Hank: There's nothing quite so terrible as needing something that's sitting right in front of you but not being able to get it, like say you're on a lifeboat in the ocean and you're super thirsty, and there's 300,000,000 cubic miles of water sitting right in front of you, but you can't drink any of it. Or having to sit next to Megan Kale every day in math class, but knowing she's really dramatically out of your league. A lot of organisms on earth find themselves in this situation, pretty much constantly, except that the thing that's everywhere that they can't have isn't water or physical closeness, it's nutrients, and specifically, nitrogen and phosphorus.

Of course, there are tons of elements that cycle around the earth, hanging out in one place or form for a while before moving on to the next, and as you know, living things need a bunch of stuff, animals, for instance, need oxygen and carbon and hydrogen. These elements basically cover the water cycle and the carbon cycle that I talked about last time, but we're also about 3% nitrogen and 1% phosphorus. Those numbers might not sound super significant, but even though we've just got teensy bits of the stuff in our bodies, we need nitrogen to make like, amino acids, which make proteins, which make our whole bodies up, and DNA and RNA, too. DNA and RNA also require phosphorus, not to mention that phosphorus is the P in ATP, and the Phosphorus in phospholipid bi-layer. So we might not need a ton of the stuff, but it is important, and it's hanging out everywhere--the air we breathe is mostly nitrogen, and the water and rocks all around us are jam-packed full of phosphorus, but like I said, they're rarely in a form that's biologically available. And as per usual, the organisms that solve this problem are the plants. Anything else that needs these nutrients are just gonna have to eat some plants or eat something that ate some plants.

But how do plants solve this problem? And why is it a problem in the first place? Well, give me a few minutes, I'll explain.

(CrashCourse intro)

So let's talk about the nitrogen cycle first, since nitrogen really is actually all around us, like I can feel it right now, there it is in the air. So why is it so hard to get this stuff that's constantly surrounding us in the air into our actual bodies to be useful for us? Because even though nitrogen gas makes up 78% of the atmosphere, you'll notice here that nitrogen gas is made up of two nitrogen atoms stuck together with a triple bond. And it's one thing to break apart a single covalent bond, but three? So as you can imagine, those two nitrogen atoms are a total pain to pry apart. But that molecule has to be split in order for a plant to get at the pieces. In fact, plants can assimilate a bunch of different forms of nitrogen, nitrates, nitrites to a lesser extent, and even ammonium, which is what you get when you mix ammonia with water. But all that darn nitrogen gas in the atmosphere is beyond their powers of assimilation. So plants need help taking advantage of this ocean of nitrogen that we're all swimming in, which is why they need to have that nitrogen fixed, so that they can use it

Even though plants aren't wily enough to wrangle those two nitrogen atoms apart, certain nitrogen fixing bacteria are. These bacteria hang out in soil or water or even form symbiotic relationships with the root nodules of some plants, most of which are legumes, that's a pretty big family of plants: soybeans, clover, peanuts, kudzu, all legumes. So these bacteria just sit around converting atmospheric nitrogen into ammonia, which then becomes ammonium when it's mixed with water, which can be used by plants. They do this with a special enzyme called nitrogenase, which is the only biological enzyme that can break that crazy triple bond. Ammonia can also be made by decomposers, fungi, protists, other kinds of bacteria that munch on your proteins and DNA after you die, but they're not picky, they like poop and urine, too.

Then once this has happened, other bacteria known as nitrifying bacteria can take this ammonia and convert it into nitrates, three oxygen atoms attached to a single nitrogen atom, and nitrites, two oxygen atoms attached to a nitrogen, and those are even easier than ammonium for plants to assimilate. So the take home here is that if it wasn't for these bacteria, there'd be a whole lot less of biologically available nitrogen hanging around, and as a result, there'd be a lot fewer living things on the planet, so as usual, thanks bacteria, we owe you one!

But I should mention that it's not just bacteria who can wrangle those two nitrogen atoms apart. Lightning, of all things, has enough energy to break the bonds between nitrogens, which is obviously awesome, and therefore worth mentioning, and in the 20th century, smartypants humans also figured out various ways to synthetically fix a ton of nitrogen all at once, which is why we have synthetic fertilizers now and so much food growing all over the place. Once the atmospheric nitrogen is converted into a form that plants can use to make DNA and RNA and amino acids, organic nitrogen takes off up the food chain and animals eat the plants and use all that sweet, sweet bio-available nitrogen to make our own amino acids, and then we pee or poop it out or die and the decomposers go to town on it, breaking it down to ammonia and it all keeps going...until! One day, that organic nitrogen finds itself in denitrifying bacteria, whose job it is to metabolize the nitrogen oxides, turn them back into nitrogen gas using a special enzyme called nitrate reductase. These guys do their business and then release the N2 back into the atmosphere. And that, my friends, is the nitrogen cycle. If you remember nothing else, remember that a) you owe bacteria a solid because they were smart enough to make an enzyme that can bust open the triple bonds of nitrogen gas, b) you owe plants a solid for wrestling nitrogen into their bodies so that you can just eat a carrot and not have to think about it, and c) nitrogen is awesome and everywhere and yet, also elusive and deserving of your respect.

So, moving on, to the phosphorus cycle. The interesting thing about phosphorus is that it's the only element that we're going to talk about that doesn't involve the atmosphere. Phosphorus wants nothing to do with your air.

However, the lithosphere, fancy word for the earth's crust, is amply supplied with phosphorus. Rocks contain inorganic phosphates, especially sedimentary rocks that originated in old ocean floors and lake beds where living things died and sank to the bottom where their phosphorus rich bodies piled up and made phosphorus rich rocks over time.

Unfortunately, there aren't a lot of rock-eating organisms on earth, just a couple bacteria, which are called lithotrophs, by the way, however, when these rocks are re-exposed and water erodes them, some of the phosphates are dissolved into the water. These dissolved phosphates are immediately available to and assimilated by plants, which are then eaten by animals.

From here, the same thing goes for the decomposers as with the hydrogen cycle, when a leaf drops or something poops or dies, the decomposers break it down and release the phosphates back into the soil or water. And phosphates get about as much downtime in the soil as a $20 bill on the sidewalk.

Decomposed phosphate is immediately reassimilated back into plants and this little cycle just keeps going and going. Plants to the animal to the decomposers to the soil and back into a plant — that is, until that atom of phosphorus makes its way into some kind of body of water. Because aquatic and marine ecosystems need phosphorus like crazy.

Once a phosphorus atom makes its way into a deep lake or ocean, it cycles around among the organisms there--algae, plankton, fish, and this cycling can go on for a long time, I mean, not as long as a phosphorus atom trapped in a rock, that can be millions of years, but by some estimates, a single phosphorus atom can be caught in a biological cycle for a hundred thousand years.

Eventually, it's in something that dies and falls into a hole so deep that decomposers can't survive there, then sedimentation builds up and turns into rock, which are eventually uplifted into mountains and exposed and the phosphates are weathered back out and it's a cycle!

So yeah, that's the deal with nitrogen and phosphorus, living things need them, but even though they're all over the place, they're at a premium in biological systems because they're hard to get at, either because they have to be converted into a form that organisms can use, or they're locked away underground.

But you know who the smartest monkeys are? Us. And yeah, you can bet your face that we've figured out how to unleash all kinds of nitrogen and phosphorus into this big green planet. Mostly, in an effort to help feed our children and each other, we usually mean well, but we can be a bit overbearing sometimes.

It's just the human way, to see something in nature that seems to be lacking or imperfect and try to make it the best thing ever. So with the phosphorus and nitrogen cycles, we have introduced fertilizers, lots and lots of fertilizers, the main ingredients of which are, you guessed it, nitrogen and phosphorus.

The story of how we learned to synthesize nitrogen into ammonia for fertilizers and chemical weapons is a very, very interesting one involving an evil lunatic, and I suggest as soon as this is over, you watch this video on Fritz Haber, the guy who made all this happen during World War I.

You've heard of too much of a good thing, right? Well, through the miracle of synthetic fertilizers, we're able to grow much, much more food than we ever have before and as a result, ecosystems all over the world are being bombarded by these incredible amounts of nitrogen and phosphorus.

This takes us into the next chapter in our exploration of ecology, the human impacts on the biosphere. Sometimes, out of desire to make nature better, sometimes out of stupid human selfishness and most often both, we've ended up really messing up the environment in more ways than we can count.

And that's what we're going to be talking about next week--be sure to wear your gas mask and HazMat gloves, and thank you for watching this episode of CrashCourse Ecology.

This episode was written by Jesslyn Shields, Blake de Pastino, and myself. Our technical director is Nick Jenkins, he's also filming this, and he will also be editing it. Sorry, Nick. Graphics are courtesy of Peter Winkler, and sound is from Michael Aranda.

There's a table of contents over there if you want to review anything we went over in today's episode and of course, we're on Facebook and Twitter and in the comments below if you have any questions for us, we'll see you next time.

(Endscreen)