

Ocean Fertilization with Macronutrients

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Summary

This submission discusses ocean fertilization with macronutrients as a geoengineering method to mitigate climate change. Some essential features of this method are briefly addressed, in some cases with comparison to related technologies. Space precludes dealing with all issues related to ocean fertilization with macronutrients. The aim of the submission is to show that macronutrient ocean fertilization is a contender for greenhouse gas mitigation and thus should be targeted for research.

Key Points:

- Macronutrient ocean fertilization has the potential to sequester up to 0.8 GtC/yr, using nitrogen fertilization alone. With the addition of phosphorous to the fertilizer, the potential is much larger.
- Macronutrient ocean fertilization has a number of potential advantages in comparison with micronutrient fertilization. Further research is needed to clarify.
- Macro and micronutrient ocean fertilization are applicable in complementary parts of the ocean.

Introduction

The problem of rising levels of carbon dioxide in the atmosphere is addressed in many documents. Biosequestration of carbon by fertilization of the ocean is one of the geoengineering approaches that have been proposed to help mitigate the problem.

Ocean fertilisation has the ability to drawdown CO₂ from the atmosphere. This technique is technically relatively simple to implement. It shows promise of being inexpensive, in comparison with existing and expected future prices of carbon credits.

To date, much of the emphasis of research and discussion has gone into the use of the micronutrient iron as the fertilizer. However, we believe that fertilization of the ocean with macronutrients, such as nitrogen and phosphorus, holds even greater promise of providing sequestration of large quantities of carbon.

Macronutrient Fertilization

Nitrogen is an essential ingredient for macronutrient fertilization of the oceans. The concentration levels of phosphorous (another macronutrient) are important for consideration of ocean fertilization. The macronutrient balance in the world's oceans (Figure 1), averaged over the annual cycle, is such that 80% of the surface area has an excess of phosphorous above the Redfield ratio for nitrogen. (The Redfield ratio is the elemental ratio applicable to growth of phytoplankton in the ocean.) The remaining 20% of the world's ocean corresponds approximately to the region that has a shortage of the micronutrient iron.

For a threshold of 0.2 µmol/l phosphorous excess, 50% of the ocean is available for fertilization by nitrogen only. For 0.4 µmol/l phosphorous excess, 16% of the ocean is available. These values are calculated using data from the World Ocean Atlas (2005) for nitrate and phosphate levels, on a 1° grid, in the surface ocean.

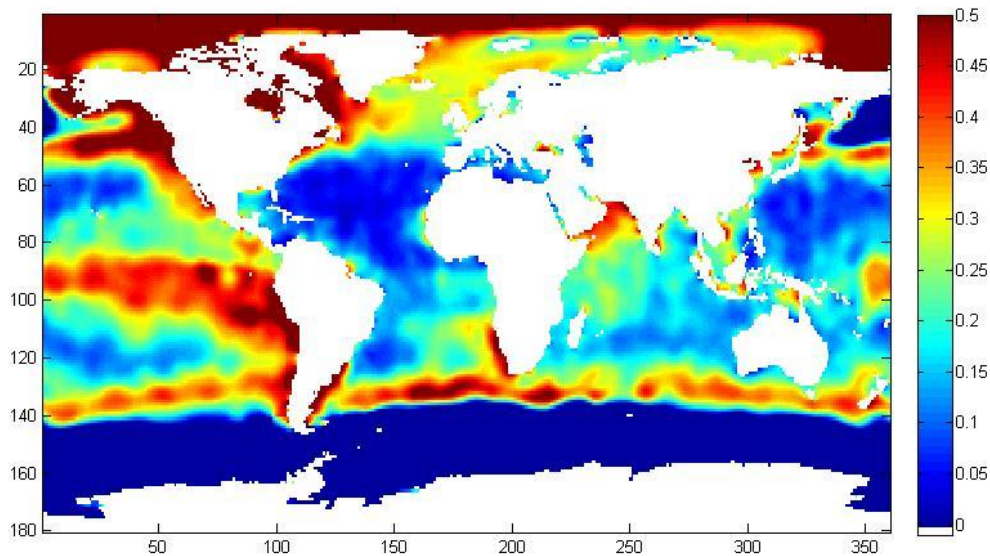


Figure 1: Excess of phosphorous over nitrogen in the surface ocean expressed in $\mu\text{mol/l}$. Zero is at the Redfield ratio. Plotted values are limited to range 0.0 to 0.5 $\mu\text{mol/l}$ excess phosphorous. Values outside this range are set to the limiting values. (Data are from World Ocean Atlas 2005).

The quantity of carbon that could potentially be sequestered by fertilization with nitrogen alone is estimated to be 0.8 GtC/yr (which corresponds to 2.9 GtCO₂/yr). To achieve greater levels of sequestration, phosphorous would need to be added to the nitrogen fertilizer.

The above potential sequestration limit is determined by first calculating the quantity of carbon that is the (Redfield) equivalent to the excess phosphorous in the 80% of the ocean with excess phosphorous. This quantity of carbon is 8.0 GtC. To obtain a sustainable annual sequestration value this must be divided by the replenishment time of the phosphorous. Surface water remains above the seasonal thermocline for order of a decade (Broecker and Peng 1982). Using this estimate of replenishment time leads to the estimate of 0.8 GtC/year for the upper limit of ocean biosequestration by nitrogen (alone) fertilization.

Clearly the above sequestration values are not precise, nor do they account for various inefficiencies that might arise in the process. However, they do serve to provide the current best estimate of the size of benefit that might be available by this technology, using nitrogen alone.

Reactive nitrogen can be produced in required quantities in the same way used for agriculture on land. Any CO₂ produced in manufacture of fertilizer is easily accommodated in the overall carbon accounting of ocean fertilization. The total cost involved in producing and delivering nitrogen fertilizer from ships is favourable compared with the current price of carbon credits.

To achieve even greater levels of sequestered CO₂, phosphorous could be added to the ocean along with nitrogen. The economics of this approach will depend on the price of phosphorous which has been fluctuating considerably in recent times. However, this approach also appears to be economically viable, based on selling carbon credits.

Aspects of Ocean Biosequestration

It is known that ocean fertilization will convert CO₂ into organic form and sequester some fraction of it for long periods of time. The recent review by Lampitt et al. (2008) covers ocean fertilization in general. The article by Jones (2004) addresses macronutrient ocean fertilization.

The following discussion attempts to bring out issues of technical relevance for ocean fertilization with macronutrients, contrasting with micronutrient fertilization where appropriate.

- **Ocean Regions:** The proportion of the world's surface ocean that is primarily limited by the lack of micronutrients (primarily iron) is approximately 25% of the world's ocean (Lampitt et al. 2008), with the remaining 75% being limited by lack of macronutrients.
- **Sequestration Efficiency:** On adding fertilizer to the surface ocean, new primary production will convert inorganic carbon into organic carbon. After the timescale of the life of individual phytoplankton (about one week), some of this organic carbon will be exported out of the surface layer. Remineralisation of the dead organic matter remaining in the surface layer then occurs, providing nutrients for the next generation of phytoplankton. Provided the area has not been over fertilized, the process repeats until the added nutrient has left the surface layer. In the case of macronutrients, it is expected that all of the added macronutrient will take carbon with it as it moves to deeper waters, leading to a very high efficiency in sequestering carbon. In the case of iron fertilization, there is considerable uncertainty as to the expected efficiency of sequestration (Lampitt et al. 2008).
- **Sequestration Period:** Some carbon that is exported from the surface zone will enter the mid water levels and from there come back to the ocean surface. Some will enter the deep waters before returning to the surface, while another fraction will reach the sea floor and remain there for a very long time. More study is required of the fractional distribution of sequestration periods. For example, for a given fertilization process, how much carbon will be sequestered for in excess of 100 years and how much for in excess of 1,000 years?
- **Atmospheric drawdown of CO₂:** As pointed out by Lampitt et al. (2008), it takes time for CO₂ to move from the atmosphere to the ocean, after fertilization reduces the level of dissolved CO₂ in the surface ocean. CO₂ depleted water must stay in contact with the atmosphere for sufficient time for this exchange to take place. Again, from Broecker and Peng (1982), surface water remains above the seasonal thermocline for order of a decade. This is a substantial period in which the surface water depleted in CO₂ level (by fertilization) will be in contact with the atmosphere, thus assisting atmospheric drawdown.
- **Nitrous Oxide Production:** Any production of N₂O, a powerful greenhouse gas, will reduce the efficiency of the ocean biosequestration process. It has been suggested (Duce et al. 2008) that for ocean biosequestration by addition of reactive nitrogen, much of the effect of CO₂ sequestration could be negated by N₂O production. However this analysis did not consider all relevant effects. It is also necessary to take into account the relative longevity of the N₂O gas in the atmosphere as against the sequestration lifetime of the CO₂ in the ocean. The nitrous oxide stays in the atmosphere for 114 years (IPCC Report: Denman et al. 2007), while the carbon dioxide is sequestered in the ocean for 1,000 years (Duce et al. 2008). Taking this into account leads to a loss of efficiency of the macronutrient ocean biosequestration process of approximately 5%. Jin and Gruber (2003) have considered the issue of N₂O emissions from ocean iron fertilization.
- **Nutrient Stealing:** Advection of fertilized water can lead to "nutrient stealing", in which the benefits from adding nutrient in one location results in a lack of nutrient in another location. Modelling has predicted that this could be a problem with iron fertilization due to macronutrient limitations in temperate waters (Dutkiewicz et al. 2005). In contrast, fertilization with macronutrients should not be greatly impacted by advection of fertilized

water. However this issue requires more study. Macronutrient fertilization will consume trace nutrients. This may not be a problem as there are no areas of the ocean currently recognized as having limiting trace nutrients (with the exception of iron in certain locations). Nitrogen only fertilization would lead to reduced phosphate levels. What are the implications of this, e.g. for diazotrophs? If there are problems arising with nitrogen only fertilization, it may be prudent to fertilize with a combination of nitrogen and phosphorous.

- **Unknown Risks:** Because ocean fertilization has not previously been practised on a large scale, it has been suggested that some unknown or unexpected negative effect might eventuate. The technical issues need to be investigated to clarify whether there is an actual risk. There may be a different level of risk for each type of ocean fertilization. There is unlikely to be much progress on the issue of unknown risk without large demonstrations of the techniques. This concern can never be completely allayed solely by theoretical considerations and laboratory testing.

Future Research

It is clear that there will be need for a geoengineering solution in the near to mid-term. This is true even if the most optimistic international agreements are concluded and implemented. For this reason it is essential for there to be a rapid increase in the resources dedicated to scientifically exploring the various options for geoengineering. It is only when the science is clear that policy makers will be able to make an informed decision.

We strongly advocate that scientific research into ocean fertilization should include both macronutrient and micronutrient fertilization. The two types of fertilization have sufficient differences that one may be more attractive than the other from a technical viewpoint. Further, the two types of fertilization are applicable in different regions of the world's ocean.

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