GRAINS and MOISTURE

A Survey of Microbiological Storage Hazards

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From: The Main Organic Farmer, Vol. II, No. 5

There are endless sides to grain growing that can be discussed, but often enough, as with hay-making, the final note will be sounded by just one element; water, and its impact – good and bad – on quality. As prospective grain growers in a humid climate, we will ask, "What can moisture do to our grains"? A lot of the answers we may already know. Grain research in the last few decades has incresingly pinpointed the causes of heating, spoilage, loss of germinability, discoloration, change in bread-making quality, souring and others. More recently have been the important discoveries isolation and identification o. dangerous toxins produced by fungi ('mycotoxins') which commonly grow on overly moist grains. A consequence of this has been a certain amount of re-examination of grain handling methods, and a proportionate amount of updating of the technology of grain production. The last point may be of little concern to the small homesteader interested in small scale grain growing, however, what is important are some of the findings, which a small grower can certainly use to his benefit.

Problems associated with moisture on grasses have long ocurred. Epidemic diseases related to ingestion by humans and animals of fungi affected grasses have happened more than once in history, notably in connection with ergotism of rye. The "ignis sacer" or holy fire that raged in Europe during the Middle Ages commonly ocurred in areas where ergot infected rye was used as bread, and although two forms of this disease, gangrenous and convulsive ergotism, were recognized, the causative agent was not. As late as the early part of this century an epidemic called ATA disease (Alimentary Toxic Aleukia) ocurred in Russia, causing widespread human illnesses and deaths and only later traced to ingestion of fungi-infected grains. In the 30's, again in the USSR, a widespread disease affecting mostly horses ocurred (it lasted about 7 years), and was later found to be caused by the stachybotrys fungi infection of straw. (In the meantime it had been named "NZ", neivestnoe zabolevanie – disease of unknown etiology). This disease ocurred throughout the Ukraine, in Crimea and Moldavian S.S.R., and earlier in Hungary. (Today, it still occurs in many animals fed moldy hay.) Humans were affected where they were in contact with fodder or slept on straw mattresses, displaying symptoms of dermatitis with pus exudations and incrustations followed by death of local skin tissue. Elsewhere, in the 50's reports were heard of cattle and swine diseases caused by ingestion of moldy corn. In New Zealand, facial eczema of sheep and cattle ocurred where grass affected by fungi was fed. In the 60's, the famous "Turkey X" disease swept the poultry industry in England and concurrently diseases in fish hatcheries, both later traced to moldy feeds (grains and seeds). In other places the poultry hemorrhagic syndrome was associated with moldy feeds. Clover and fescue related illnesses in animals have ocurred commonly where these fodders where infected with fungi. In underdeveloped countries, distresses traceable to moldy grains and cereal products have and continue to occur. Fungi infection of grains and grain products have been found in Uganda, Nigeria, Kenya, Polynesia, India, Thailand, Asia, and correlations between human and animal distress and a humid climate of humid conditions surrounding harvest times have been established.

Obviously, evidence exists to show that *health* hazards associable with moist grasses and grains have always existed. The more recognized side of the matter has been the *spoilage per se* of these products under moist conditions. This common occurrence has, however, been largely connected with colonization of the grains by fungi, putting to death an apparent habit of farmers for placing the blame of bad grains on "spoilage", instead of on fungal proliferation due to bad handling or bad storage.

Whether, therefore, it is the new awareness of the problem of fungi, or an actual worsening of it in an unecological world that is apparently causing farmers to include "fungi" on their common list of apprehensions for a growing season is not clear. In any case a common impression seems to be to wonder how any grain grower can survive in the long term who does not incorporate into his operation some measure of the results of modern findings. Actually, this article was prompted by this writer's experience of a series of calamities which occurred probably due to just this failure. It may be that everything is alright so long as the scale of production is kept low; this minimizes yields as well as the risks. But how to suceed in the proper sense at small scale grain production in a humid climate should prove an erea of interesting and probably difficult study. Towards this end I will attempt to offer some of the facts, whose value to the small grower may be to encourage an element of interpretation and prediction of obstacles – which is at least one step towards success.

Two broad categories of grain fungi are acknowledged, though not taxonomically correct. These are 1) Field fungi, and 2) Storage fungi. The delineation of these two groups is mostly based on their requirements of moisture; the field fungi characteristically invading kernels in the field in the presence of high levels of moisture, and the storage fungi where low levels of moisture narrow the microbial competitivity to the point of allowing a few organisms to take full advantage. Representative genera of the Field fungi group are Fusarium, Alternaria, Helminthsporium, Claviceps and Cladosporium. There are actually many more and those responsible for smuts and especially rusts of grains should be mentioned, because they are common in Maine. Unlike those named above, which, with the exception of Claviceps species, belong taxonomically to the class Fungi Imperfecti, these smut and rust producing organisms are Basidiomycetes and though quite damaging, are less significant health-wise and also less fastidious in their moisture requirements. Also, the field fungi named above characteristically colonize the grain kernels whereas the others are found also on the leaves and stems.

Activities of these organisms include the so called 'weathering' (discoloration) of kernels, weakening or killing of the embryo, shriveling of the seed, seedling blight and root rot. The general physical harm caused by these fungi is compounded by the fact that some are responsible for the production of metabolic by-products which can be very toxic to other plants, animals or humans. For example, Fusarium is capable of directly causing wilt diseases of many plants but also produces the toxin which was the cause of the previously mentioned ATA Disease. Alternaria, which can cause leaf spots and blight of many plants, produces a toxin which has been associated with incidence of the poultry hemorrhagic syndrome. Claviceps, which attacks many grass species, produce a number of deadly alkoloids known and exploited for their medical and hallucinogenic properties (LSD derives from these ergot species).

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The effects of fungus versus fungus-produced-toxin are sometimes hard to separate, as with Helminthsporium species (known for oat root rot) which parasitize plants and simultaneously produce highly phytotoxic (plant-toxic) substances, capable by themselves of inciting disease. Damage to crops planted on grain refuse results from a build-up in the soil of either the actual Helminthsporium fungi or their toxins, or both.

Because of their moisture requirements, the extent to which these field fungi will belong to the life cycle of grains depends largely on the environment, a humid climate naturally promoting the relationship. In the study I have done, I have, however, found no specific indications of, say, how much and how great a length of time of humidity would have to be present. to enable successful infections. What is admitted is that fog, for one, more than enough provides these organisms with what they need in the way of moisture. There is also the possibility that after initial infection, invasion by fungal hyphae of plant tissue would enable a certain amount of independence from outer moist conditions. Concievably then, the organisms could survive through periods of dry until the next wet period. Rusts are definately very good at this. With the more fastidious ones, like Alternaria and Fusarium nothing is certain; if toxins are produced, that is another matter entirely, because apparently they can survive unusual conditions.

The second group, so named 'Storage fungi', characteristically invade grain kernels during their storage after harvest where levels of moisture in the grain range from about 14 to 19%. These levels of moisture are actually often lower than those normally found in harvested and threshed grains which are anyway considered "dry". Infact, apparently if it weren't for fungi, grains could be properly considered "dry" at just about any level of moisture they happened to be at harvest. This is important to realize, and there are two interesting facts connected with it: If grains were rated "dry" according to moisture levels known to be favorable for animal feed then a characteristically higher level of moisture would be chosen. Secondly, the general indication today that grains are "dry" at moisture levels of 14% or lower is really based on facts of fungal preferences, that is, "dry" actually means "safe from the reach of fungi". Earlier peoples, lacking any specific awareness of problems related to fungal proliferation, quite rightly considered a harvested kernel "dry"; it had lost a considerable portion of its water and was therefore dry. A few percent moisture either way hardly bothered; however, some researchers have stated that a bushel of grain in this "dry" state may contain as much as a gallon of water. But for all purposes it was dry; except for the storage fungi.

The so called storage fungi consist of two main genera, Aspergillus and Penicillium. Their effects on stored grain include killing and discoloration of the germ, heating, spoilage and production of toxic byproducts.

At this point it is difficult to say which direction the discussion should go in. There is the subject of toxins associable with moldy grains and the subject of spoilage per se of grains; both are large (the former probably the larger), important and interrelated. *However*, production of toxins is not necessarily related to the rate, extent and type of spoilage although microbial growth, which is responsible for the toxins, is definately closely related. Fungi on grains will apparently produce toxins according to no general law and at the slightest whim. This is probably why human and animal distresses resulting from ingestion of fungi contaminated grains can be so mercilessly sudden and inproportionate to either the amount ingested or the extent of the fungal infestation. Grains which appear perfectly sound can constitute a sever health risk while seriously mold damaged ones may contain no toxins at all. For this reason, discussing spoilage and toxins together can be particularily difficult and even confusing though by rights they belong together. The problem is obviously compounded by the fact that my knowledge of the matter is relatively small.

As was previously stated, the storage fungi will generally without question, proliferate on grains with moisture contents above 14%. This is a rough figure and not consistent with all grains by any means. It is, however, an accurate threshold value. Grains stored below this moisture level will rarely become infected; consequently, their storage value and duration of germinability is increased.

Aspergillus flavus, a species of the Aspergillus genus, is responsible in part for killing and discoloring the germ, causing heating, and decay of the whole kernel. More recently, however, its toxigenic value has become of great interest to those concerned with natural hazards in foods. A potent carcinogen called aflatoxin has been isolated from aspergillus flavus species and found to occur naturally on various grains stored improperly. Already the FDA has set a tolerance level of 15 *parts per billion* for this toxin, although Ralph Nader's group says this is too high! Aflatoxin has now been found in all areas of the world and mostly in seeds and grains and cereal products. Contamination of beer from moldy barley, of dried fish, chili peppers and dried sweet potatoes have also been reported. Apparently, corn, peanuts and cottonseed meal are highly susceptible to aflatoxin contamination, and laboratory studies have shown that many if not most grains are excellent mediums for aspergillus flavus elaboration of aflatoxin. Furthermore, aspergillus flavus has been found responsible for the production of other toxins as well; these include kojic acid, tremorgen, B-nitropropanoic acid and oxalic acid. All of these have been observed to have damaging effects when administered to animals. Many other aspergillus species are responsible for toxin production. These toxins include aspergillic acid, endotoxins, fumagillin, fumagatin, helvolic acid, ochratoxin and tolquinones, most of which also display marked toxicities when fed to animals. In Africa, high incidence of human diseases in certain areas was partially correlated with aspergillus ochraceous (producer of ochratoxin) contamination of local cereals and legumes.

The penicillium species invade grains at moisture levels around 16%; they commonly kill and discolor the germ and whole kernels and cause mustiness and caking. An identifying feature of some of these species is that fact that they produce pigments, ranging in color from yellow to orange and deep red, which can at times be observed on moldy grains and bread.

There is a whole host of so called Yellowed Rice Toxins attributable to penicilium organisms. Other toxins of these species include penicillic acid and cyclopiazonic acid, the latter of which has been commonly associated with animal distresses on farms, having been found on hay, grains and processed feeds. It is produced by Penicillium cyclopium which is acknowledged to be a common storage fungi and often found on grains destined for human consumption. In Tennesee, contamination of a lot of feed by this fungi accounted for the decimation of an entire flock of sheep.

One of the more interesting facts regarding moisture and grain storage is the law that grains always tend to equilibriate with the relative humidities of the surrounding air. This means that whatever the initial moisture content of the grains, they will either give off or take up moisture in accordance with atmospheric conditions. Variation of

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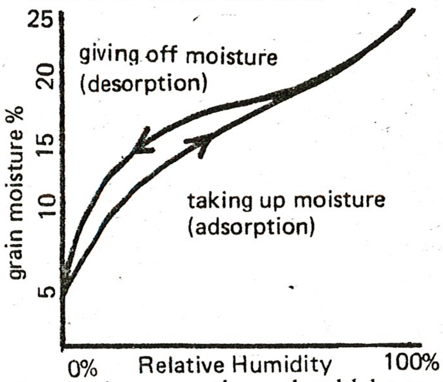
moisture percentages of grains during a year have been largely correlated with fluctuations of the humidity of the air. This means that grains in a humid climate tend to maintain a higher level of moisture than those in warmer, dryer areas.

Equilibrium values for various grains can be plotted, forming to so called moisture-sorption isotherms which look about like this:



As can be seen, there should be a certain percent of relative humidity which at equilibrium would correspond with the threshold moisture level of 14% in grains. This value is generally agreed upon as being around 75(% relative humidity). At 75% relative humidity, moisture levels in grain at equilibrium will be about as follows:

Wheat, Hard Red Winter	14.6%
Wheat, Hard Red spring	14.8%
Wheat, Durum	14.1%
Wheat, Soft Red Winter	14.7%
Barley	14.4%
Buckwheat	15.0%
Corn	14.4%
Oats	13.4%

As seen here, all the values for grains are very borderline as far as levels of moisture condusive to fungal growth are concerned. For this reason, 65% relative humidity is recommended to be considered the maximum safe level of air moisture that may be in contact with stored grains if they are to be kept for any length of time. For instance, the safe storage life of grains containing 14% moisture and stored at 50 degrees F is computed to be about 256 days, whereas at 20% moisture the storage life is only 16 days. At 70 degrees the figures are quartered. (This may serve to give some idea of how soon after harvest grains should be brought to decent levels of moisture.) One other point regarding figures of grain moisture in equilibrium with relative humidities, is the effect of temperature. At lower temperatures grains, like anything else, will take up more moistere per relative humidity than at higher temperatures. This amounts to about 0.7% change in moisture content of grains for every 18 degree increase or decrease of temperature.

For a cool humid climate like our own, the figures for grain moisture as given above will therefore be higher (the figures were computed for room temperature). As far as coolness per se goes, this does discourage fungal proliferation, however, penicillium will grow down to temperatures of 22 degrees F whereas Aspergillus flavus needs at least 50 degrees F for growth. (It may be for this reason that more Penicillium vs. A. flavus contamination of grains is found in the N.E. as opposed to the S.E. of this country).

The most obvious method for driving off excess moisture in grains is heat, which should reduce the relative humidity of the air sufficiently enough to induce grains to give off moisture in the attempt to equilibriate. This occurs naturally in the field during ripening until the grain is what one might call dry. After harvest (mowing), shocking of the grains is generally required to further reduce their moisture content. As to whether this will actually be successful depends entirely on the weather conditions surrounding this period. The problem of humidity during the time of shocking may at least partially account for the fact that, according to some research, a higher proportion of Alternaria fungi (Field fungi) were present on freshly stored grains in the Northeast of this country than all other areas except one.

After threshing, often grains are subjected to further intensive drying, as for instance, in the Far East where they are spread on hard pavements in the presence of a baking sun. In this climate such a thing would be impossible, but in all probability necessary in any case. Therefore a method of encouraging release of moisture would have to be available, and, of course, it is for this reason that all the gadgetry of modern grain drying operations has been designed. However, this does not mean that only after a great outlay of cash can the proper implements of drying be had. In fact, with proper design drying can be properly accomplished with a minimum of technology, using a method which is commonly used even on larger scales, called the on-floor drying method.

Grains are effectively dried in relatively short order when spread thinly in the presence of dry air. At 45% relative humidity, the equilibrium moisture content in kernels will be around 10-11%. I regret not being able to indicate how long this equilibration would take, however, a period of a few days is considered minimum. The drying can be greatly speeded if the air is warm and in motion. This forms the basis for the on-floor drying method, which passes slightly warm air over grains for a certain period of time. If the air is very warm and the humidity low, drying can be accomplished in a matter of hours. Air at 30% relative humidity and 129 degrees F will, when passed over oats, dry them from 30% moisture to 10 in 8 hours.

The on-floor method is adapted for bulk grain by incorprating aeration ducts on the floor at about every three feet. Failrly powerful fans are then required to force air into ducts and up through the grain. This method is used extensively in England and whether or not heated air is needed depends entirely on the moisture conditions surrounding the drying operation. Apparently, these english farmers are able to get by some years without the use of any heated air, other years not. They are apparently capable of predicting well in advance whether the heat will be necessary. In the presence of higher levels of humidity heat is required to provide the extra amount of energy to drive off excess water.

This should be a natural ending point for this discussion, but in a way we are back to grain storage. After all this work drying, contact of grains with fog humidity has been shown to raise the grain moisture content to 20% in the space of a day. The drying operation must then be repeated. With shocks in the field we can only hope the sun will come out and dry the air. A space of a week is decisive in such cases. If the grain is already in storage, paper bags will not prevent its absorbtion of moisture. In bulk storage the fans will have to be used intermittently, according to weather conditions.

One can only imagine the proper grain storage room for a humid climate. In the meantime, suffice the warmest, dryest room in the house for such. If that is not available, grains should simply be consumed as they arrive, unless small enough amounts are being handled, which can safely be kept in glass jars. For bulk storage, my own experience with grain rooms is that even very nice ones — rodent proof and double fan aerated — can be ineffective in the long term in combating equilibrium forces along the coast. This could even be true further inland, it all depends. With the grain room I am thinking of, micro-biological studies showed presences of Aspergillus and Penicillium species in stored corn, rye, oats and wheat. I would not wish on anyone such a discovery. In this climate, however, the possibility of it may be in various ways hanging by a thread.