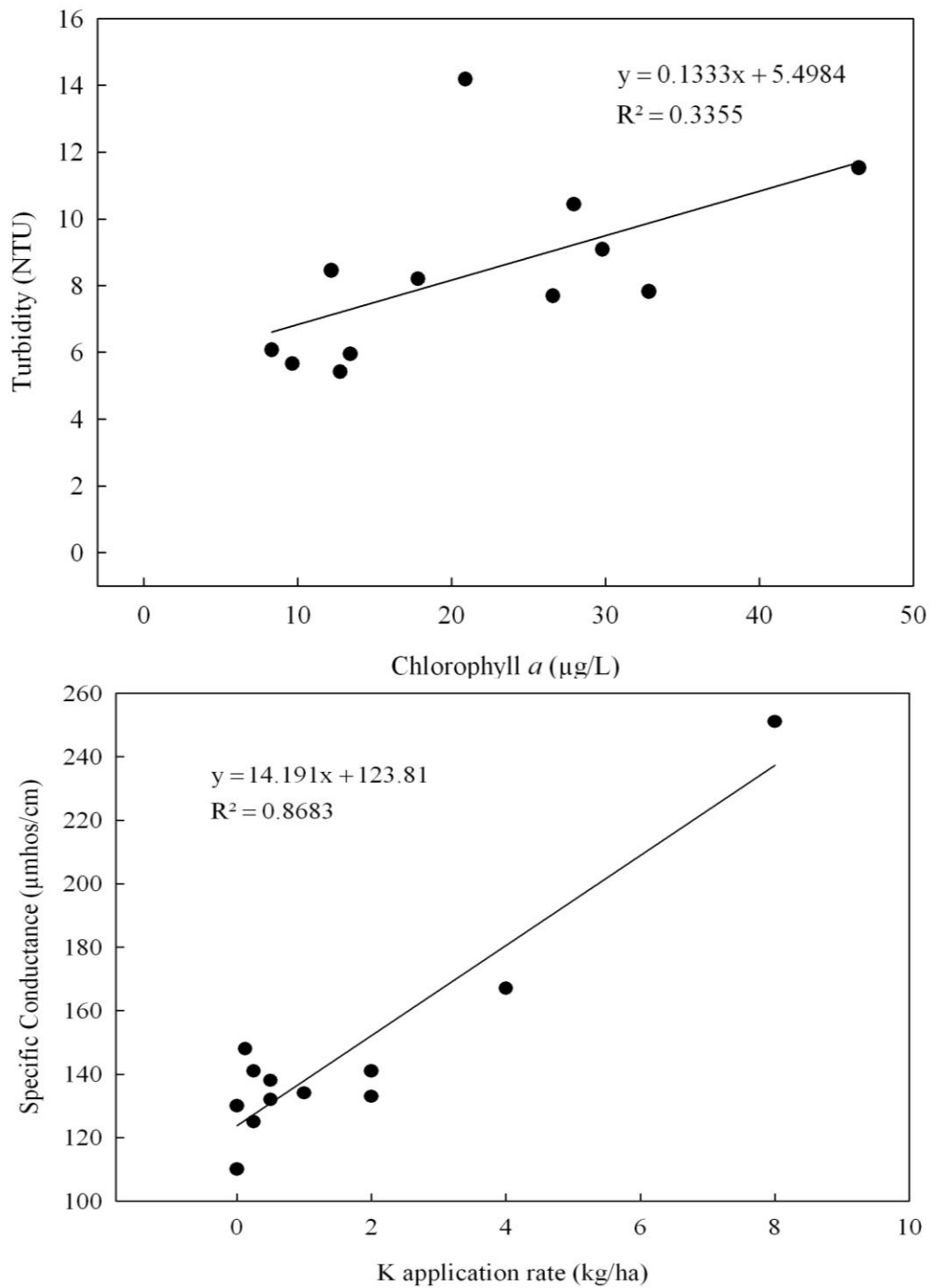$$y = 14.191x + 123.81$$
$$R^2 = 0.8683$$

Figure 4 Upper : Relationship between average chlorophyll *a* concentration and turbidity of pond water. Lower: Relationship between potassium fertilization rates and specific conductance.
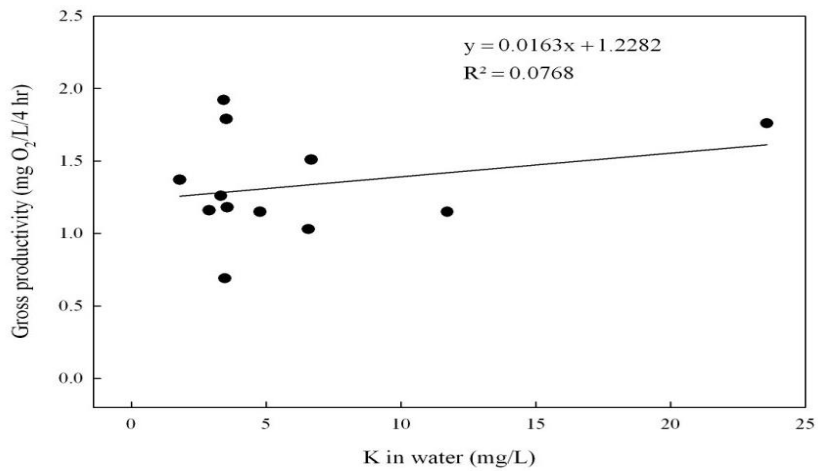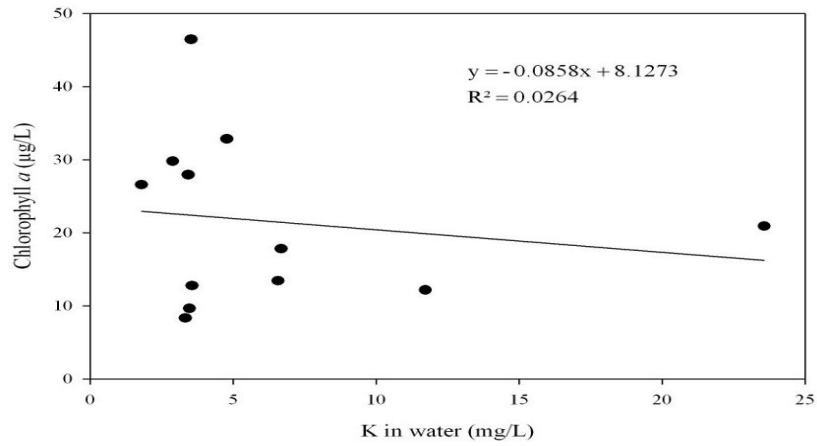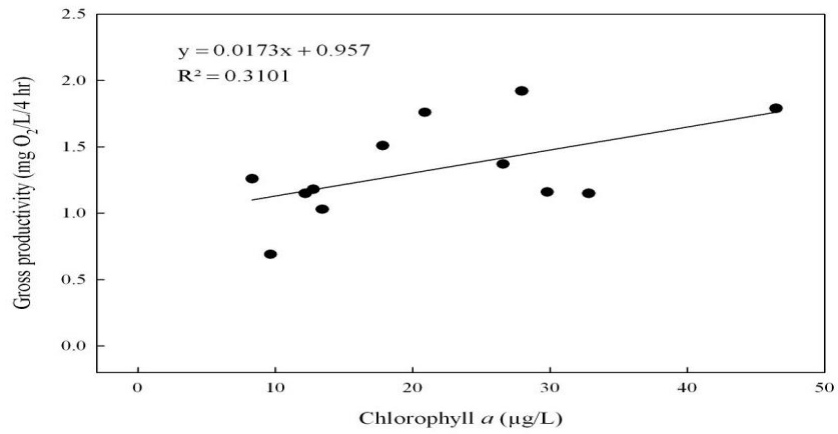
Figure 5 Relationship between average chlorophyll *a* concentration and gross

photosynthesis in pond water.(upper). Relationship between average potassium

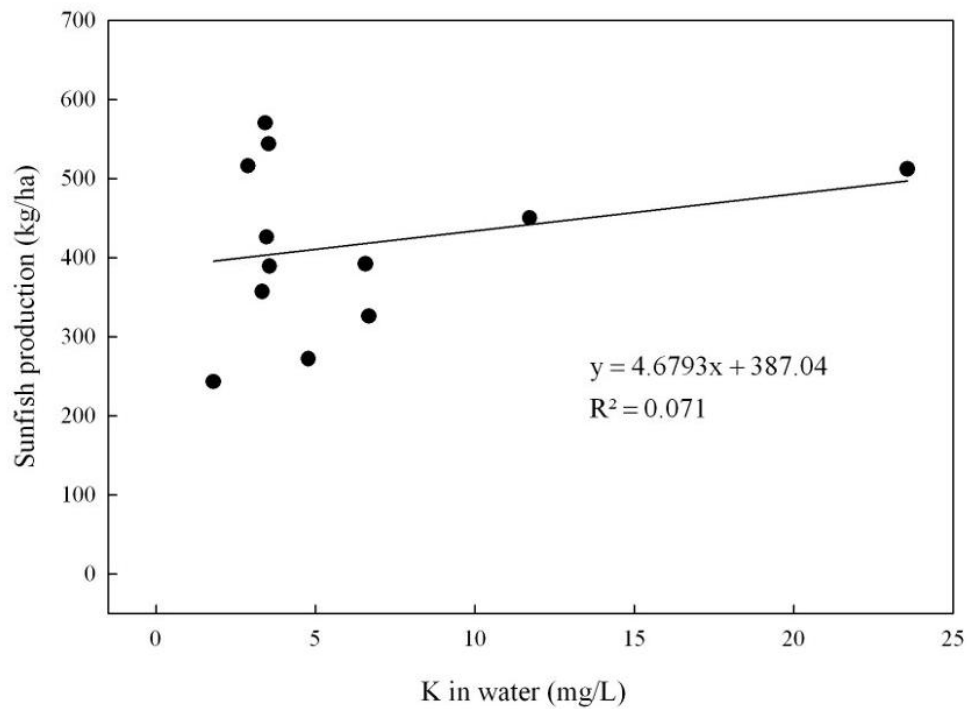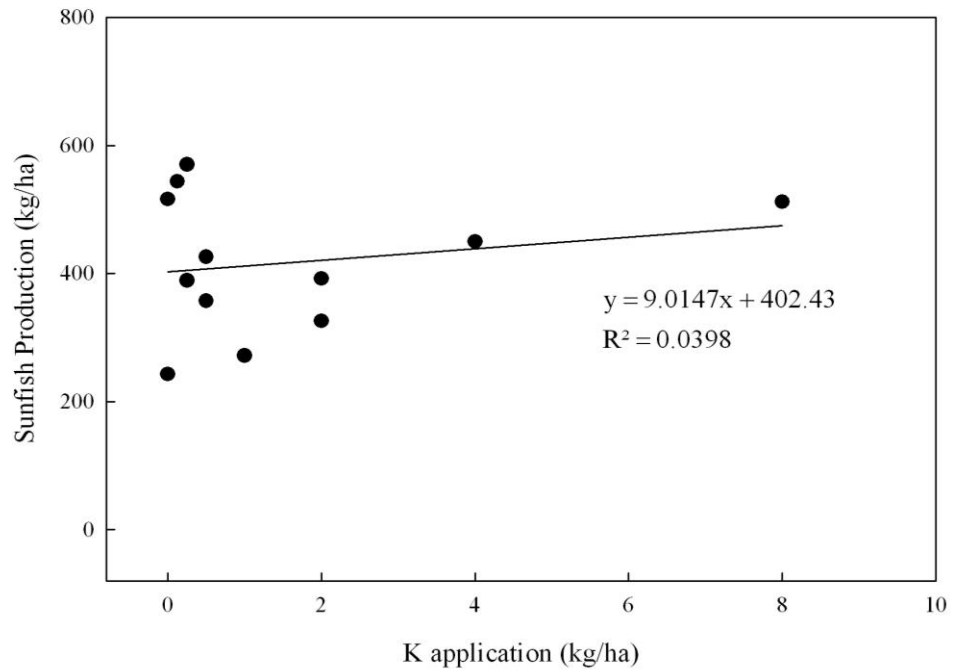concentration and chlorophyll *a* concentration (middle) and gross photosynthesis (lower)

$$y = 9.0147x + 402.43$$
$$R^2 = 0.0398$$

$$y = 4.6793x + 387.04$$
$$R^2 = 0.071$$

Figure 6 Upper : Relationship between potassium fertilizer application rate and sunfish production in ponds. Lower: Relationship between average potassium concentration and sunfish production in ponds.
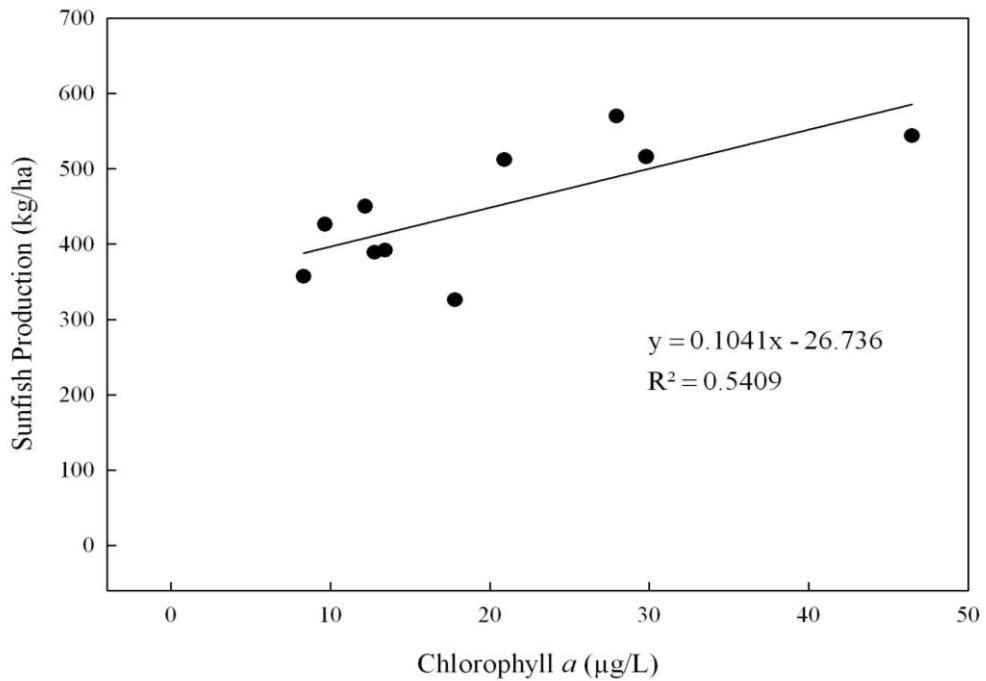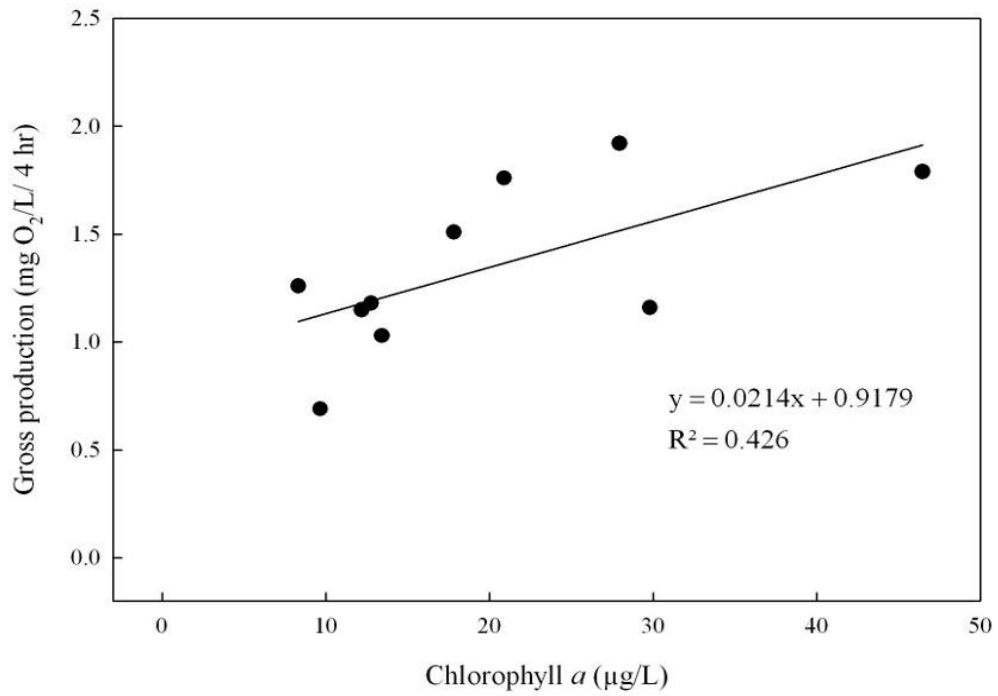
Figure 7 Relationship between average chlorophyll *a* concentration and sunfish production in sunfish ponds : Upper (all ponds); lower (two ponds without incomplete fish recovery become of algae mats excluded)
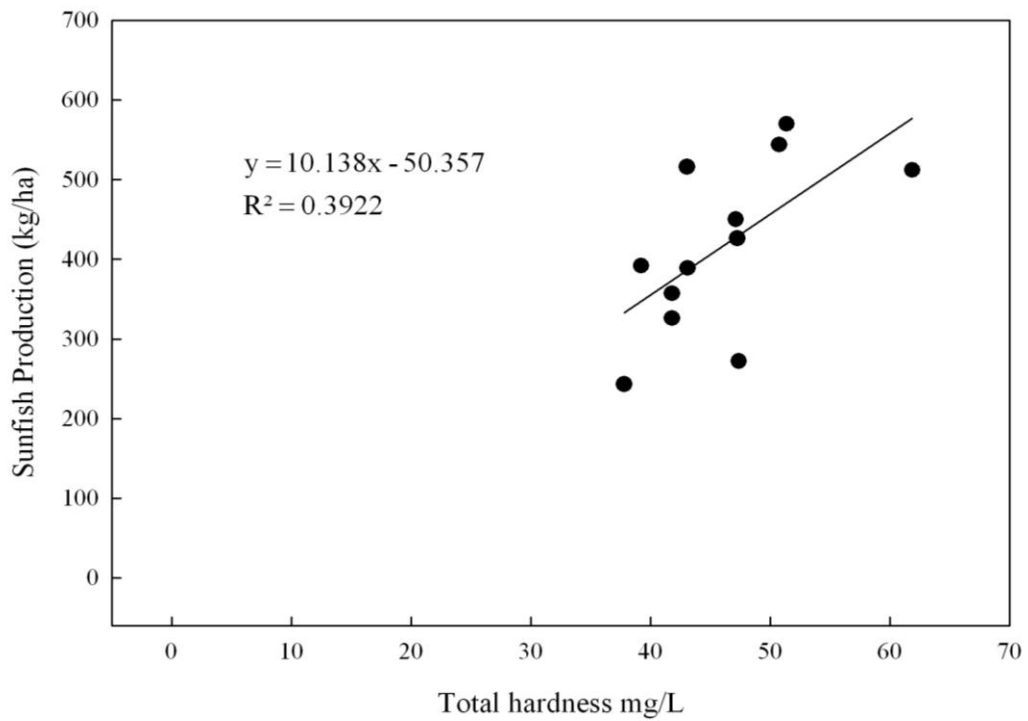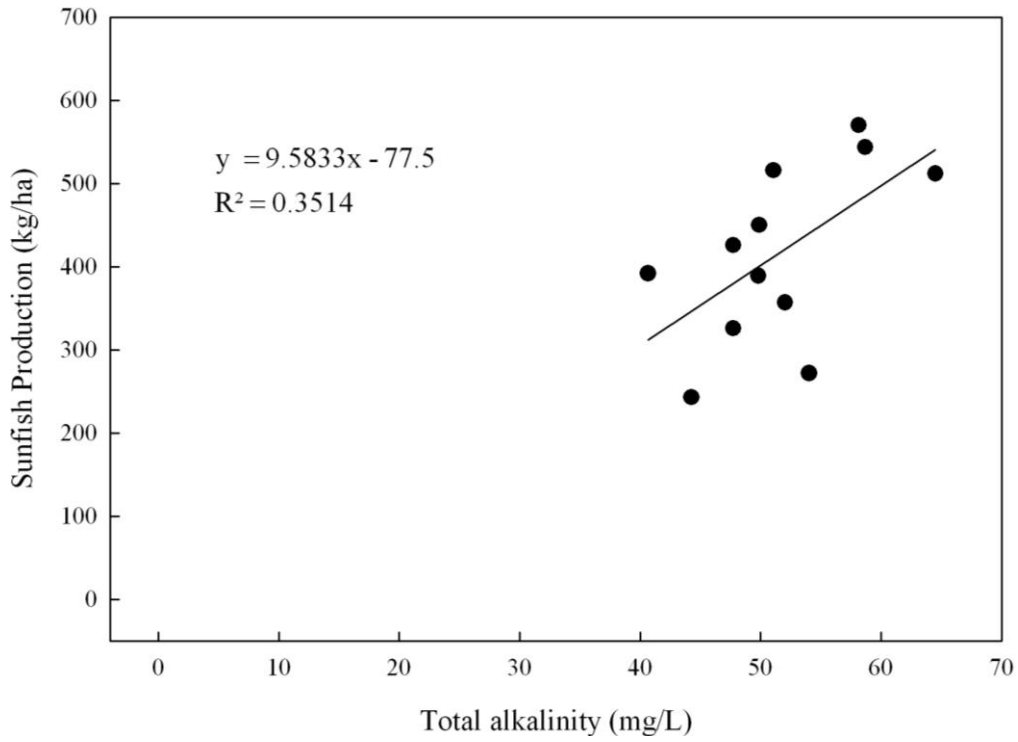
Figure 8 Relationship between total alkalinity concentration (upper) and total hardness (lower) and sunfish production in ponds

LITERATURE CITED

Bideh, S., and L.C. Rai. 2006. Potassium-induced inhibition of photosynthesis and associated electron transport chain of *Microcystis*: implication for controlling cyanobacterial blooms. Harmful Algae 5:184-191.

Boyd, C.A., P. Pengseng and C.E. Boyd. 2008. New nitrogen fertilization recommendations for bluegill ponds in the southeastern United States. North American Journal of Aquaculture 70(3):303-313.

Boyd, C.E.,J. Querioz, and R. Wright. 2002. Managing sport fish ponds to lessen nutrient discharge to streams. Wildlife Trends 2(7):13-15.

Boyd, CE. 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Boyd, C.A., C.E. Boyd, and D.B. Rouse. 2007. Potassium adsorption by bottom soils in ponds for inland culture of marine shrimp in Alabama. Journal of the World Aquaculture Society 38(1):85-91.

Boyd, C.E., and C.S. Tucker. 1992. Water quality and pond soil analyses for aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Boyd, C.E., and C.S. Tucker. 1998. Pond aquaculture water quality management. Kluwer Academic Publishers, Boston, Massachusetts, USA.

Boyd, C.E. 2003.Chemical fertilizers in pond aquaculture. Global Aquaculture Advocate :74-75.

Boyd, C.E. 1985. Pond evaporation. Transactions of the American Fisheries Society
114:299-303.

Clesceri, L.S., A.E. Greenberg, and A.D. Eaton. 1998. Standard Methods for the
Examination of Water and Wastewater, 20th edition. American Public Health
Association, Washington, D.C.

Das, S.K., and B.B. Jana.1996. Pond fertilization through inorganic sources: an overview.
Indian Journal Fisheries 43(2):137-155.

Dobbins, D.A., and C.E. Boyd. 1976. Phosphorus and potassium fertilization of sunfish
ponds. Transactions of the American Fisheries Society 105:536-540.

Doyle, K. M., and C.E. Boyd. 1984. The timing of inorganic fertilization of sunfish
ponds. Aquaculture 37:169-177.

Hepher, B. 1962. Ten years of research in fish pond fertilization in Israel. I. The effect of
fertilization on fish yields .Bamigdeh, 14:29-38.

Hepher, B. 1963. Ten years of research in fish pond fertilization in Israel. II. Fertilizers
dose and frequency of fertilization. Bamidgeh 15:78-92.

Hickling, C.F. 1962. Fish cultures. Faber and Faber, London England. 295pp.

Jaworski, G.H.M., J.F. Talling, and S.I. Heaney. 2003. Potassium dependence and
phytoplankton ecology: an experimental study. Freshwater Biology 48:833-840.

Lin, C. K,. V. Tansakul, and C. Apinhapath. 1988. Biological Nitrogen Fixation as a
Source of nitrogen Input in Fishponds, 53-58.

McNevin, A., C.E. Boyd, Silapajarn, O., and Silpajarn, K. 2004. Ionic supplementation
of pond waters for inland culture of marine shrimp. Journal World Aquaculture
Society 35:460-467.

Masser, M. undated. Management of recreational fish ponds in Alabama. Alabama

Cooperative Extension Service, Auburn University, Alabama, USA

Metzger, R.J., and C.E. Boyd. 1980. Liquid ammonium polyphosphate as a fish pond

fertilizer. Trans. Amer. Fish. Soc. 109:563-570.

Mortimer, C.H. 1954. Fertilizers in fish ponds. Fisheries Publication Number 5, Her

Majesty's Stationery Office, London, England.

Murad, A.A., and C.E. Boyd 1987. Progressive Fish Culturist 49:100-107.

Swingle, H. S. 1947. Experiments on pond fertilization. Bulletin 264, Alabama

Agricultural Experiment Station, Alabama Polytechnical Institute, Auburn,

Alabama, USA.

Saha, G.N. 1979. Techniques of pond fertilization and use of fertilizers in freshwater

aquaculture for increased fish production. Fertilizer News 24(2):3-6.

Swingle, H.S., and E.V. Smith 1938. The relationship between plankton production and

fish production in ponds. Trans. American Fisheries Society 68:309-315.

Swingle, H.S., B.C. Gooch, and H.R. Rabannal. 1963. Phosphate fertilization of ponds.

Proceedings of the Annual Conference of Southeastern Association of Game and

Fish Commission 17:213-218.

Wetzel, R.G. 2001. Limnology lake and river ecosystems. Academic Press, San Diego,

California, USA.

Wudtisin, W., and C.E. Boyd. 2005. Determination of the phosphorous fertilization rate

for bluegill ponds using regression analysis. Aquaculture Research 11:14 1-7.

Yuvanatemiya, V., and C.E. Boyd. 2006. Physical and chemical changes in aquaculture

pond bottom soil resulting from sediment removal. Aquacultural Engineering 35(2):199-205.