JEP> Vol.2 No.6, August 2011

OPEN ACCESS

Model Estimates of Nutrient Uptake by Red Spruce Respond to Soil Temperature

PDF (Size:225KB) PP. 769-777 DOI: 10.4236/jep.2011.26089

Author(s)

J. Michael Kelly, Frank C. Thornton, J. Devereux Joslin

ABSTRACT

A better understanding of the mechanisms that control nutrient acquisition in the context of plant and ecosystem responses to climate change is needed. Mechanistic nutrient uptake models provide a means to investigate some of the impacts of temperature change on soil nutrient supply and root uptake kinetics through the simulation of key soil and plant processes. The NST 3.0 model, in combination with literature values on plant and soil parameters from a red spruce (Picea rubens L.) site in the southern Appalachians, was used to conduct a series of model simulations focused on the combined effects of changes to the maximal rate of nutrient influx at high concentrations (I_{max}), root growth rate (k), concentration of nutrient occurring in the soil solution (C_{li}), and the ability of the soil solid phase to buffer changes to the soil solution nutrient concentration (b). Previous research has indicated that these four parameters are responsive to changes in root zone temperature. Simulated uptake of NH4 increased by a factor of up to 2.6 in response to increases in soil temperature of 1 ° C to 5 ° C. The model also projected an increase in P uptake coupled with up to an 80% reduction in solution P concentration in response to a 1 ° C -5 ° C increase over a 147-d simulation period. These hypothetical changes, if validated, have interesting implications for plant growth and competition and point to a need for additional studies to better define the impacts of soil temperature on soil nutrient supply and root uptake.

KEYWORDS

Mechanistic Modeling, Imax, Root Growth Rate, Soil Buffer Power

Cite this paper

J. Kelly, F. Thornton and J. Joslin, "Model Estimates of Nutrient Uptake by Red Spruce Respond to Soil Temperature," *Journal of Environmental Protection*, Vol. 2 No. 6, 2011, pp. 769-777. doi: 10.4236/jep.2011.26089.

References

[1] M. E. Gavito, P. S. Curtis, T. N. Mikkelsen and I. Jakobsen, “ Interactive Effects of Soil Temperature, Atmospheric Carbon Dioxide and Soil N on Root Development, Biomass and Nutrient Uptake of Winter Wheat during Vegetative Growth, ” Journal of Experimental Biology, Vol. 52, No. 362, 2001, pp. 1913-1923.

[2] J. S. King, K. S. Pregitzer and D. R. Zak, “ Clonal Variation in above- and below-Ground Growth Responses of Populus Tremuloides Michaux: Influence of Soil Warming and Nutrient Availability, ” Plant and Soil, Vol. 217, No. 1-2, 1999, pp. 119-130. doi:10.1023/A:1004560311563

[3] P. S. Karlsson and K. O. Nordell, “ Effects of Soil Temperature on the Nitrogen Economy and Growth of Mountain Birch Seedlings Near Its Presumed Low Temperature Distribution Limit, ” Ecoscience, Vol. 3, 1996, pp. 183- 189.

[4] L. E. Rustad and I. J. Fernandez, “ Soil Warming: Consequences for Foliar Litter Decay in a Spruce-Fir Forest in Maine, USA, ” Soil Science Society of America Journal, Vol. 62, No. 4, 1998, pp. 1072-1080. doi:10.2136/sssaj1998.03615995006200040031x

[5] M. Weih and P. S. Karlsson, “ Growth Response of Mountain Birch to Air and Soil Temperature: Is Increasing Leaf-Nitrogen Content an Acclimation to Lower Air Temperature? ” New Phytologist, Vol.

150, No. 1, 2001, pp. 147-155. doi:10.1046/j.1469-8137.2001.00078.x

[6] M. Stromgren and S. Linder, "Effects of Nutrition and Soil Warming on Stemwood Production in a Boreal Norway Spruce Stand," Global Change Biology, Vol. 8, No. 12, 2002, pp. 1195-1204. doi:10.1046/j.1365-2486.2002.00546.x

[7] A. Gessler, S. Schneider, D. Von Sengbusch, P. Weber, U. Hanemann, C. Huber, A. Rothe, K. Kreutzer and H. Rennenberg, "Field and Laboratory Experiments on Net Uptake of Nitrate and Ammonium by the Roots of Spruce (Picea abies) and Beech (Fagus sylvatica) Trees," New Phytologist, Vol. 138, No. 2, 1998, pp. 275-285. doi:10.1046/j.1469-8137.1998.00107.x

[8] M. L. Adam, J. M. Kelly, W. R. Graves, and P. M. Dixon, "Net Nitrate Uptake by Red Maple Is a Function of Root-Zone Temperature," Journal of Plant Nutrition, Vol. 26, No. 1, 2003, pp. 203-222. doi:10.1081/PLN-120016505

[9] J. M. Kelly, "Temperature Affects Solution-Phase Nutrient Concentrations and Subsequent Calculation of Supply Parameters," Soil Science Society of America Journal, Vol. 57, 1993, pp. 527-531. doi:10.2136/sssaj1993.03615995005700020038x

[10] S. A. Barber, "Soil Nutrient Bioavailability: A Mechanist Approach," 2nd Edition, John Wiley & Sons, Inc., Hoboken, 1995.

[11] S. C. Sheppard and G. J. Racz, "Effects of Soil Temperature on Phosphorus Extractability. I. Extractions and Plant Uptake of Soil and Fertilizer Phosphorus," Canadian Journal of Soil Science, Vol. 64, No. 2, 1984, pp. 241-254. doi:10.4141/cjss84-025

[12] K. Sardi, P. Csatho and E. Osztoics, "Changes in the Soil Phosphorus Content of a Long-Term Fertilization Field Trial Studied in Laboratory Incubations," Communications in Soil Science and Plant Analysis, Vol. 37, No. 15-20, 2006, pp. 2833-2840.

[13] K. Simpson, "Factors Influencing Uptake of Phosphorus by Crops in Southeast Scotland," Soil Science, Vol. 92, 1961, pp. 1-14. doi:10.1097/00010694-196107000-00002

[14] K. Oats and S. A. Barber, "Nutrient Uptake: A Minicomputer Program to Predict Nutrient Absorption from Soil by Roots," Journal of Agronomic Education, Vol. 16, 1987, pp. 65-68.

[15] A. R. Gillespie and P. E. Pope, "Rhizosphere Acidification Increases Phosphorus Recovery of Black Locust. II. Model Predictions and Measured Recovery," Soil Science Society of America Journal, Vol. 54, No. 2, 1990, pp. 538-541. doi:10.2136/sssaj1990.03615995005400020042x

[16] K. C. J. Van Rees, N. B. Comerford and W. W. McFee, "Modeling Potassium Uptake by Slash Pine Seedlings from Low-Potassium-Supplying Soils," Soil Science Society of America Journal, Vol. 54, No. 5, 1990, pp. 1413-1421. doi:10.2136/sssaj1990.03615995005400050034x

[17] J. M. Kelly, A. H. Chappelka and B. G. Lockaby, "Measured and Estimated Parameters for a Model of Nutrient Uptake by Trees," New Zealand Journal of Forest Science, Vol. 24, 1994, pp. 213-225.

[18] N. Claassen and B. Steingrobe, "Mechanistic Simulation Models for a Better Understanding of Nutrient Uptake from Soil," In: Z. Rengel, Ed., Mineral Nutrition of Crops: Fundamental Mechanisms and Implications, Food Products Press, New York, 1999, pp. 327-367.

[19] R. D. Hangs, J. D. Knight and K. C. J. Van Rees, "Nitrogen Uptake Characteristics for Roots of Conifer Seedlings and Common Boreal Forest Competitor Species," Canadian Journal of Forest Research, Vol. 33, No. 1, 2003, pp. 156-163. doi:10.1139/x02-169

[20] J. M. Kelly and P. A. Mays, "Root Zone Physical and Chemical Characteristics in Southeastern Spruce-Fir Stands," Soil Science Society of America Journal, Vol. 53, No. 4, 1989, pp. 1248-1255. doi:10.2136/sssaj1989.03615995005300040043x

[21] F. C. Thornton, P. A. Pier and C. McDuffie Jr., "Response of Growth, Photosynthesis, and Mineral Nutrition of Red Spruce Seedlings to Ozone and Acidic Cloud Deposition," Environmental and Experimental Botany, Vol. 30, No. 3, 1990, pp. 313-323. doi:10.1016/0098-8472(90)90043-4

[22] J. M. Kelly, S. A. Barber and G. S. Edwards, "Modeling Magnesium, Phosphorus and Potassium Uptake by Loblolly Pine Seedlings Using a Barber-Cushman Approach," Plant and Soil, Vol. 139, No. 2, 1992, pp. 209-218. doi:10.1007/BF00009312

[23] J. D. Joslin and M. H. Wolfe, "Red Spruce Soil Solution Chemistry and Root Distribution across a Cloud Water Deposition Gradient," Canadian Journal of Forest Research, Vol. 22, No. 6, 1992, pp. 893-904. doi:10.1139/x92-119

[24] R. Parsons, " Handbook of Electro-Chemical Constants, " Academic Press, Waltham, 1959.

[25] O. W. Edwards and E. O. Huffman, " Diffusion of Aqueous Solutions of Phosphoric Acid at 25?, " Journal of Physical Chemistry, Vol. 63, 1959, pp. 1830-1833. doi:10.1021/j150581a011

[26] J. D. Joslin and M. H. Wolfe, " Foliar Deficiencies of Mature Southern Appalachian Red Spruce Determined from Fertilizer Trials, " Soil Science Society of America Journal, Vol. 58, No. 5, 1994, pp. 1572-1579. doi:10.2136/sssaj1994.03615995005800050042x

[27] J. M. Kelly, J. D. Scarbrough and P. A. Mays, " Hardwood Seedling Root and Nutrient Parameters for a Model of Nutrient Uptake, " Journal of Environmental Quality, Vol. 30, 2001, pp. 427-439. doi:10.2134/jeq2001.302427x

[28] R. D. Yanai, K. J. McFarlane, M. S. Lucash, S. E. Kulpa and D. M. Wood, " Similarity of Nutrient Uptake and Root Dimensions of Engelmann Spruce and Subalpine Fir at Two Contrasting Sites in Colorado " , Forest Ecology and Management, Vol. 258, No. 10, 2009, pp. 2233-2241. doi:10.1016/j.foreco.2009.04.035

[29] T. D. Perkins, G. T. Adams, S. T. Lawson, P. G. Schaberg and S. G. McNulty, " Long-Term Nitrogen Fertilization Increases Winter Injury in Montane Red Spruce (Picea Rubens) Foliage, " Journal of Sustainable Forestry, Vol. 10, No. 1, 2000, pp. 165-172. doi:10.1300/J091v10n01_19

[30] S. Catovsky and F. A. Bazzaz, " Nitrogen Availability Influences Regeneration of Temperate Tree Species in the Understory Seedling Bank, " Ecological Applications, Vol. 12, No. 4, 2002, pp. 1056-1070. doi:10.1890/1051-0761(2002)012[1056:NAIROT]2.0.CO;2

[31] M. Silberbush and S. A. Barber, " Sensitivity of Simulated Phosphorus Uptake to Parameters Used by a Mechanistic-Mathematical Model, " Plant and Soil, Vol. 74, No. 1, 1983, pp. 93-100. doi:10.1007/BF02178744

[32] H. Van Miegroet, D. W. Cole and N. W. Foster, " Nitrogen Distribution and Cycling, " In: D. W. Johnson and S. E. Lindberg, Eds., Atmospheric Deposition and Nutrient Cycling in Forest Ecosystems of the Integrated Forest Study, Springer-Verlag, Berlin, 1992, pp. 178-196.

[33] J. D. Joslin, J. M. Kelly and H. Van Miegroet, " Soil Chemistry and Nutrition of North American Spruce-Fir Stands: Evidence for Recent Change, " Journal of Environmental Quality, Vol. 21, No. 1, 1992, pp. 12-30. doi:10.2134/jeq1992.00472425002100010002x