NITROGEN FIXATION: ITS SCOPE AND IMPORTANCE*

William E. Newton and Barbara K. Burgess

Charles F. Kettering Research Laboratory
Yellow Springs, Ohio 45387, USA

INTRODUCTION

Although many factors, like climate, plant strains, herbicides, and pesticides, influence agricultural productivity, total dependence rests on photosynthesis and supply of inorganic nutrients. The essential nutrient most often limiting in crop productivity is combined or "fixed" nitrogen. Because plants do not have the capability of "fixing" nitrogen, it must be provided externally for maximal productivity. However, only a very small proportion of the nitrogen on earth (less and 0.001%) is cycling at any one time between its usable fixed form in terrestrial pools and its inert molecular form in its atmospheric pool. Nitrogen fixation controls the atmosphere-to-terrestrial (land or sea) flow, nitrification and denitrification convert ammonia to nitrate and then to nitrogen gas which is lost to the atmosphere, while leaching and erosion move fixed nitrogen between land and sea. The biological world apparently stays ahead of a nitrogen deficiency because the fixation rate is just above the denitrification rate.[1]

Molecular nitrogen is fixed[1-3] either by natural nonbiological and biological processes or by commercial processes. The global biological contribution is estimated at 122 x 10^6 t/yr, industrial fixation contributes about 50 x 10^6 t/yr for fertilizer uses while other processes, like lightning and combustion, fix about 30 x 10^6 t/yr. Thus, the biological process represents the major contributor to the total annual fixation rate. Although how the benefit was

*Contribution No. 782 from the Charles F. Kettering Research Laboratory.

derived was not understood, the Chinese and Greeks used biological nitrogen fixation thousands of years ago in the form of legumes and Azolla as green manures. However, shortly after World War II, commercially produced nitrogenous fertilizers became widely available and relatively cheap. Together with the trend toward larger farms and mechanization of farming, these sources of fertilizer displaced biologically produced fixed nitrogen fertilezer (in the form of both green manures and crop rotation), as the means to maintain soil fertility. The importance of these commercial N fertilizers in agriculturally advanced countries is unquestioned. However, attempts to increase these commercial supplies to cultivate evermore intensely the arable land of the earth are running into major problems, such as the increasing cost and declining availability of fossil fuel for feedstock and energy supplies and the enormous ($150,000,000) capital investment required for building new production facilities. In any case, the increasingly intensive cultivation of the arable land of the earth is a short-range solution to the growing problem of global food supply, which has been exacerbated by a continuing population increase. The various natural processes for fixing atmospheric nitrogen hold the key to long-term global food supply. In certain instances, like the legumes (peas, beans, alfalfa, etc), nature has provided a mechanism for biological interaction between the plant and a nitrogen-fixing bacterium. This symbiotic association allows the plant to receive nitrogen fixed by the bacterium directly because the bacterium is harbored in nodules on its roots. Carbohydrate is supplied in return by the plant. Although this approach works well, it is limited and important food crops, like the cereal grains (rice, wheat, and corn), and root and tuber crops, do not harbor symbiotic partners. Hence, for crop productivity to reach commercially acceptable levels currently, extensive augmentation by commercially produced nitrogen fertilizer is necessary. Such problems have encouraged present-day research into all areas of nitrogen fixation.

INDUSTRIAL PROCESSES

Until the early 19th century, the available fixed nitrogen, stockpiled by natural processes over millions of years, was enough to sustain the earth's population. But with rapidly increasing populations and the dramatic growth of large cities in industralized nations, the demand for increased supplies led to the beginnings of the nitrogenous fertilizer industry. So, guano (hardened bird droppings) was imported into Europe from Peru, as was saltpeter (sodium nitrate) from Chile. These fertilizer forms were further supplemented by the ammoniacal by-products from coal gas production. Further increasing demand led to the invention of several processes, some of which were commercially successful.

The first process, implemented in 1905, was the Birkeland-Eyde