1. [17pts] Seed plants have been around a long time (seed ferns, then gymnosperms, and now angiosperms). Over the last 10,000 years humanity has produced a wide diversity of cultivated seeds that have been domesticated from their wild ancestors. These domesticated seeds (and their wild ancestors) present a treasure trove of genetic traits - a library from which humanity can draw from to continue towards the aim of a stable and abundant food supply for everyone on Earth. However, there are ethical concerns surrounding how this "genetic treasure trove" should be managed, used, and who (if anyone) should control it. Using the core ideas from the three papers listed below, develop a **summary** of some of the major ethical issues surrounding the management, use, and control of humanity's genetic treasure trove of cultivated plant genetics - **be specific**. Additionally provide your own science-backed opinion on the ethical use of humanity's genetic treasure trove of cultivated plant genetics. (*there are LOTS of different directions you could go with this)

- The Core Dilemma: seed sovereignty and globalization (C. O'Grady Walshe)
- “Hey Plants, Take a Walk on the Wild Side!”: The ethics of seeds and seed banks (Nicole Karafyllis)
- CRISPR/Cas in crop breeding: Why ethics still matter (Frauke Pirscher)

There are many ideas surrounding the ethics of the management, use, and access to seeds. This answer provides one example about how this might be structured. Paradoxically humans wield great power in the form of hybridization, cisgenic, and transgenic manipulation of plant genetics to create new plant varieties while also holding the legislative and regulatory power to lose much of the agricultural diversity built up over the last 10,000 years. Globalization and the proliferation of hybrid and GM crops - specifically through the export of industrial ag and green revolution ideas - has reduced genetic diversity of crops within agricultural systems globally. Indeed these improved varieties do enable massive yields per acre - but only in the context of high nutrient supply and stable year-to-year weather conditions. Additionally, the money required for farmers to afford these seeds and agrochemicals puts producers in a precarious financial position if a crop does not produce as intended. CRISPR/Cas is a relatively new and powerful tool that can both transfer genes within species (cisgenic) as well as across species (transgenic). Opinion is still divided regarding the ethical use of CRISPR, with some folks making an appeal to “naturalness” - especially when it comes to crops that humans eat. Another contentious issue is whether plants can be seen as “biofacts” - genetic material that can be used and recombined - or if plants have an intrinsic right to flourish within a “natural” state. Seed banks have arisen as one potentially powerful tool to preserve plant diversity for future use. Again we run into the question of “biofact” - genetic info to be used as needed - or “naturalness” seeing plants as part of plant communities within a specific context. However, regardless if you are talking about seed banks, CRISPR, or the globalization of the food system - there is still the issue of control. To what degree are we comfortable handing the genetic future of humanity’s crops to central agencies vs. making sure they are available to all?

In my personal opinion, I see room and space for a lot of perspectives. With scientific certainty we will need all the genetics we can get our hands on for the novel climate regimes that are already starting to develop on Earth. Similarly we will need the technical know-how of using these genes via CRISPR to increase drought tolerance, switch C3 crops to a C4 pathway, etc. However, these plants are not mere "biofacts". Instead we also need to respect the cultures and ecosystems these seeds come from and make sure that some form of these systems and seed economies remain intact so as not to completely hand the keys to the food system over to biotech and agrochemical companies. This could be achieved through the right type of regulation or emerge through consumer choice. Truly how we view plants affect how we treat the ecosystems (and agroecosystems) that they are part of.

2. [17pts] Trees are not a genetic classification but instead a growth form that has evolved multiple times throughout the evolutionary history of plants to solve the same problem - how to grow above surrounding foliage to capture more sunlight. Please describe to me how a tree grows - specifically the process of secondary growth following primary growth. Remember there are two cambiums involved. Compare and contrast this with how the first trees (*Cladoxylopsids* - a precursor to scale trees) grew larger and wider. Additionally, modern trees don't reach these heights alone but rely on relationships with other organisms in the forest. Please describe the types of relationships important to develop and maintain forest structure (as described in class) and how this scientific reality relates to some of the ideas in "Forest Ethics (by Robin Attfield)".

The woody trees that we see around us today produce their annual woody growth from a very thin vascular cambial ring. When plants are young they contain mainly pith. Secondary (woody growth) - which is a basal trait found in many families - begins after this primary growth. To start with, vascular bundles are arranged around the center of the stem. These vascular bundles have xylem towards the center of the stem and phloem towards the outside. The meristematic tissue within these vascular bundles produces new xylem cells (towards the inside) and new phloem cells (towards the outside). At the same time, the meristematic parenchyma cells between these bundles also start to produce xylem and phloem in the same orientation. From these cells the vascular cambial ring is formed. The tree increases its girth from the "inside out" by adding xylem layers to the inside that form first the sapwood, then the heartwood, of the tree. The phloem gets crushed into the inner bark as new phloem cells grow to replace them. The vascular cambial ring grows in diameter year by year - thus the actively growing part of the tree trunk allows for more and more growth. Similarly there is a cork cambial ring that produces the bark of the tree. This is very different from how the first trees on Earth grew. These trees had not developed cambial rings and instead grew using the initial vascular bundle configuration. However, as these vascular bundles increased in diameter they would push against each other. This would basically rip the trunk of the tree apart to accommodate the additional growth. Because these trees were not using the "inside out" approach the trunks were not woody, but instead were pithy. The pith enabled the "tearing apart" to not be catastrophic to the tree.

Current trees are often dependent on fungal connections with each other within a forest in order to keep the entire forest strong. This idea - the “wood wide web” posits that trees can communicate and share resources through a hyphal network of mycorrhizal fungi. Trees can make sugar - this is their specialty. Fungi can digest organic matter - this is their specialty. Trees trade sugar for nutrients (like nitrogen and phosphorus) while also shuttling nutrients to other trees nodes in the network. There is some variation regarding how much certain species connect to the network. The area of forest ethics intersects with this “connected” understanding of forest systems. Forests cannot be seen as individual plants (as some plant ethics frameworks are prone to do). Instead forests are living and connected systems where individuals depend on each other for survival - even while competition for resources is going on as well. As humans interact with forests - we can now think about ways to keep the network intact, even if we remove some trees for resources. (can also mention rhizophagy and trees that connect to N-fixing bacteria)

3. [17pts] One of the gigantic developments of angiosperms is the production of the fruit and true endosperm. Seed ferns produced seeds but no endosperm and gymnosperms produce seeds and haploid "primary endosperm". Angiosperms produce seeds that are encased in a fruit - the seed contains an embryo with triploid endosperm (true endosperm). Please describe different ways in which angiosperms form fruits. Pay close attention to how the **structures of the ovary and flower** are incorporated to form the fruit and provide **examples** from things we eat. Include ALL the following terms in your answer:

"aggregate fruits, multiple fruits, simple fruits, berries, pomes, drupes, hesperidium, pepo, accessory fruit"

Additionally, a **caryopsis** is a single-seeded fruit with a fused pericarp and seed coat (ex: cereal grains like wheat, barley, rice). Please take the example of a wheat "berry" and explain how the different parts of the seed provide different types of nutrients when we eat it. Relate the nutrients present to what function that part of the seed fulfills for the plant.

There are a diverse set of names for angiosperm fruits that match the diverse ways that angiosperms go about making fruits. All fruits are formed by the walls of the ovary - but there is a lot of variation! You can have simple fruits (formed from a single ovary from a single flower - like a peach), aggregate fruits (formed from a single flower containing multiple pistils - hence multiple ovaries - like a blackberry), or multiple fruits (formed from multiple flowers that fuse together - like a mulberry). From there fruits can be defined as either drupes (a peach is a simple drupe, a blackberry is an aggregate drupe, a mulberry is a multiple drupe), berries (all are simple - like tomatoes), and pomes (like apples and pears - where the actual fruit is hidden inside a fleshy layer formed by the receptacle - fleshy base of flower). Apples and pears are also examples of accessory fruits - where the fruit is formed by more than just the ovary. The main difference between drupes and berries is that drupes have one seed at the center (peach) whereas berries have many seeds embedded in the seed wall (tomatoes). Other types of berries such as a pepo are characterized by a hard rind (watermelon) while hesperidium (oranges) are full of juice sacs formed by hairs within the ovaries.

Wheat is most often used to make flour. The starchy and glutenous part of the seed is the endosperm. This contains the most calories and makes up the bulk of most shelf-stable white flours. This calorie dense endosperm is intended to provide the energy for the plant to develop until it can get photosynthesis up and running. The bran is the hard outer seed coat/pericarp. Bran is included in whole grain wheat and provides dietary fiber and micronutrients. The bran is a tough outer covering that protects the embryo inside. The germ is the actual embryo inside the seed and is only included in raw flours that are refrigerated. This is because the germ contains fats (embryonic structures) and these will go rancid if left on the shelf.

4. [17pts] Grasslands and mammals have coevolved throughout the Cenozoic. Grasslands contain grasses (obviously) as well as forbs (broadleaf-type plants, some of them legumes). Some grasslands (called savannas) even contain widely spaced trees. While fire has always been a factor in grasslands humans have historically used fire to manage these ecosystems - keeping back woody encroachment and providing fresh new shoots to attract wild grazers. More recently humans have managed domesticated livestock on grasslands. Most recently, grasslands have been tilled to make way for annual crops like corn, soybeans, and wheat. Please describe the broad arc of grassland coevolution with animals (include examples of how animals adjusted to grasslands AND how grass plants adjusted to these animals). Include in this description what tectonic/climate variables led to the emergence of grasslands as a dominant ecosystem on Earth. Finally, provide a basic description of how nitrogen and carbon cycle in and out of grasslands and how human activities like fire, grazing, and tillage affect these cycles.

Broadly speaking, grass has been developing ways of dealing with (and living with) grazers while grazers have been developing ways to eat tough grass and run in open grassland systems. The Cenozoic climate became drier and cooler due to the isolation of Antarctica via the opening of the Drake passage as well as mountain building events. In this drier climate grasses had an advantage compared to forests and spread rapidly globally. Grasses developed tough cellulose rich structures that incorporated silica crystals - making them difficult for animals to graze regularly. Additionally the meristems are located below the surface which makes grasses better able to survive and grow back after grazing and fire. In response some mammals evolved thicker tooth enamel and higher ridged teeth to deal with the wear and tear of eating tough grasses. Some animals also developed digestive processes to break down the tough cellulose in grass (i.e. ruminants) to extract more nutrients. The evolution of hoofed animals was also in response to wide open grasslands where animals could run.

Carbon is released via burning as well as aerobic respiration (mainly microbial). Nitrogen is also lost from the system through volatilization in fire and denitrification. Tilling would enhance the rate that carbon is lost from respiration because it would expose more of the carbon in the soil to aerobic microbe metabolism. Carbon is pumped into the prairie system via plant photosynthesis and can accumulate on the surface as litter or in the subsurface via root exudates and microbial necromass. Nitrogen can be pumped into grasslands via leguminous forbs (N-fixing nodules) and lost via nitrate leaching. The addition of grazing animals leads to less surface litter but an enhanced cycling of nitrogen via the creation of manure. Nitrogen loss could be enhanced depending on the cattle number and the activity of the soil microbiome or nitrogen could just cycle within the system. Additionally - deep prairie plant roots are routinely abandoned when aboveground biomass is grazed where they enhance subsurface soil organic carbon in situ. (can also mention rhizophagy and effects of fire on the volatilization of C and N as well as PyC)

5. [17pts] Provide a summary of the arc of understanding humans have gone through (as described in class) to understand genetics, especially as they relate to plants. Include both the relevant people involved as well as each new discovery and how that brought us closer to a more complete understanding of plant genetics and heredity. Bring this arc all the way to the present day.

Mendel first observed the effects of genetic heritability in the mid 1850s. He didn't know what it meant but he observed a 3:1 ratio in traits of his pea plants. This information was lost to obscurity because there was no framework to explain it. Then Bateson came along in the late 1800s and "rediscovered" Medel's earlier work. He combined this with his own observations on animal breeding and began to nucleate this idea of a "gene" - that is that there was some discrete thing through which traits were handed down - and one came from each parent. Wheldale, working with Bateson, found that not every trait followed a simple Mendelian ratio. Wheldale spent a lot of time tracking the color of snapdragons and found that some traits had a single gene that codes for them while other traits might have multiple genes that code for them. WIth this in mind Mendelian genetics still held up. Valvilov knew that genetic knowledge could be really useful in creating improved ag crops but Bourlag (with a little luck) was the one who capitalized on this by combining different wheat varieties to produce high-yielding wheat, which is commonly seen as the start of the Green Revolution. McClintock observed "lost" traits come back up in her corn and started to develop an idea that genes were not static, but instead could influence the expression of other genes. Her work paved the way for gene mapping and ultimately the genetic modification we can do today via CRISPR, bacteria, and gene guns.