Relation of Light Intensity with Dissolved Oxygen and Chlorophyll-a in Nile Tilapia Ponds

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ABSTRACT

This study investigated the relations among the parameters of light intensity, dissolved oxygen and chlorophyll-a in earthen ponds used to rear tilapia. Fifteen ponds at sites located in 5 provinces in northern Thailand - Chiangrai, Chiangmai, Phayao, Lampang and Nakhonsawan - were sampled monthly between May 2013 and May 2014. Elevation of pond sites ranged from 25 to 582 meters above sea level (masl). Ponds were 0.8 to 2.0 meter deep and 0.16 to 0.64 hectare in area. Ponds were categorized according to elevation (low, <400 masl and high, >400 masl) and culture system (intensive and extensive). Pond water samples were further classified according to season (hot, wet and dry) and time of the day for analysis. ANOVA was used to analyze differences in mean light intensity, DO and chlorophyll-a in ponds by elevation, culture system, season and time of the day. The results showed that light intensity varied significantly with elevation, season and time of the day. Mean light intensity ranged from 16.0 to 951.9 µmol m^{-2} s^{-1}. DO varied significantly with season, culture system and time of the day. Mean surface DO ranged between 1.83 to 10.53 mg/l. Light intensity was high from the afternoon to late afternoon and DO in fish ponds increased as light on ponds increased. Chlorophyll-a varied significantly by season and culture system. Intensive culture ponds contained higher concentrations of chlorophyll-a and hence higher DO levels than extensive culture ponds. In intensive culture ponds, the levels of DO in early morning (04:00 to 06:00) in 68% of observations were lower than the low threshold value for Nile tilapia. These findings suggest that farmers who raise fish in intensive culture ponds should adopt appropriate strategies that maintain favorable levels of DO in order to reduce risk of production losses, for example, from periods of prolonged cloud cover which block sunlight reducing photosynthesis by phytoplankton.

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Key words: Light intensity, Dissolved Oxygen, Chlorophyll-a, Tilapia

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INTRODUCTION

Tilapia culture in earthen ponds is expanding dramatically in Thailand (DOF, 2011). Farmers, especially in the north and northeast raise these popular freshwater fish under either intensive or extensive methods. Water quality in fish ponds is influenced by a complex interplay of many factors (Ahmed *et al*., 2011) that influence feeding, growth, disease burdens and survival (Pandit and Nakamura, 2010). Light is an essential resource for phytoplankton photosynthesis and thus oxygen generation in fish ponds (Chang and Ouyang, 1988; Litchman *et al*., 2004; Smith and Piedrahita, 1988). Light intensity at the water surface varies with time of the day, season and cloud conditions (Grobbelaar *et al*., 1992; Litchman, 1998). Light intensity at lower water depths is also affected by water turbidity and phytoplankton concentrations (Foder *et al*., 2002). Reduced light intensities are thus important because they reduce photosynthesis by plankton which could ultimately result in lower levels of DO in fish ponds as fish and phytoplankton respire especially during the night. Low DO levels reduce fish growth and can result in mass mortality (Chang and Ouyang, 1988; Noor El Deen and Zaki, 2010). Cloud cover is influenced by weather, seasons and climate; thus, light intensities important to aquaculture may also be influenced by changes in climate (Handisyde *et al*., 2006; Janjai and Wattan, 2011; Warren *et al*., 2007). In northern Thailand, prolonged cloud cover is concerned by farmers and fisheries experts as one of the most important risks to tilapia culture (Pimolrat *et al*., 2013). The main objectives of this research were to: (1) investigate the patterns in variation in light intensity, DO content and chlorophyll-a among different culture systems, seasons and elevations-sites; and (2) to identify whether and how cloud cover, as it influences light intensity, is a relevant climate-risk, and if so, effective ways for improving water quality management to reduce risks of DO depletion in fish ponds during periods of reduced light intensities.

MATERIALS AND METHODS

1. Study site.

Observations were made in 5 farms in 5 provinces in Northern Thailand: Chiangrai, Chiangmai, Phayao, Lampang and Nakhonsawan. Three ponds were observed in each farm giving a total of 15 ponds (Figure 1). The ponds on same farm were treated as independent replicates because they were different sizes, stocked on different dates and densities, and water management also differed. Samples for water quality analysis were collected every month between May 2013 and May 2014 yielding a total of 825 samples. Mean elevation of the ponds ranged from 25 to 582 meters above sea level (masl). Pond sizes ranged from 0.16 to 0.64 hectare and water depths ranged from 0.8 to 2.0 meter. Pond samples were grouped according to: elevation – low (<400 masl: n=9) and high (>400 masl: n=6); season – hot (May 2013 and March to May 2014), wet (June to October) and dry (November 2013 to February 2014); and, culture system. Ponds under intensive culture were stocked at high densities (2-3 fish/m^2) and received high inputs of nutrients either from regular feeding with pellet feeds or from manure fertilization (n=9). Ponds under extensive culture were stocked at lower densities (0.5-1 fish/m^2) and received much lower inputs of nutrients as they had no fertilizer inputs and feeding was sporadic (n=6).

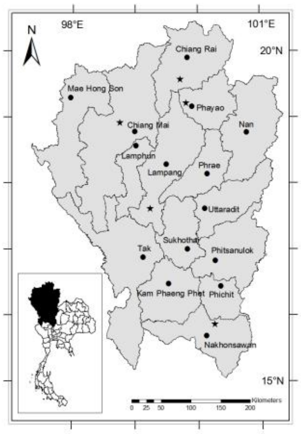

Figure 1 Map of study area in Northern Thailand. Stars indicate farm locations, dots the city district in each province.

2. Light intensity and water quality analysis.

Light intensity was monitored every 2 hours on one 24-hour period each month with a lux meter (Lux/Fc light meter DL-204) at 10 centimeters above the water surface (as instrument could not be safely submersed) in the middle of the pond. Intensities were converted from lux to Photosynthetically Active Radiation (PAR in μmol m^{-2} s^{-1}) using a conversion factor of 0.019 (Environmental Growth Chambers, 2013; Janjai and Wattan, 2011). In photosynthesis plant uses solar radiation in the wavelength range of 400–700 nm. Water temperature and dissolved oxygen (DO) were monitored at 2-hour interval over a 24-hour period at 30 centimeter depth with a multi-meter (TOA DKK WQC-22A model, Japan). Chemical analyses were carried out for Chlorophyll-a, Nitrate-Nitrogen (NO_3^--N) and Orthophosphate (PO_4^{3-}-P) according to standard methods (APHA, 1998).

3. Data analysis.

Analysis of variance (ANOVA) was used to compare means across the two elevation groups, two culture systems, three seasons and time of the day (every 2 hours in a 24 hour cycle). Chlorophyll-a measures were transformed to homogenize variances.

RESULTS AND DISCUSSION

1. Variation in light intensity

Light intensities just above the pond surface varied with elevation, season and time of the day. Photosynthetically Active Radiation (PAR) in the dry season was higher than in the wet and hot seasons (Figure 2a). In the wet and dry season PAR was higher at higher elevations but in the hot season elevation had no effect. Skies were often clear in the dry season, whereas in the wet and hot season cloud cover was often high and it sometimes rained, especially in the afternoons. During the day (06:00 to 18:00) PAR was highest between 12:00 to 14:00, and overall ranged between 16 to 952 µmol m^{-2} s^{-1} (Figure 2b). Janjai and Wattan (2011) reported PAR in Northern Thailand is normally highest between 11:00 to 14:00. The southwest monsoon from the Andaman Sea to Thailand first brings clouds and rainfall in May and gradually strengthens from June to October, reducing PAR levels over the region (Janjai and Wattan, 2011).

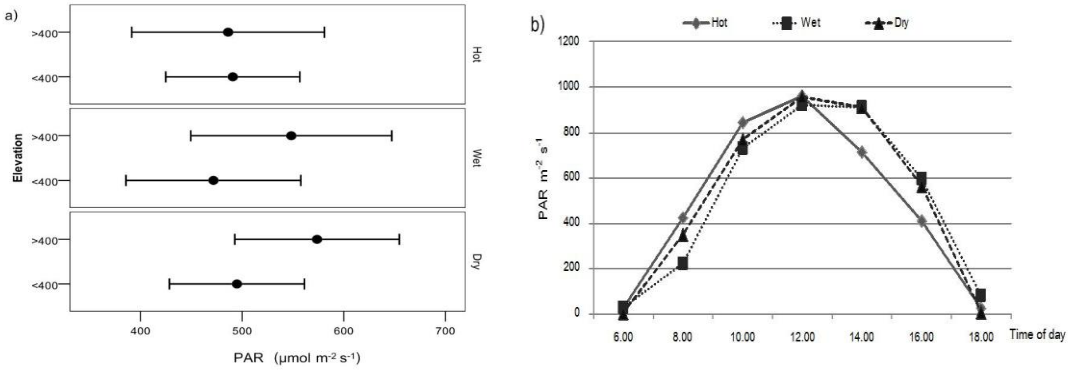

Figure 2 Variation in PAR. (a) Mean 12 hour PAR in different elevations and seasons. Plotted symbols are means and bars 95% confidence intervals (CI) for those means. (b) Mean PAR at different times of the day in three seasons.

2. Effect of light intensity on Dissolved Oxygen (DO)

Over the day amount of DO in fish ponds increased as PAR increased. Mean surface DO ranged between 1.83 to 10.53 mg/l (5.57±4.48 mg/l). The maximum DO was found in the afternoon around 14:00 to 16:00 and continuously decreased from after sunset to early morning (Figure 3a). Multifactor-ANOVA was used to analyze the influence of season, time of the day and fish culture system on DO level. A significant interaction between season, time of the day and culture system was found ($P<0.05$). Intensive culture ponds had higher mean DO level than extensive culture ponds in the hot and dry season but not in the wet season (Figure 3b). In intensive culture ponds DO was higher than in extensive culture ponds in middle of day and lower early in the morning (Figure 3a). The observed increase in DO as PAR increase was due to algal photosynthesis (Ekubo and Abowei, 2011). The pattern of DO being lowest in the early morning, increasing during daylight hour to a maximum in late afternoon and decreasing again at night (Figure 3a) is similar to that reported by others (Boyd and Lichtkoppler, 1979). In the intensive culture ponds, 68 % of DO measurements in early morning (04:00 to 06:00) were lower than the suggested threshold minimum DO concentration at which feed intake and growth of Nile tilapia starts to decline (0.8 mg/l at 26°C) (Duy *et al.*, 2008) whereas in ponds under extensive culture this occurred in only 14 % of samples. Ponds under intensive culture were at much higher risk of hypoxia conditions at dawn than those under extensive culture.

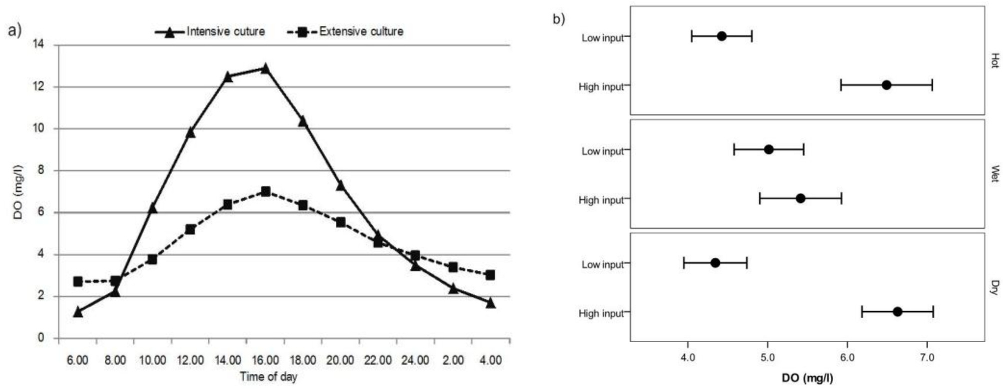

Figure 3 Mean DO levels of different culture systems: (a) at different times of the day and (b) in different seasons. Plotted symbols are means and in (b) bars are 95% confidence intervals (CI) for those means.

The effect of thick and prolonged cloud cover on PAR and DO levels in fish ponds was obvious from observations. On a clear sky day, PAR was normally high from 12:00 to 14:00 and DO level was high from 14:00 to 16:00 (Figure 4a). However, on a day with high cloud cover and rain mean PAR dropped from 625 μmol m^{-2} s^{-1} at 10:00 to 302 μmol m^{-2} s^{-1} at 14:00 leading to the decrease of mean DO level from 14.5 mg/l at 14:00 to 12.1 mg/l at 16:00 (Figure 4b). From the observations in August, one intensive culture pond had a mass mortality event losing about 400 kg of full-sized fish during a week of cloudy and rainy days when DO levels stayed low. After that, the fish farmer obtained a paddle wheel mixer to help aerate the fish pond. Measurements show that the aerator helped to increase DO level in early morning from 0.21 mg/l to 0.98 mg/l. Good management in fish culture is important to preventing and reducing production losses from unfavorable weather conditions.

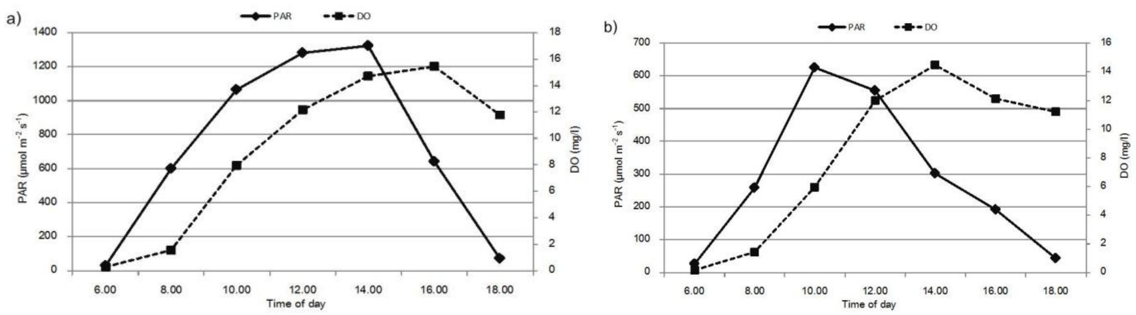

Figure 4 Mean PAR and mean DO of pond at Chiangrai site on a clear sky day (a) and on a day with high cloud cover (b).

3. Effect of light intensity on chlorophyll-a

Multifactor-ANOVA was used to analyze simultaneously the influence of light levels, fish culture system and season on chlorophyll-a. In the model light was treated as a covariate and fish culture and season as fixed factors without an interaction term. The analysis showed that culture system had a significant effect on chlorophyll-a ($F=146.106$, $df=1$, $P<0.001$) while light level and season did not. The mean concentration of chlorophyll-a in intensive culture ponds (95 % CI= 215.8-221.7 µg/l) was significantly higher than in extensive culture ponds (22.8-28.7 µg/l) which was consistent with amount of DO in waters. Chlorophyll-a positively correlated ($r=0.11$, $p<0.05$) with orthophosphate (mean 0.06±0.07 mg/l) while it negatively correlated with nitrate-nitrogen ($r=0.24$, $p<0.05$, mean 0.07±0.21 mg/l). In this study intensive culture systems included both conventional feed pellet-based and integrated fish farming systems. Conventional farms stocked at high densities and provided pellet feeds regularly while integrated farms combined fish ponds with pig lots in which manure fertilization stimulates production of natural food for fish. Nutrient loads are high in both culture systems. Fish waste and uneaten feed accumulate in sediments in the bottom of the pond and nutrients are subsequently released into the water and taken up by phytoplankton which bloom (Koch *et al*., 2004). When the amount of phytoplankton increases, the amount of chlorophyll-a increases as well (Hardy, 1973).

Light and nutrients in fish pond are important limiting factors for phytoplankton (Dickman *et al*., 2006; Diehl, 2002). In many aquatic systems phytoplankton competes not only for light but also for nutrients (Litchman *et al*., 2004). Several factors have been linked to limitation of phytoplankton production, but nutrient availability has frequently been observed to outweigh others (Domingues *et al*., 2005). Light limited conditions arise not only from persistent cloud cover, but may also result from movement towards surface of a deeper layer of water with high background turbidity (e.g. dissolved organic carbon or suspended particles) and/or high biomass of phytoplankton (Litchman, 2003). Light intensity decreases with depth because photons are absorbed by water, dissolved organic matter, phytoplankton species, and many other light-absorbing substances in the water column (Huisman *et al*., 2004). Phytoplankton at surface water prevents light penetration into lower layer leading to the increase of water temperature and DO level at the surface to be higher than the bottom layer (Sriyasak *et al*., 2013).

CONCLUSION

Elevation, season and time of the day had effects on light intensity near the surface of fish ponds. Light intensity was relatively higher in the afternoon to late afternoon and amount of DO in fish ponds increased as light intensity increased. Season, time of the day and culture system had an effect on DO. The DO level in pond under intensive culture was higher than in pond under extensive culture, DO in the hot season and dry season were higher than the wet season. Amount of chlorophyll-a in intensive culture was higher than in extensive culture and could be related to the amount of DO in surface waters. These findings altogether suggest that farmers adopting intensive culture ponds should manage nutrients so as to not generate to high concentrations or blooms of phytoplankton and be prepared to use aerators or mechanical water mixers to maintain safe levels of DO in the pond, especially early in the morning and during periods of prolonged cloud cover that lead to low DO levels.

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REFERENCES

Ahmed, Z., A. Hisham and A. Rahman. 2011. Ecomonitoring of climate impact on earthen pond water quality in El-fayoum, Egypt. **International Research Journal of Microbiology** 2: 442-454.

APHA. 1998. **Standard Methods for the Examination of Water and Wastewater.** Washington, DC.

Boyd, C.E. and F. Lichtkoppler. 1979. **Water Quality Management in Fish Ponds.** International Centre for Aquaculture (J.C.A.A) Experimental Station Auburn University, Alabama.

Chang, W.Y.B. and H. Ouyang. 1988. Dynamics of dissolved oxygen and vertical circulation in fish ponds. **Aquaculture.** 74: 263-276.

Dickman, M.E., J.M. Vanni and J.M. Horgan. 2006. Interactive effects of light and nutrients on phytoplankton stoichiometry. **Oecologia.** 149: 676-689.

Diehl, S. 2002. Phytoplankton, light, and nutrients in a gradient of mixing depth: Theory. **Ecology.** 83: 386-398.

DOF. 2011. **Tilapia Development Strategy (2010-2014)** Department of Fisheries, Ministry of Agricultural and Cooperatives, Bangkok.

Domingues, B.R., A. Barbosa and H. Galvao. 2005. Nutrients, light and phytoplankton succession in a temperate estuary (the Guadiana, South-western Beria). **Estuarine, Coastal and Shelf Science.** 64: 249-260.

Duy, A.T., J. Scharama, A.V. Dam and A.J. Verreth. 2008. Effects of oxygen concentration and body weight on maximum feed intake, growth and hematological of Nile Tilapia, *Oreochromis niloticus*. **Aquaculture.** 275: 152-162.

Ekubo, A.A. and J.F.N. Abowei. 2011. Review of some water quality management principles in culture fisheries. **Research Journal of Applied Sciences, Engineering and Technology.** 3: 1342-1357.

Environmental Growth Chambers. 2013. **Lighting Radiation Conversion**. Available source: http://www.egc.com/useful_info_lighting.php.

Foder, S., J. Urabe and Z. Kawabata. 2002. The Influence of fluctuating light intensities on species composition and diversity of natural phytoplankton communities. **Oecologia.** 133: 395-401.

Grobbelaar, J., B.M.A. Kroon, T. Burger-Wiersma and L. Mur. 1992. Influence of medium frequency light/dark cycles of equal duration on the photosynthesis and respiration of *Chlorella pyrenoidosa*. **Hydrobiologia.** 52-62.

Handisyde, N.T., L.G. Ross, M.-C. Badjeck and E.H. Allison. 2006. **The Effect of Climate Change on World Aquaculture: A Global Perspective.** Department for International Development.

Hardy, J.T. 1973. Phytoneuston ecology of a temperate marine lagoon. **Limnology and Oceanography.** 18: 525-533.

Huisman, J., J. Sharples, M.J. Stroom, M.P. Visser, A.W. Kardinaal, M.H.J. Verspagen and B. Sommeijer. 2004. Changes in turbulent mixing shift competition for light between phytoplankton species. **Ecology.** 85: 2960-2970.

Janjai, S. and R. Wattan. 2011. Development of a model for the estimation of photosynthetically active radiation from geostationary satellite data in a tropical environment. **Remote Sensing of Environment.** 115: 1680-1693.

Koch, W.R., L.D. Guelda and A.P. Bukaveckas. 2004. Phytoplankton growth in the Ohio, cumberland and Tennessee rivers, USA: Inter-site differences in light and nutrient limitation. **Aquatic Ecology.** 38: 17-26.

Litchman, E. 1998. Population and community responses of phytoplankton to fluctuating light. **Oecologia** 117: 247-257.

Litchman, E. 2003. Competition and coexistence of phytoplankton under fluctuating light: experiments with two cyanobacteria. **Aquatic Microbial Ecology.** 31: 241-248.

Litchman, E., C.A. Klausmeier and P. Bossard. 2004. Phytoplankton nutrient competition under dynamic light regimes. **Limnology Oceanography.** 49 (4, part 2): 1457-1462.

Noor El Deen, A.I.E. and M. Zaki. 2010. Impact of climatic change (oxygen and temperature) on growth and survival rate of Nile Tilapia (*Oreochromis niloticus*). **Report and Opinion.** 2: 192-195.

Pandit, N.P. and M. Nakamura. 2010. Effect of high temperature on survival, growth and feed conversion ratio of Nile Tilapia, *Oreochromis niloticus*. **Our Nature.** 8: 219-224.

Pimolrat, P., N. Whangchai, C. Chitmanat, J. Promya and L. Lebel. 2013. Survey of climate-related risks to tilapia pond farms in northern Thailand **International Journal of Geoscience** 4: 54-59.

Smith, D.W. and R.H. Piedrahita. 1988. The relation between phytoplankton and dissolved oxygen in fish ponds. **Aquaculture.** 68: 249-265.

Sriyasak, P., C. Chitmanat, N. Whangchai, J. Promya and L. Lebel. 2013. Effects of temperature upon water turnover in fish ponds in northern Thailand. **International Journal of Geoscience.** 4: 18-23.

Warren, G.S., M.R. Eastman and J.C. Hahn. 2007. A survey of changes in cloud cover and cloud types over land from surface observations, 1971–96. **Journal of climate.** 20: 717-738.