Research for alternative material and its effect on seed germination in seed tapes products

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Abstract

‘Seed tapes’ are a length of biodegradable tissue paper, acting as a carrier, containing seeds. The seed tape is unrolled into a shallow trench and covered with soil, ensuring that all seeds are planted at even intervals. Manufacturers in the seed tape industry aim to produce products with crop sizes that are as good as, or better than, loose seeds. However, little is known about the principal component that affects the crop size produced by seed tapes, the carrier material, and its influential properties.

The focus of this report is to describe a series of experiments, used to test the suitability of alternative seed tape materials. The experiments analysed the performance of the seed tape products on a number of metrics; germination count, germination rate, penetration count and penetration rate; all are factors that influence the growth performance of the seed tapes. The fundamental performance indicator for consumers is crop size, which is measured by the penetration of seedlings through the seed tape material.

The experiments analysed twelve different species and batches of seeds with a total of six thousand, two hundred seeds over the three phases of the experiments. The first phase of the experiment demonstrated that the crop size produced from loose seed is higher than the crop size produced from seed tape products. The final two phases of the experiment analysed a variety of alternative seed tape materials, including traditional tissue papers, toilet papers and novel rice paper seed tapes, resulting in a new seed tape material being successfully identified as producing significantly larger crops than a tradition seed tape material. In parallel to the identification of an alternative seed tape material, the experiments also demonstrated that extra layers of tissue paper act as a restraint during early plant growth. The output from this research will stimulate innovation in the seed tape industry, whilst the series of experiments

are also regarded as a template for future seed tape experimentation. Recommendations are provided for further work in this area, specifically with the addition of soil.

Contents

1. Introduction

A ‘seed tape’ is a length of multi-ply tissue paper containing seeds that are spaced evenly along the product (see Figure 1.1). The consumer digs a small trench and a seed tape is simply laid inside, covered with soil and then watered as prescribed. Ease of planting and evenly spaced plants are the two major benefits of this product over conventional seed sewing. The unique properties of the tissue paper allow it to degrade quickly and become weak when water is added, minimising the effects on plant growth performance.

Figure 1.1, An image of a Seed Tape surrounded by soil.

Little is known about the early history of seed tape products, however, records of product patents provide an outline of the progress of product development. The first patent to specifically detail a seed tape was submitted by William Nelson Mccomb (1913), from New York. This first evidence of a seed tape describes a material designed to improve the seed sowing technique, which will disintegrate in the ground. Development of the seed tape product has since continued; exploring the specific material types including fibrous materials (Gray and Gray, 1915) and polymers (Haruto *et al*, 1966). More recently developments have included a circular seed disk and square seed mat versions of the product, intended for use in plant pots or beds. Seed tapes are now manufactured on a commercial scale to supply a global market. As the market continues to grow, there is a requirement for further research and development in the industry. Research is required particularly in the field of material engineering, and specifically into the relation between the substrate material and plant

penetration rates. This research is necessary due to the lack of scientific evidence to support the link between seed tape properties and increased performance, in a developing seedtape market. Previous work is analysed in this report to discuss links in the knowledge of early plant growth and development of the mechanical properties of the seed tapes raw materials.

Before this research project, the correlation between the ingredients and mechanical properties of the material used in seed tapes and the effects on germination rates was unknown. In the absence of existing biological, physical or other theoretical models, this report will help to link individual material properties to germination rates, so that the most appropriate materials can be selected by the industry.

To deliver scientific evidence, a series of experiments were required, identifying the significant and non-significant properties of tissue paper that effect germination and penetration. Detail is given in this report of the most appropriate experimental approach to analyse the germination rates of seed tapes. This approach will act as a plan for future experiments involving germination and penetration of seed tape products.

This report also describes the experimental process used to identify an alternative seed tape material with improved seedling penetration results than that of the current tissue paper used in the production of seed tapes. The existing seed tape material has been analysed to provide a baseline for the results.

Different materials (predominantly tissue papers) with different properties, are used by seed tape manufacturers across the world. The choice of material is based on cost, availability, manufacturability and its effect on plant germination rates. Seed tape is a niche market and, until now, there has been very little reported research material to identify a link between crop sizes and specific tissue papers properties. However, the market is increasing in size, and since the product has grown in popularity, so has the commercial interest and relevance for

scientific grounding. This research will provide the seed tape industry with a fuller understanding into the scientific background of the germination and penetration processes within seed tape products.

To provide industrial context, a case study of a manufacturer of seed tapes has been explored. 'Seed Developments Limited' is a leading manufacturer of bio-degradable seed tapes and pre-sown associated products based in Somerset, England. The seed tapes are made from lengths of 2, 3 or 4 ply tissue with seeds placed between the layers at even intervals. The tapes are designed to make planting flowers or vegetables simpler and tidier. The present tissue paper used in the seed tapes is the only known option for Seed Developments Limited. Improved understanding of the effects of tissue paper alternatives on germination and early plant growth rates will provide knowledge for advanced product development. This will enable the use of more commonly available tissue papers, leading to a greater supplier security and offer the use of lower priced raw materials. All of the factors above will have a direct impact on job security in Seed Developments Ltd. An improved understanding of the fundamental raw material will help to produce a much more desirable product, which, in turn, will stimulate the seed tape market.

The experimental work outlined in this document has been created to test three key hypotheses:

Hypothesis A

The ‘crop size’ produced from loose seed will be higher than the ‘crop size’ produced from seed tape products.

Hypothesis B

The tissue paper material currently used by Seed Developments Limited (Paper A), produces maximum seedling penetration rates.

Hypothesis C

Penetration rates of seedlings through the seed tape material will be greater in 2 ply format seed tapes than 4 ply format seed tapes of the same material.

These hypotheses reflect theories and expectations drawn from the anecdotal evidence of consumers and the seed tape industry. Understanding the validity and the contributing factors of each hypothesis will influence the development of future seed tape products.

To test the above hypotheses, a series of experiments were executed, documenting the effects of various tissue paper properties. To ensure the validity of the experimental outcomes and related empirical models, it is crucial that the results of the experiments are reliable, for this reason considerable attention has been paid to the design of experiments. Due to the number of variable material properties and the large variation of seed types involved, the design of each experiment was paramount; improving efficiency, saving time and costs. Good planning of experiment design is critical (Walker, 2000). The reliability and accuracy, including the strengths and limitations are discussed later in this report, highlighting areas recommended for future research.

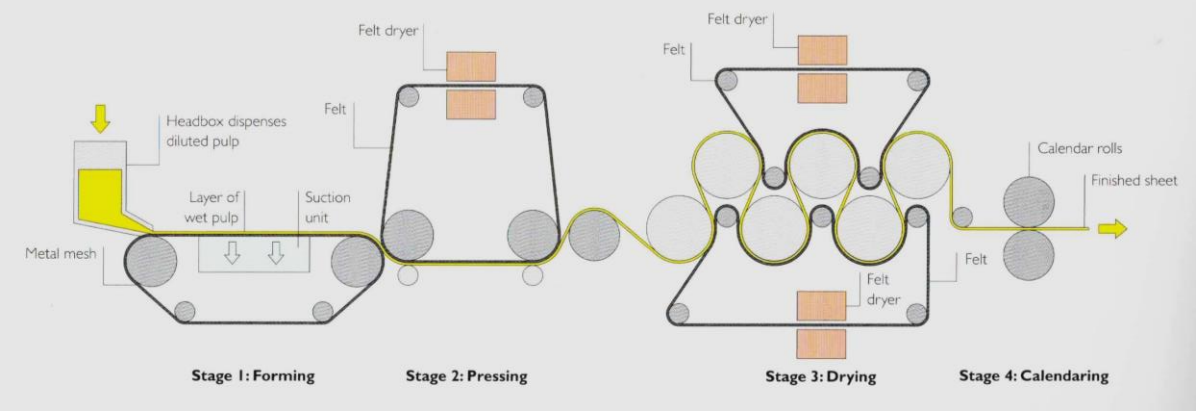
2. Previous Work

To provide academic context, various related topics have been investigated. There are two core areas of research that are fundamental to seed tape products; literature related to tissue paper (as the primary material used in seed tapes); and work connected to the early growth of plants and seed germination. Both of these areas hold equal importance and are interlinked with regard to the performance of the seed tape.

The material surrounding the seed tape is critical to the growth of the plant; therefore variations in tissue paper production have the potential to vary the properties of the seed tape. Manufacture of tissue paper is a multi-phased process; beginning with creating a paper pulp by grinding and mixing raw materials. A variety of different raw ingredients can be used in the pulp to achieve specific properties, such as a mix of woods for longer fibres to achieve improved stretch or chemicals to influence colour. The pulp is then fed into the forming process, see Figure 2.1. The size of the mesh used in the forming process can affect mechanical properties such as tensile strength and multidirectional stretch. The tissue paper is then passed through a drying process before passing through heated rollers to refine texture, known as calendaring.

For the seed tape industry, the tissue paper is then rewound onto cardboard cores and received as a raw material by the Seed Tape industry in roll format. Seeds are then inserted into the tissue paper plys as they are simultaneously embossed together.

Figure 2.1, The standard paper forming process (providing the raw material for tissue paper based seed tape products), beginning with the pulp inserted into the hopper on the left-hand side, ending with finished product on the right-hand side (Thompson, 2013).



The British Standards Institution (2011) has published documentation defining key terms to describe tissue paper properties and manufacturing processes (in the production of tissue paper). The terms can be used throughout this research to maintain a level of clarity and understanding. The term "tissue" describes products and base papers made from lightweight, dry or wet creped and some "non-creped" papers; tissue products can be made of one or several plies, each ply being of one or several layers, prepared as sheets or rolls, folded or unfolded, embossed or unembossed, with or without lamination, printed or not printed and possibly finished by post-treatment, e.g. lotion application (British Standards Institution, 2011).

There are numerous potential influential properties of the tissue paper that effect the early plant growth. The most apparent properties of the material affecting early plant growth are; thickness, wet tensile strength and water absorbency. The thickness and wet tensile strength properties of the tissue paper are expected to influence the force required by the seedling to penetrate the material. The water absorbency of the tissue paper is likely to effect the

irrigation of the plant. These properties are recognised by the tissue paper industry and the seed tape industry, and measured using standards of practice to harmonise evaluating techniques; for instance, BS EN ISO 12625-3:2014 (The British Standards Institution, 2014) specifies a test method for the determination of thickness and bulking thickness and the calculation of apparent bulk density and bulk of tissue papers. Similarly, standards such as BS EN ISO 12625-4:2005 (The British Standards Institution, 2005) outline recognised procedures for the determination of tensile strength, stretch at break and tensile energy absorption. These standards are used in the tissue paper industry to set tolerances of the individual properties of specific tissue paper brands, ensuring a guaranteed level of uniformity in the material. This level of standard is inherently transferred to the seed tape products, and therefore holds relevance on the topic of seed tape germination and penetration rates. The tissue paper properties ultimately form the fundamental properties of the seed tape, and are therefore likely to affect the growth of the seeds therein.

Seed tapes are primarily, but not exclusively produced from tissue paper. Hongguang Cui et al (2010) discuss the production of a polylactic acid (PLA) non-woven seed tape. This may be a suitable alternative to a tissue paper based seed tape, it would, however, involve a radical change to the manufacturing machinery in the Seed Developments Ltd production line. For that reason it was not reasonable, given the resources and time scale of this project, to produce and test a specimen of a seed tape manufactured from this material. However, given the development rate of new materials, the use of alternative materials cannot be ruled out for future research.

Dissanayake (2008) investigates the potential of direct seeding plants as an alternative to a transplanting method, focusing on a single species of plant, Guayule (*Parthenium argentatum Gray*), using seed tapes as a method to increase seedling emergence and vigour. Dissanayake (2008) explains that as well as allowing even spacing, seed tapes *may* protect the seed from

adverse environmental conditions and pests, calling for further studies. This is not something that will be explored in this research; however, the design of experiment may act as a template for future exploration of the effects of adverse environmental conditions or pests.

Parallel to the investigation of seed tape materials, it is equally relevant to study plant growth stages. Before the seed is planted it is in a state of dormancy, when the circumstances are appropriate a transition is made and germination takes place. Dormancy is the condition where germination or growth is inhibited by the seed's physiology, dictating when the conditions generally will remain favourable for further growth and development (Preece and Read, 2005). Dormancy may constructively limit the time or location at which seeds will germinate, for example desert seeds which will germinate only at the beginning of the rainy season, or cypress seeds which normally require standing water for germination (Leopold and Kriedmann, 1975). The conditions must be replicated in germination experiments such that the triggers to exit the dormancy phase are activated, therefore facilitating the transition from the dormancy to germination.

Germination is defined by Leopold and Kriedmann (1975) as arousing a dry seed to start growth into a new plant, involving four groups of processes; the imbibition of water, the formation of enzyme systems, the commencement of growth and radicle emergence, and finally the growth of the seedling with the characteristic features associated with subterranean plant up to the time of emergence from the soil. The contents of the seed absorb water and the internal tissues swell, which places great pressure on the testa of the seed and ultimately allows the radicle to emerge (Scott, 2008). Germination is said to have occurred at the time when the radicle emerges from the testa of the seed (Scott, 2008). In the classification of specimens in this research, a seed will be classed as germinated when a radicle is visible with the naked eye.

Typical factors that promote germination are: light, temperature, oxygen, soil conditions, gibberellic acid concentration in the embryo, ethylene, smoke or heat from fires (Scott, 2008). Temperature may be the most important environmental factor that limits the distribution of plants; temperature greatly influences plant growth, development, dormancy and propagation (Preece and Read, 2005). The International Seed Testing Association (2014) provides information with regard to the optimum growth conditions for seed testing; recommending a light period (at a temperature of thirty degrees Celsius) for eight hours, followed by a dark period (at a temperature of twenty degrees Celsius) for the remaining sixteen hours per day. Similarly, Dissanayake (2008) used the following conditions for the experiment: eight hours of light followed by sixteen hours of dark, daily, at twenty degrees Celsius. As discussed above, Dissanayake focused on a single species of plant, Guayule (Parthenium argentatum Gray), the optimum test conditions for this plant differ from the ideal test conditions for the plant species that were tested during the experiments described in this research project, therefore the guidance from The International Seed Testing Association (2014) was followed throughout the design of experiments.

Plants are required to adapt to their local environments as they are unable to relocate to optimal habitats. While this adaptation can occur on a physiological level, it may also be achieved through the flexible patterns of development that characterise vegetative growth (Taiz and Zeiger, 2010). Adaptation to the surroundings provides plants with the ability to grow according to their environment, therefore, in the case of a seed tape, in order to grow towards the light it is essential that the seedling penetrates through the tissue paper. If the plant fails to penetrate through the tissue paper, it will continue to grow within and along the seed tape until the lack of photosynthesis and the moist underground conditions will cause death.

Esashi and Leopold (1968) discuss the physical forces produced by seeds during germination. Their work focuses on one particular species, the *Xanthium* plant, despite this their results hold relevance for this research project, providing an approximate value on the force produced. The estimated force produced by germination can be compared to the tensile strength of tissue paper samples, to estimate the success of test specimens. Queiroz et al (2012) investigated the forces required to puncture the micropylar endosperm in *Genipa americana (Rubiaceae)* seeds. Queiroz et al produce a range of results before and after imbibition, the highest required puncture force was three Newtons (3N), decreasing to 0.8 Newtons (0.8N) after 16 days of imbibition (the absorption of water by the seed). From this data, it may be assumed that a successful tissue paper specimen must be able to be punctured with an applied force of approximately 0.8 Newtons. This force will vary significantly with alternative plant species, therefore a representative range of seed sizes and weights were required for testing. Seed selection is critical as physical seed size and weight affects seedling emergence, vigour and growth (Arteca, 1996). The seeds that were analysed represent the range used in the production of seed tapes; utilising a mix of herbs, flowers and vegetables of various sizes and expected germination times.

In the matter of germinating speed, late germinating seeds may be shaded by earlier germinating seeds and result in an uneven crop (Preece and Read, 2005). This holds relevance because of the importance of uniformity in plant growth to consumers. Relatively even seed spacing can be achieved with seed tapes, however if there are significant differences in the speed of germination, uneven crops may be yielded. The point at which significant advantage is gained by faster germinating seeds is unknown, and is likely to vary significantly with the plant species.

The medium on which germination trials take place is also an important factor. An ideal germination medium must have good water holding capacity, but be well drained (Preece and

Read, 2005). Moisture retention in soils can vary significantly, depending on porosity; water will percolate rapidly through the soil if it is very sandy, or water retention will be much higher if the soil is constructed from fine textured and organic particles with smaller pore spaces (Fitzpatrick, 1986). Many pot experiments are conducted using pure quartz sand or some other pure medium, particularly when testing the effects of microelements, and therefore offer advantages over field trials (Fitzpatrick, 1986). However, most germination experimentation is conducted using an absorbent paper or cloth in petri dishes or other plastic containers, and monitored inside an environmentally controlled germination chamber (Preece and Read, 2005). In order to achieve uniform moisture in the samples, an absorbent blotting paper substrate was used in this experimentation.

Leopold and Kriedmann (1975) describe the advantages and disadvantages of utilising various growth analysis calculations; such as 'relative growth rate', the increase in weight per unit of weight over a time interval; 'leaf-area ratio', the ratio of leaf area to whole-plant dry weight; 'unit leaf rate' (or net assimilation rate, NAR), the rate of increase in dry weight per unit leaf area; and 'relative leaf-growth rate' (RLGR), analogous to relative growth rate of the whole plant. These metrics are used to measure plant growth at any stage in the life of a plant; however, the research in this paper is primarily focused on investigating the number of seedlings that are able to grow through the seed tape. In the seed tape industry, the critical figure is the number of seedlings that penetrate through the tissue paper. The reason for the importance of tissue penetration rates is that this number correlates to the number of plants that are likely to survive, hence the crop size. There are few seeds that have more than one shoot apical meristem (Scott, 2008), therefore counting the number of shoots is a reliable method of counting the number of germination and penetration instances. Therefore, rather than measuring the growth of the plant by means of weight gained, a count of the number of shoots that penetrate of the tissue paper is more informative.

Conclusions of Previous Work

The fundamental previous pieces of work analysed offer key insights that have influenced this research. Seed tape specifications and performance is interlinked by two parallel topics; mechanical properties of tissue paper and the behaviour of plants during and immediately after germination. The manufacturing methods of the tissue paper, including the raw ingredients used in the pulp and the size of the mesh used in the forming process, directly influence the properties of the paper, as presented by Thompson (2013). The effects of influential properties of the tissue paper, such as wet tensile strength and absorbency, have been analysed in this research in order to identify an alternative material to that used by Seed Developments Ltd. It has also been found that as an alternative to tissue paper, non-fibrous materials have previously been used in the production of seed tapes; subsequently a starch based material, rice paper, was examined in this research.

The seedlings that are able to penetrate the material fastest are likely to have an advantage over the seedlings that take longer to penetrate, as they will be able to develop their leaves and shadow the slower plants from light. In order to mitigate this problem, it was important to ensure that the seeds were evenly spaced within the seed tapes throughout the experiments. It was also important that the growth conditions were optimised and monitored, for this reason a versatile environment controlled chamber was used to guarantee that conditions were maintained in accordance with the International Seed Testing Association (2014). With regards to equipment, growth trays and an absorbent blotting paper substrate were used, based on information provided by Preece and Read (2005).

Information gathered during the review of previous work, provided a strong basis of knowledge to ensure that the conditions were ideal for plant growth, producing reliable and repeatable results that can be used to support development in the seed tape industry.

3. Experiment Process

Project Scope

In recent years the seed tape market has been growing and so the market value has prompted competition in the industry, subsequently leading to a greater level of investment. There is limited scientific research to support the seed tape industry; this research will provide knowledge to stimulate the industry and support opportunities for further research and development, ultimately supporting growth in the industry.

Historically, the material properties used in seed tapes have remained a commercial secret, creating an impression of complexity that may or may not be the reality. There have been concerns with the transparency of market of the raw materials used in seed tapes; until now it has not been known if supplier's claims of superior material properties are realistic, therefore this research aims to shed light on the effects of properties on the performance of the product in an objective manner.

This research project investigated the following three hypotheses:

Hypothesis A

The 'crop size' produced from loose seed will be higher than the 'crop size' produced from seed tape products.

Hypothesis B

The tissue paper material currently used by Seed Developments Limited (Paper A), produces maximum seedling penetration rates.

Hypothesis C

Penetration rates of seedlings through the seed tape material will be greater in 2 ply format seed tapes than 4 ply format seed tapes of the same material.

The experiments were designed and conducted to produce data to test each of the three hypotheses. Areas that were not included in the project scope are detailed in Chapter 6.

Design of the Experiments

Before conducting the experiments, planning was carried out to ensure that the most reliable data could be extracted. It was also important that each experiment be carried out in the most efficient manner. To ensure that test conditions are optimised and to validate the results, it was decided that the series of experiments would comprise of three fundamental phases; a control phase (to test the optimal control conditions), a broad comparison phase, and a validation phase.

All three phases were planned before the first experiment was initiated. After each phase, the plan for the next phase would be reviewed and updated where necessary based on the finding from the previous phase; ensuring that lessons learnt would be carried forward (specific examples are detailed in Chapter 4).

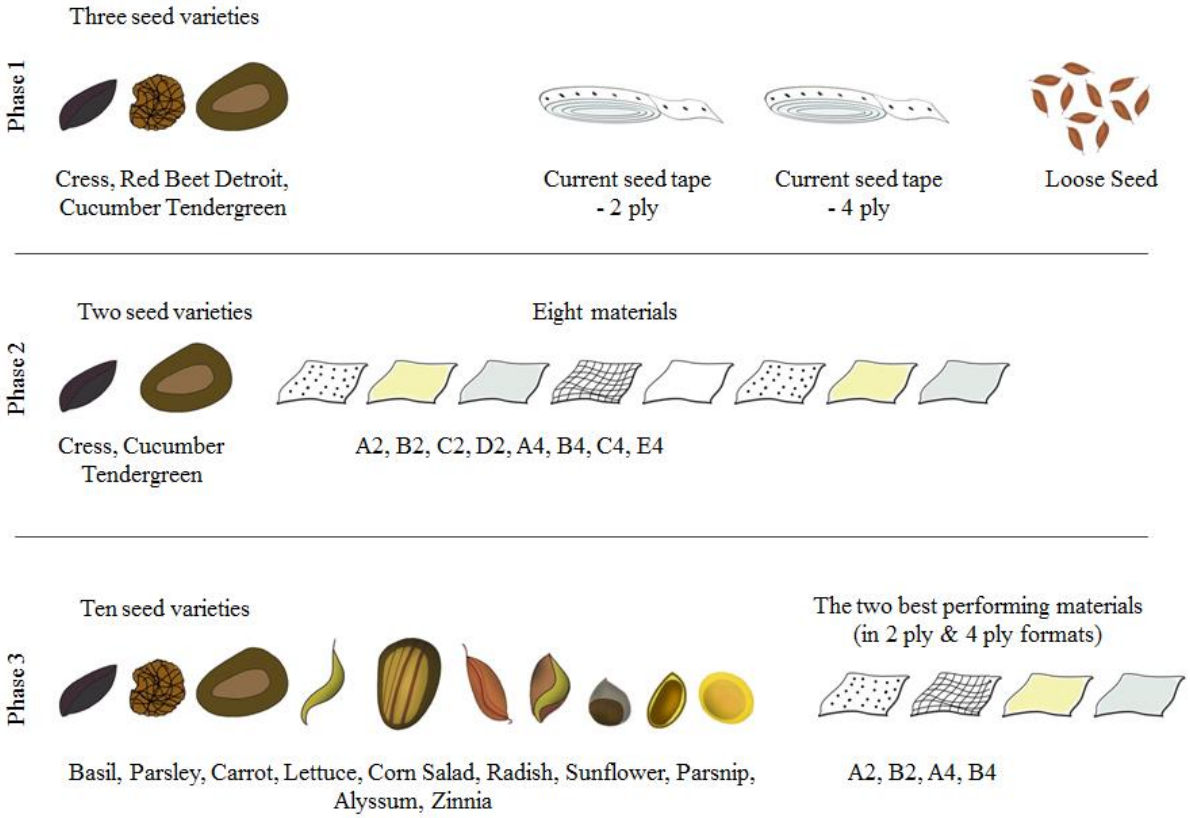
Introduction to the Experiments

The experiment analysed the performance of the seed tape products on a number of metrics; germination count, germination rate, penetration count and penetration rate; these have been chosen as factors that influence the growth performance of the seed tapes. The metrics were compared in a number of different seed tape materials, using a range of seed species.

The large number of seed tapes that required monitoring added complexity to the experiments. In order to eliminate unsuitable materials, it was decided that firstly an early screening stage would be conducted to refine the testing. Eliminating the seed tape materials early on in the process allowed for sensitivity of results in the final assessment, because it was possible to test a greater number of seed species. The seed tape materials that were not eliminated in the first instance were subsequently subjected to further much more detailed

tests, and therefore it would not have been possible to conduct all of the tests simultaneously. In order to conduct all of the tests systematically, the experiments was divided into three phases, as seen in Figure 3.1.

Figure 3.1, A breakdown of the three experiments, displaying the independent variables. The number of seed species are displayed in the left-hand column and the seed tape formats are detailed in the right-hand column.



The initial experiment acted as a control, ensuring that the conditions and procedures for data collection were appropriate and reliable. Designing an experiment is an iterative process and so in the beginning there was a learning process used to influence the design of later phases of the experiment (Montgomery, 1997). The initial phase also formed a comparison between the germination rates of loose seed and seed tapes. The second phase was used to identify a suitable alternative material, predominantly based on the highest germination and penetration rates. The practicality of using the material in a seed tape product and the manufacturing

process was also considered. Finally, in Phase 3, the most effective alternative material (found in Phase 2) was compared against the current baseline tissue paper (Paper A) across a range of seed species, representative of the seed species used across the seed tape industry.

To increase the reliability and accuracy of the results, the experiments took place in controlled laboratory conditions. Temperature, light and irrigation were all monitored to ensure that all seed tapes were exposed to equal and optimum conditions for growth. The humidity inside the chamber was not regulated because the seed tapes were contained in sealed dishes.

Table 3.1, Listing the experiment constants, dependent variables and independent variables, each requiring intense monitoring.

Constants	Dependent Variables	Independent Variables
Temperature	Germination Count	Seed Tape Material
Lighting	Germination Rate	Seed Variety
Humidity	Penetration Count	
Irrigation	Penetration Rate	

By controlling these conditions, it does not only ensure that all of the specimens are exposed to the exact same environmental circumstances, it also increases the reliability and repeatability of the results.

Preparation of Equipment

The equipment required initial calibration before the experimental runs. This was necessary in order to establish confidence in the experimental data and also to isolate any faults that the equipment might have. The calibration was conducted prior to the experimentation, by monitoring the cyclic light and temperature by use of a versatile environment controlled

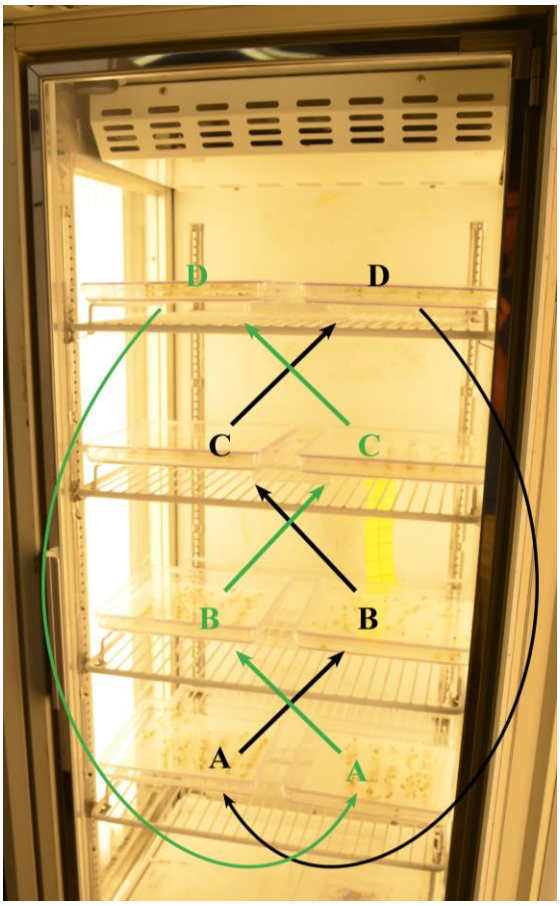
chamber. Following the procedure in accordance with the International Seed Testing Association (2014) as discussed in Chapter 2, the light period (at a temperature of 30 degrees Celsius) was set for 8 hours (beginning at 00:38 hours and finishing at 08:38 hours), followed by the dark period (with a temperature of 20 degrees Celsius) for the remaining 16 hours per day.

The chamber was kept secure in a locked room with limited access, and also clearly signed as not to be disturbed. The security of the specimens ensured that stable conditions were maintained; eliminating errors caused by unauthorised changes to the environment.

Each shelf in the test chamber supported two large square bioassay dishes (245 x 245 millimetres) containing the specimens. These dishes were chosen to allow for relatively long strips of seedtape to be examined, giving a fairer representation of sowing conditions in reality. The square shape of the dishes allowed for space inside the chamber to be maximised so that more samples can be tested simultaneously, reducing the overall time of the experiment.

During each experiment, the bioassay dishes were rotated through the shelves, to dispel any unforeseen advantages of shelf position within the chamber. Figure 3.2 shows the daily movement of the bioassay dishes within the chamber.

Figure 3.2, A demonstration of the rotation of each sample. The dishes were moved from left to right as well as up a shelf; specimen 'A' would move to position 'B' and so on.



Another important feature of the bioassay dishes was the lid. The use of a transparent lid ensured that photosynthesis could take place during the light periods of the cycle.

The bottom of the bioassay dishes were lined with blotting paper to absorb loose water, guaranteeing that the seeds would not be flooded whilst also acting as a store of water to prevent the seeds from drying out. A soil or compost base was not used in any of the experiments, in order to limit the quantity of control variables and improve the reliability of the results; the use of soil in germination experiments is discussed further in Chapter 6.

The process of adding water to the specimens was carefully executed. The disturbance of pouring the water onto a concentrated point on the seed tape may weaken or tear the tissue paper. During a trial run, there were a number of instances when the seed tapes were

displaced by the water, with a risk of impairing the counting process during data collection. When watering, it is important that the water is poured on an area that is not covered by seed tape; the water will then be dispersed by the blotting paper lining during absorption, ensuring that the seed tape is not subjected to any external force. Care was needed also when watering loose seed specimens, as a rush of water is likely to displace the seeds. If the seeds are displaced by a rush of water then they are liable to group together or be carried to an inconvenient position in the bioassay dish, hindering the germination counting process.

A lid was used on each bioassay dish to keep a constant humidity rate inside, giving the seeds a consistent probability of growth. The lid of each dish was removed for no more than three minutes per day to allow time for photography of the samples and to count the number of seeds germinating or penetrating the material samples.

An identification label (as seen in Figure 3.3) was placed onto the lid of each bioassay dish in order to prevent confusion and minimise the risk of misrepresenting data. The labels were positioned in the top left corner of each lid and were all approximately the same size. To avoid obscuring seeds from light, care was taken throughout the experiments to position the lid so that the label would not be located directly above any sample.

Figure 3.3, Demonstrating the label size and position on each bioassay tray, as not to obscure the seeds from light.

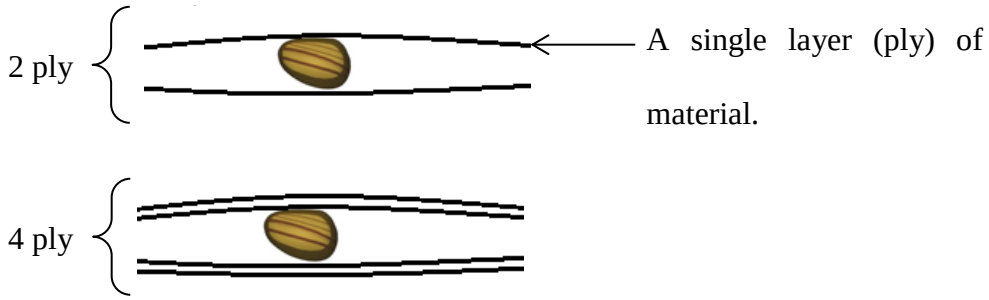
Specimen Specifications

Seed tapes for all of the experiments were manufactured using production machinery at the Seed Developments Ltd factory. The use of standard seed tape production machinery ensures that the authenticity of seed tape quality is maintained. In this case, as is the industry standard practice, loose seeds are placed into a hopper, a 'pick and place' vacuum device then collects the seeds and places them onto the bottom ply of tissue paper, the top ply of tissue paper is almost simultaneously embossed to the bottom ply. This is a continuous process and the seed tape is cut to the desired length.

In these experiments, where possible, two variants of the tissue paper materials were tested, these will be referred to as a '2 ply' specimen and a '4 ply' specimen. The 2 ply specimen will constitute a number of seeds enclosed by a *single layer* of material above and a *single*

layer of material below the seed, whereas a 4 ply specimen will constitute a number of seeds enclosed by *two layers* of material above and *two layers* of material below.

Figure 3.4, A diagram to demonstrate the arrangement of both 2 ply and 4 ply seed tapes.



Currently, in the manufacturing process of seed tapes, the number of tissue paper plys that are used is predominantly dependent on the physical size of the seed. During the manufacturing process, the seeds will puncture the seed tape material if the size of the seed is relatively large. When a seed variety is found to puncture the material (usually based on trial and error experimentation), the plys of material on top and underneath the seed are doubled to strengthen the seed tape; creating a 4 ply version. There is little advantage of a 3 ply seed tape, as it will still expose a weak material layer on one side of the seed tape. In order to test Hypothesis C, where possible, both 2 and 4 plys of tissue paper were used.

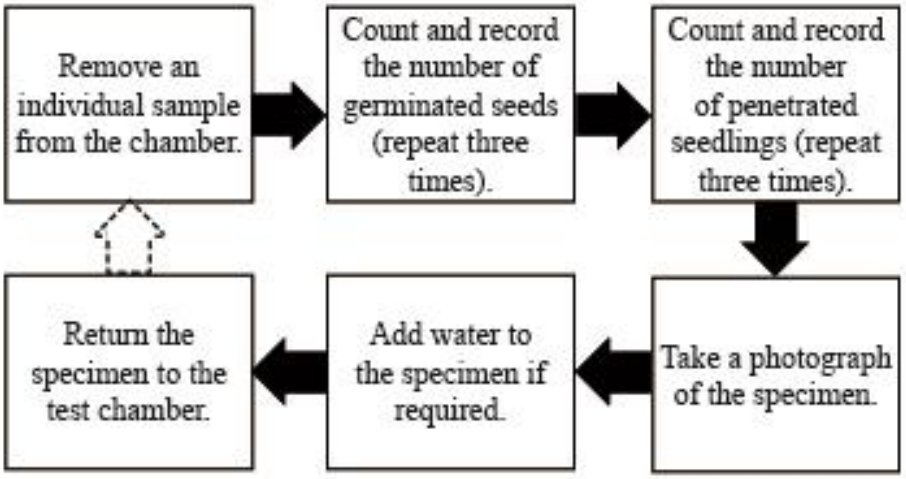
The second imperative specification of the specimens is the quantity of seeds contained within the seed tapes. In order to analyse a representative range of data, and for a percentage to be produced efficiently and quickly, one hundred seeds were used in each seed tape.

The seed tape length is determined by the seed spacing. The industry uses a range of seed spacing, depending on the seed variety and customer preference. The seed spacing ranges used in this research were typical of that used in the industry.

Data Collection Method

The reliability of the method for collecting the data was increased by implementing a system of six steps as seen in Figure 3.5.

Figure 3.5, Data collection process diagram; providing a routine to ensure fair treatment of specimens and reduce the risk of mistakes during data collection.



This process was repeated for all of the specimens, once daily. A daily collection of the plant growth data provided sufficient opportunity for growth to take place, without too much development that would prevent progress from being tracked. This same method was used by Finch-Savage and Mcquistan (1988) in the analysis of carrot seeds.

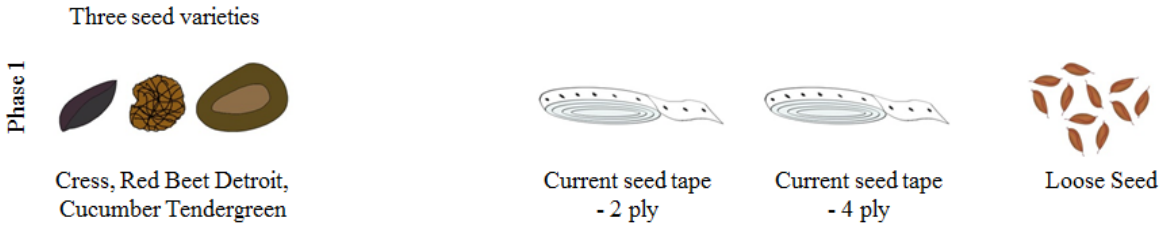
This robust procedure was adopted to mitigate the risk of errors during the data collection process, thus creating a relatively simple routine and ensuring that each specimen is treated fairly. To further reduce the risk of miscounting, the germination and penetration data of each specimen was counted three times before taking the mean.

Each phase ended at the point when the data displayed no change for three consecutive days after the initial germination of that specimen (i.e. no additional germination and also tissue penetration for that period). This gave significant opportunity for all growth activity of a

specimen. After this time, the tissue varieties without change were removed, whilst other seed tapes in the trial continued to be examined.

Phase 1

Figure 3.6, Phase 1 configuration of specimens.



During the Phase 1 experiment, three seed species were tested with both the current seed tapes and loose seeds, as seen in Figure 3.6.

The seed samples used for this phase were ‘Cress’, ‘Red Beet Detroit’ and ‘Cucumber Tendergreen’. These seeds where chosen because they represent a range of physical sizes of seeds used in seedtape production; ‘Cress’ seed is one of the smallest seeds used, ‘Red Beet Detroit’ is a medium sized seed and ‘Cucumber Tendergreen’ is the largest possible seed used. The size of the seed affects the stretch of the tissue paper; the larger the seed, the greater that the tissue paper is stretched. It is likely that the tissue paper is weaker when stretched, allowing for quicker growth of seedlings from larger seeds (but it is unknown if this produces a marked advantage).

The seed tape samples were manufactured on 15/08/14, and stored in a controlled environment with no light at 16 degrees Celsius until the experiment commenced (with the exception of transportation) in accordance with the International Seed Testing Association (2014). All of the samples for Phase 1, including the samples of loose seed, were stored in the same place with the same conditions as each other at all times to prevent bias.

To further ensure that all conditions were identical throughout the experiment, all samples of the same plant species were placed on the same shelf, reinforcing the credibility of conclusions based on comparative results.

During Phase 1, five webcams were positioned inside the environmental chamber, one on each shelf, and plugged into a laptop displaying a constant live feed from each camera. Screen capture software was used to convert the live video footage into still images at a constant interval, thus capturing a record of the germination progress over the time. An image was captured every hour throughout the light period, to define the moment at which germination took place. All images taken during the periods of no light were discarded as this would break the cycle of darkness if illuminated to take the images. Although a time lapse video was created using this photography method, unfortunately the images were low resolution due to the lighting inside the chamber causing interference with the camera (producing over exposure in strips across the images) and the webcams did not have a wide enough angle to capture the entire shelves. Therefore, a DSLR (digital single-lens reflex) camera was used in addition to provide a high quality visual record of the seedling growth. These images are useful for conveying the detailed growth of the seedling within the seed tape.

Before beginning phase 2, the phase 1 specimens were discarded and the bioassay dishes were thoroughly sterilised. To ensure that residue and bacteria were removed, the trays were washed in cold water (without soap), wiped dry with a hand towel before being sprayed with 70 percent ethanol and left to air dry, killing bacteria. This process was also repeated whenever the bioassay dishes were required for re-use.

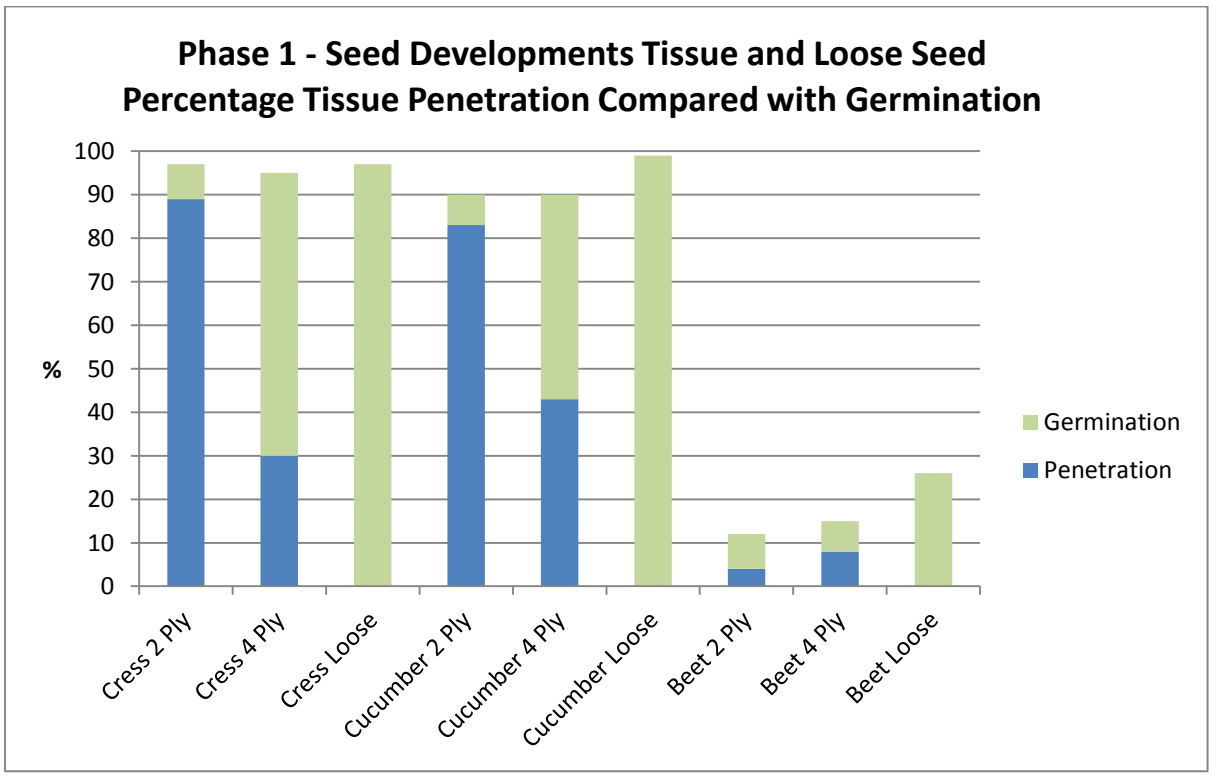
4. Data analysis

Phase 1 Results

With the completion of the data collection for Phase 1, analysis was conducted to make comparisons between hypotheses and data trends. In this section, the results of Phase 1 are discussed and conclusions are drawn where possible.

Figure 3.6 is a graph interpreting the data collected during Phase 1, including the percentage penetration and germination of plants for all specimens.

Figure 3.6, Comparing the differences between percentage germination and penetration rates in phase 1. The areas of the graph shaded blue represent the number of seedlings to penetrate the tissue paper in seed tape specimens, whilst the areas shaded green represent the seedlings that germinated but failed to penetrate the tissue paper (or seedlings that germinated in the loose seed specimens).



Firstly, it can be seen that there is a major irregularity with the germination rate of the Red Beet Detroit seeds. All three of the Red Beet Detroit samples displayed a poor percentage of germinated seeds, despite optimum conditions for growth and optimum conditions for storage before the experiment. With all of the conditions optimised, the most likely explanation for poor growth is that the seed is substandard and therefore provides a misrepresentation of the results. In this case, the reliability of the seed cannot be guaranteed, therefore the data collected in regards to the Red Beet Detroit specimens must be discarded and subsequently this variety was excluded from the remaining experiments.

The data collected from the growth of Cress and Cucumber Tendergreen seeds during Phase 1, is fully reliable and can be used to evaluate the hypotheses of the research. Hypothesis A - The 'crop size' produced from loose seed will be higher than the 'crop size' produced from seed tape products – is the key hypothesis examined in Phase 1.

The difference in crop size can be calculated by finding the difference between the number of germinated loose seeds and the number of seedlings that penetrated through the seed tape specimens.

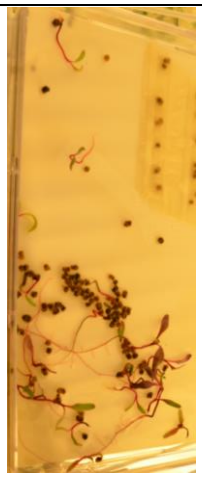
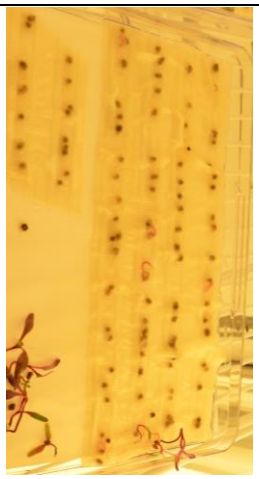
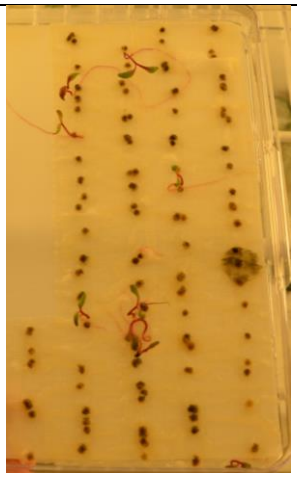
Table 3.1, Displaying crop size for each specimen during Phase 1. The marked difference between loose seed and 4 ply seed tapes is evident in these results.

Variety	Format	Crop Size
Cress	Loose	97
	2 ply	89
	4 ply	30
Cucumber	Loose	99
Tendergreen	2 ply	83
	4 ply	43

The results of the crop size of both plant species in Phase 1, as seen in Table 3.1, demonstrate a difference between sowing formats. The advantage of loose seed in comparison to 2 ply and 4 ply seed tapes with regard to crop size is evident. The difference in crop size between loose seed and a 2 ply seed tape is 8.6 percent in Cress and 17.6 percent in Cucumber Tendergreen. The difference in crop size is more dramatic between loose seed and 4 ply seed tape specimens with a 105.5 percent in Cress and a 78.9 percent in Cucumber Tendergreen. This data supports both; Hypothesis A - The crop size produced from loose seed will be higher than the crop size produced from seed tape products; and Hypotheses C - Penetration rates will be greater in 2 ply format seed tapes than 4 ply format seed tapes of the same material.

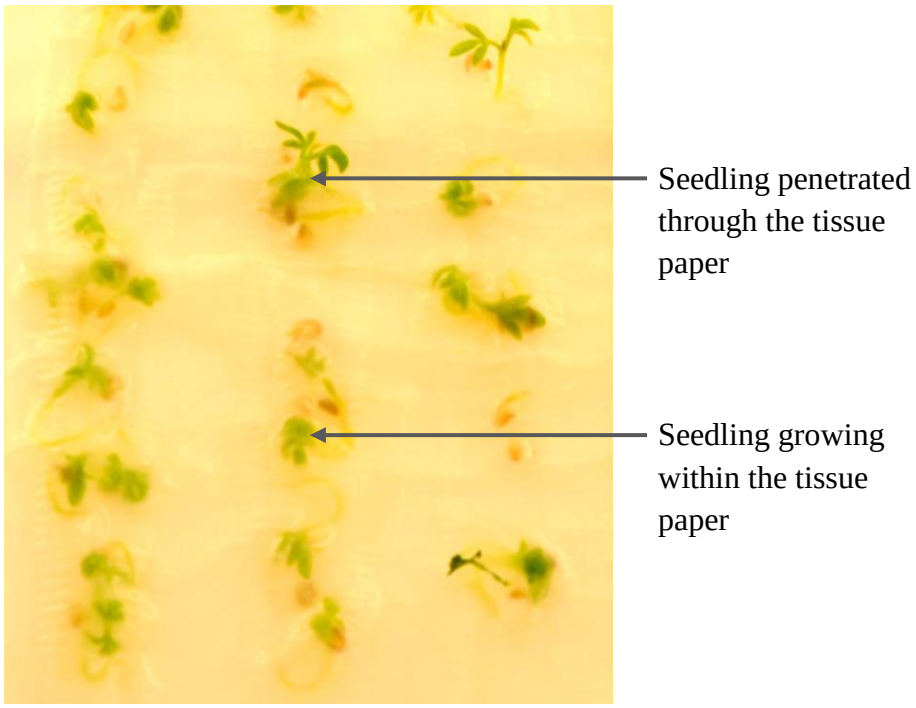
Figure 3.7 allows for a visual comparison between the growth of loose seed samples, 2 ply and 4 ply seed tape samples; each of the images were captured at the time that the individual specimen was removed from the experiment (i.e. when fully developed).

Figure 3.7, Images of fully developed Phase 1 specimens visually highlighting the differences in growth for each variant.

	Loose Seed	2 Ply Seed Tape	4 Ply Seed Tape
Cress	 A	 B	 C
Red Beet Detroit	 D	 E	 F
Cucumber Tendergreen	 G	 H	 I

It is clearly evident in images ‘C & I’, in Figure 3.7, that a large proportion of seedlings in 4 ply seed tape specimens grew inside the seed tape without successfully penetrating through the material. Figure 3.8 shows this in greater detail. These images reinforce the data in Table 3.1; for example only 43 Cucumber Tendergreen seedlings penetrated the tissue paper in a 4 ply sample, compared to 83 in a 2 ply sample. The problem appears to be even worse for the small Cress seed with only 30 seedlings penetrating the tissue paper out of the 95 that germinated.

Figure 3.8, A photograph of Cress seedlings growing within the seed tape during Phase 1.



Another possible effect of the seed tape tissue paper on plant growth is time. The time taken for seed tape penetration provided data for the rate of penetration. Table 3.2 outlines the time scale of activity during Phase 1, providing an approximate growth time. The data in Table 3.2 is supported by the raw data collection of germination and penetration figures per day, found in Appendix 1. A similar germination performance was achieved for all specimens of the

same variety, but the growth speeds appear to be prolonged when inside a seed tape and also when additional plys are added.

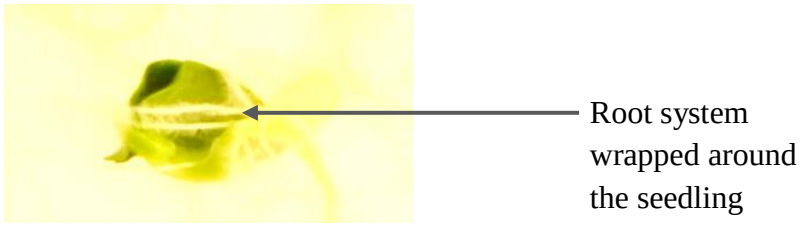
Table 3.2, Timeline of activity during Phase 1.

Date	Action
15/08/14	Samples Produced
18/08/14	Experiment Began (Samples Sown)
27/08/14	Cucumber Loose Seed Removed
28/08/14	Cress Loose Seed Removed
28/08/14	Cress 2 ply Removed
01/09/14	Cress 4 ply Removed
01/09/14	Cucumber 2 ply Removed
02/09/14	Beet 2 ply Removed
03/09/14	Cucumber 4 ply Removed
04/09/14	Beet Loose Seed Removed
05/09/14	Beet 4 ply Removed
05/09/14	Experiment Concluded

During the growth of the specimens in Phase 1, there were a number of minor unforeseen events. Firstly, on 03/09/14 the cabinet door was opened by an inspector to check for genetically modified plants, exposing the specimens to light during the dark period for approximately 5 minutes. This small period of time will have a negligible effect on the experiment results, and there is no dramatic change in the data at or around this point. Secondly, the root system of early developed seedlings occasionally restricted the growth of less developed seedlings, seen in Figure 3.9. This is an issue that occurs in both loose seed

and seed tapes; however it is unclear if containing the seed within a seed tape also contributes to this problem by restricting the root growth path. The issue is likely to be exacerbated by the solid base of the bioassay dish. Further investigation of the behaviour of root systems in seed tapes is recommended for future research, as this could demonstrate the advantages of a weaker tissue paper on the underside of the seed tape, or an odd number of tissue paper plys.

Figure 3.9, A root system restricting the growth of a Cucumber Tendergreen seedling.



In summary, the data displayed in Figure 3.6 and the images in Figure 3.7 support the hypothesis that increasing the number of tissue paper plys in a seed tape will reduce the amount of seedlings that successfully penetrate through the seed tape. Similarly, the seed tapes used in Phase 1 were proven to compromise the crop size in comparison to loose seed by 8 percent for Cress and 16 percent for Cucumber Tendergreen in 2 ply tissue papers and 67 percent for Cress and 56 percent for Cucumber Tendergreen in 4 ply tissue papers.

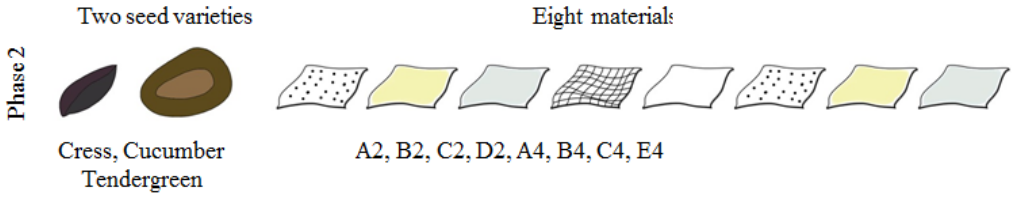
As well as a reduced crop size, the data collected in Phase 1 demonstrates that additional tissue paper plys reduced the penetration rate of the specimens. The reduced penetration rate is again exacerbated by 4 plys of tissue paper. The comparison between 2 plys and 4 plys of tissue paper is continued in the next experiments, in addition to alternative tissue paper materials.

Finally, lessons learnt during Phase 1 were used to influence the experiment design for the remaining experiments. Due to the irregularities in germination rate of the Red Beet Detroit

seeds, this variety of plant was not examined in the remaining experiments. The exclusion of the Red Beet Detroit variety ensures that the necessary level of reliability is maintained in the experiment results.

Phase 2

Figure 4.1, Phase 2 configuration of specimens.



Two seed species were tested in Phase 2, with eight variations of materials, as seen in Figure 4.1. The seed species used in this phase were ‘Cress’ and ‘Cucumber Tendergreen’, sourced from the same batch as the seeds in Phase 1.

Each of the five papers examined have unique properties and attributes that may affect the seed tapes performance and commercial attractiveness. Paper A is used in seed tape products by Seed Developments Ltd’s material; it is organic, and was developed to be advantageous for seed tape products with a low wet tensile strength and high stretch properties to encompass the seeds without puncturing. Unlike Paper A, Paper B has not previously been used to manufacture seed tape products. Paper B is an organic tissue paper and is manufactured using sugar cane fibres. The sugar cane fibres can provide comparable mechanical characteristics to traditional wood originating paper products, whilst offering significant environmental advantages; the fast growing sugar cane pulp (known as ‘bagasse’) is a waste product of the sugar extracting process, using bagasse in the paper manufacturing process is providing a use for a product that would traditionally have been burnt as waste (Lois-Correa, 2012). Paper C is a material developed for a facial tissue product and has similar mechanical properties to Paper A and Paper B, however Paper C is non-organic.

Paper D is a rice paper, manufactured from rice starch. This paper is edible therefore it contains no bleach which is a benefit for gardeners. The most important aspect regarding growth is that rice paper is soluble in water, therefore it was expected that after sufficient watering of the seed tape, the rice paper would dissolve, removing the restrictive layers of seed tape material above and below the seed, therefore the seed germination and seed penetration become equal. Paper E is the lowest costing material, which is primarily used as a toilet paper. The toilet paper chosen was a generic relatively low cost paper that is fragrance free. Toilet paper is designed to have a low wet tensile strength, which is advantageous for seed tape materials.

The eight material specimens were comprised of both 2 ply and 4 ply formats. Table 4.1 illustrates the format of each specimen. It was possible to manufacture both 2 ply and 4 ply formats of Paper A, B and C.

Table 4.1, Material formats used in Phase 2 of the experiment, including 2 ply and 4 ply variants.

2 Ply	Paper A
	Paper B
	Paper C
	Paper D
4 Ply	Paper A
	Paper B
	Paper C
	Paper E

Due to the format in which the Paper E samples were received, it was not possible to create a sample of 2 ply using this material. Similarly, seed tape samples using the rice paper material (Paper D) were only produced in 2 ply formats because of the mechanical properties of the material.

If the rice paper (Paper D) seed tapes were to be manufactured on a commercial scale, they would require production machinery that has not yet been designed, therefore the only method of producing the specimens for this experiment was by hand. For the purpose of this research, the rice paper samples were produced manually using a generic heat-sealing machine. The process used to create these samples and the large scale manufacturing process of seed tapes with this material would differ only in speed and scale; the samples represented the product as it would be manufactured and so the plant growth results would be unaffected.

Table 4.2, A representation of the time scale for specimen production.

Date	Action
15/08/14	All Samples, with the exception of Paper D, were Produced
28/08/14	Paper D Samples Produced
08/09/14	Experiment Began (Cucumber Samples Sown)

All samples for Phase 2 were produced on 15th of August 2014 with the exception of the rice paper samples, which were produced on 28th of August 2014. Despite a later production date of the rice paper samples, the seed tapes were made using identical seed that had continuously been kept in the same conditions and location as the seed used in other samples. For the duration of the production of the rice paper samples, all of the other specimens were

also removed from the temperature controlled storage, ensuring that each sample was exposed to identical conditions.

Due to size limitations, only ten specimens could be placed in the chamber simultaneously. There were sixteen specimens in total to test during Phase 2, for this reason the phase was carried out in two batches. In order to produce fair comparative results, all of the Cucumber Tendergreen specimens were tested simultaneously in the first part, followed by all of the Cress specimens in the second part of the phase. Testing all of one seed variety at the same time ensured that they were exposed to identical conditions; therefore the results can be compared without dispute.

As discussed previously, a number of amendments were made to the experiment design based on the outcomes of Phase 1. As well as the exclusion of Red Beet Detroit seed, the timings of the climate control conditions were also changed. The modified climate timings were calibrated for the light period (at 30 degrees Celsius) to be operational from 08:00 to 16:00 hours instead of the previous 00:38 to 08:38 hours. Whilst the exposure of conditions to the specimens remained consistent with Phase 1 and in accordance with the International Seed Testing Association (2014), the modified timings further reduced the chance of someone opening the chamber during the dark period; avoiding a break in the cycle by exposing the specimens to light.

In addition to the modified timings, a change to the capture of visual images was introduced. It was decided at the beginning of Phase 2 that the use of webcams provided unnecessary additional information; slowing down the data interpretation process whilst supplying little useful data. The webcams used in Phase 1 displayed multiple problems; low quality images, only partial capture of the specimens (due to the narrow angled lens) and also software update notifications on the laptop partially obscured the capture of webcam images. As an

alternative to webcams, to provide a visual record of the specimens, high quality images were captured using a DSLR camera. The DSLR camera was calibrated in the same fixed positon for each photograph, to aid comparison throughout the experiment.

Phase 2 Results

As discussed in the previous section, due to the size constraints of the environmental test chamber, Phase 2 of the experiment was executed in two parts. The experiment was divided between the two seed species; Cucumber Tendergreen and Cress. The results from both parts of phase 2 are collectively evaluated within this section.

For each of the eight material specimens, the final percentage germination and penetration results are displayed in Figure 5.1 and Figure 5.2. The differences in the number of seeds that germinated yet failed to penetrate through the seed tape can be seen to be relatively large in most cases. This suggests that a percentage of the seeds either naturally fail to grow after initial germination, or are hindered by the seed tape.

Figure5.1, Comparing the differences between germination and penetration rates in Cucumber Tendergreen during phase 2. The data suggests that Paper D produced the largest crop size. The data also highlights the marked difference between the percentage penetration 2 ply and 4 ply variants.

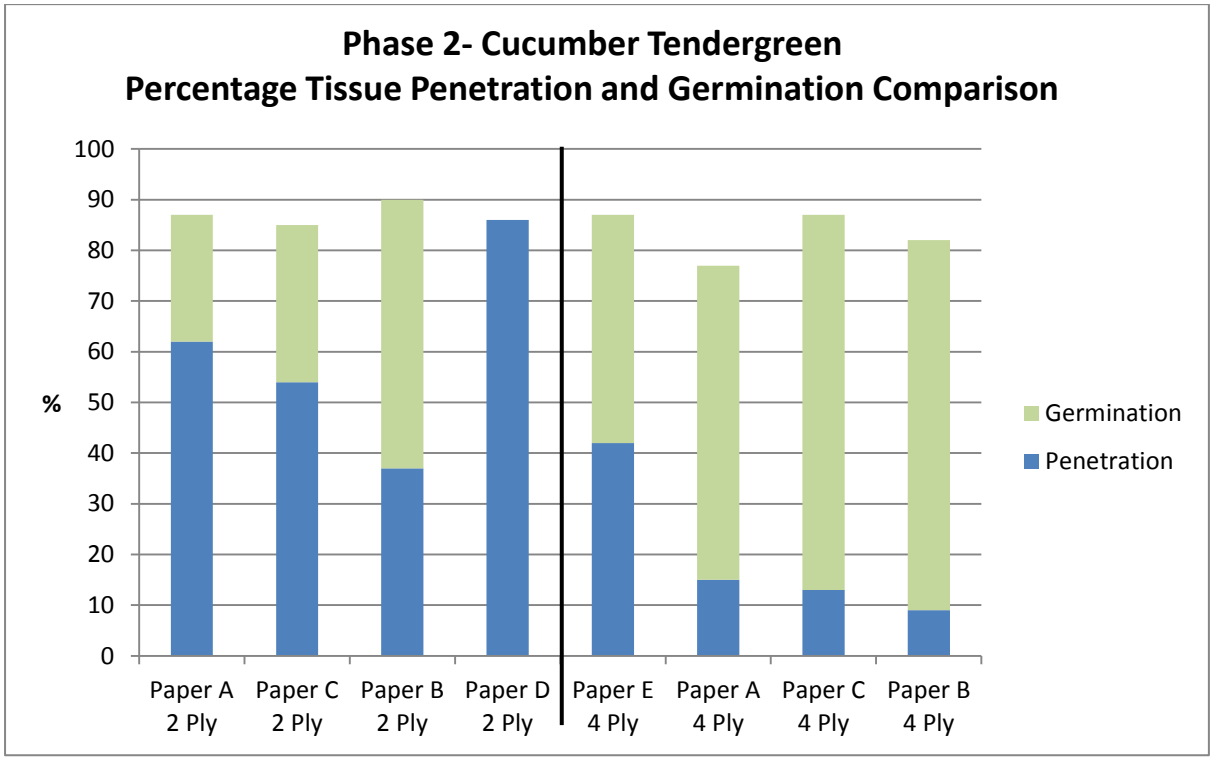
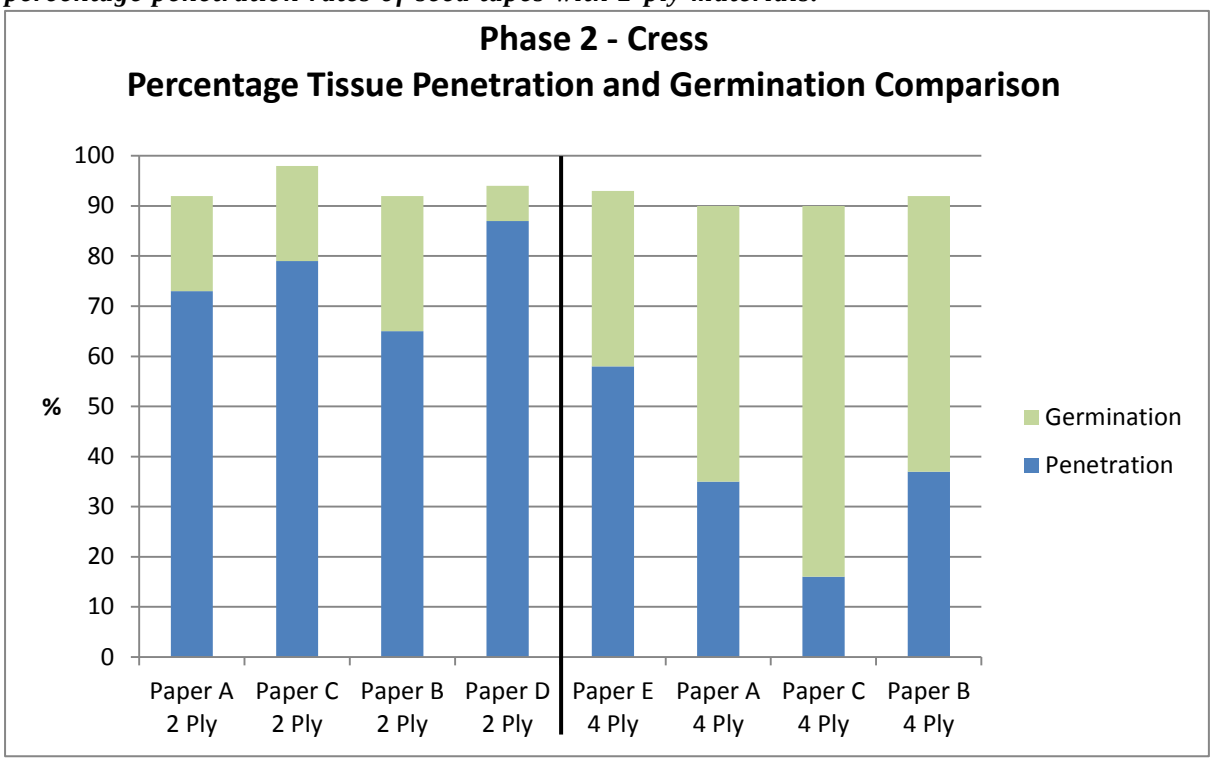


Figure 5.2, Comparing the differences between germination and penetration rates in Cress during phase 2. Similar to Cucumber Tendergreen, the data displays the advantages for percentage penetration rates of seed tapes with 2 ply materials.



The results displayed in Figure 5.1 and Figure 5.2, also show that the best penetration results during Phase 2 were produced by the Paper D specimens. Successful plant growth through these specimens can predominantly be attributed to the fact that within the first three days after planting, the rice paper samples began to dissolve until on the third day the rice paper was almost completely suspended in the liquid with very little solid rice paper remaining. This left the seed no longer enclosed by the seed tape, but instead surrounded by the dissolved rice paper in water. For this reason, by day four the majority of the seeds could be classed as penetrating the seed tape because they were no longer enclosed. This effect was seen in both the Cucumber Tendergreen and Cress species in phase 2; however there was a small area of the Cress sample that did not fully dissolve, and so the seedlings did not penetrate this area of the specimen. A seed tape that almost completely dissolves in this way would be a great benefit to the consumer, guaranteeing that if the seed will germinate then it will grow through the seed tape. Further research and experimentation is recommended to

analyse the longer term growth of the plant within a seed tape manufactured from Rice Paper. After the initial germination of the seedling, it was observed that the Paper D specimens demonstrated a much slower growth in comparison to other samples; perhaps the plant growth was inhibited by the dissolved Rice Paper solution. The reduction in growth was so significant, that it would not be practical for a consumer product in its current format (see Figure 5.3), therefore Paper D is omitted from the next experiment.

Figure 5.3, Two images comparing the growth on day 9 of Phase 2.Left: Cucumber Tendergreen Paper D, Right: Cucumber Tendergreen Paper B. The images demonstrate the reduction in growth of Paper D plants in comparison to Paper B.

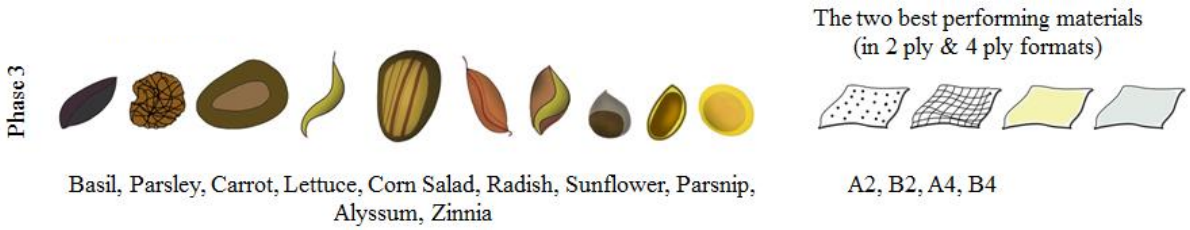
The Paper E samples produced relatively high results compared with other 4 ply tissue papers, however due to the low density of the paper, it is not currently possible to manufacture seed tapes using a 2 ply version of this material (because the tissue paper is prone to tearing in the machine). When compared to the results of 2 ply specimens, the Paper E results are relatively poor. Future tests with 2 ply versions of this material are likely to produce positive results, if the manufacturing issues can be solved.

Excluding Papers D and E, Papers A, B and C all produced relatively similar results to each other. In terms of selecting two materials to examine in Phase 3, Papers A, B and C appeared

to be comparatively equally matched with regard to germination and penetration results. However, the Paper C material was omitted from future experiments because it did not meet other necessary criteria (it is non-organic and contains bleach in its composition). Instead, Paper B was investigated in Phase 3 because of the high performance, the appropriateness for manufacture and fitting the criteria of other consumer needs. Paper A was also tested during Phase 3, providing a point of reference to measure the performance against current seed tapes.

Phase 3

Figure 6.1, Phase 3 configuration of specimens.



To investigate the performance of both Paper A and Paper B sufficiently, the germination and penetration figures from a range of plant species were tested in Phase 3 of the experiment. In order to evaluate the tissue papers with a representative spectrum of plant species, ten different seed species were selected to test in both 2 ply and 4 ply formats, as seen in Figure 6.1.

The seed species used in Phase 3 were chosen to best represent the range normally found in seed tapes. The sample represents species of herbs, vegetables and flowers with various estimated germination rates, physical sizes and expected seedling resilience. The range includes two of the most popular seed tape plant varieties; radish and lettuce. A list of the plant species used in Phase 3 is displayed in Table 6.1.

Table 6.1, Seed species used in Phase3 of the experiment. The range of seed species represents vegetables, flowers and herb; with seeds of diverse sizes.

	Common Name	Latin Name	Cultivar
Part 1	Basil	*Ocimum basilicum*	Basilkum Genoveser
	Parsley	*Petroselinum crispum*	Petersilie Mooskrause
	Carrot	*Daucus carota ssp. sativus*	Mohren Nanties
	Lettuce	*Lactuca sativa var.crispa*	Pflücksalat Lollo Blonda
	Corn Salad	*'Holl. broadleaf ' Valeria locusta*	Feldsalat Holl Breitblättriger
Part 2	Radish	*Raphanus raphanistrum subsp. sativus*	Radi Saxa
	Parsnip	*Pastinaca sativa*	Pastinaken Halblange Weibse
	Sunflower Mix	*Helianthus*	Heliathus Annuus
	Alyssum	*Lobularia maritima*	Lobularia proc. Rosie O'Day
	Zinnia	*Zinnia*	Thumbelina Mg.

The specimens for Phase 3- Part 1 were manufactured on 28/10/14. For each seed variety, specimens were manufactured using 2 ply Paper A, 4 ply Paper A, 2 ply Paper B and 4 ply Paper B materials. Therefore, 40 specimens were produced and analysed for each of the two parts of Phase 3. In the interest of maximising space, 2 ply and 4 ply samples of the same tissue paper and same seed variety were combined into the bioassay dishes, with the exception of alyssum seed samples which were small enough to combine all four of the tissue specimens into one bioassay tray.

Unfortunately, there was not enough space available in the growth chamber to test all of the specimens simultaneously in Phase 3. For this reason, the samples investigated in this phase

were analysed in two stages. The method for selecting which specimens were analysed in either Part 1 or Part 2 of the phase was based on the variety of seed, ensuring that both tissue paper samples (for each seed variety) were tested at the same time and therefore exposed to exactly the same conditions. The seed species were distributed between the two parts of the experiment phase based on the physical size of the seed, simplifying the sample manufacturing process.

Phase 3 Results

The data collected from Phase 3 produced marked results when comparing the two varieties of tissue paper in both of the penetration metrics. The four main metrics analysed in Phase 3 were germination count, germination rate, penetration count and penetration rate. The germination and penetration counts represent the total figures collected; i.e. the final, overall amount of germination and penetration that was achieved by the specimens. The germination and penetration rates are a measure of germination and penetration over a period of time. The results of the germination and penetration counts for each specimen are outlined in Figure 7.1, Figure 7.2, Figure 7.3 and Figure 7.4.

Figure 7.1, Comparing the differences of percentage germination and penetration rates between Paper A and Paper B in 2 ply samples during Phase 3 (part 1). Although percentage germination rates vary, percentage penetration rates are higher for each seed variety for Paper B than Paper A.

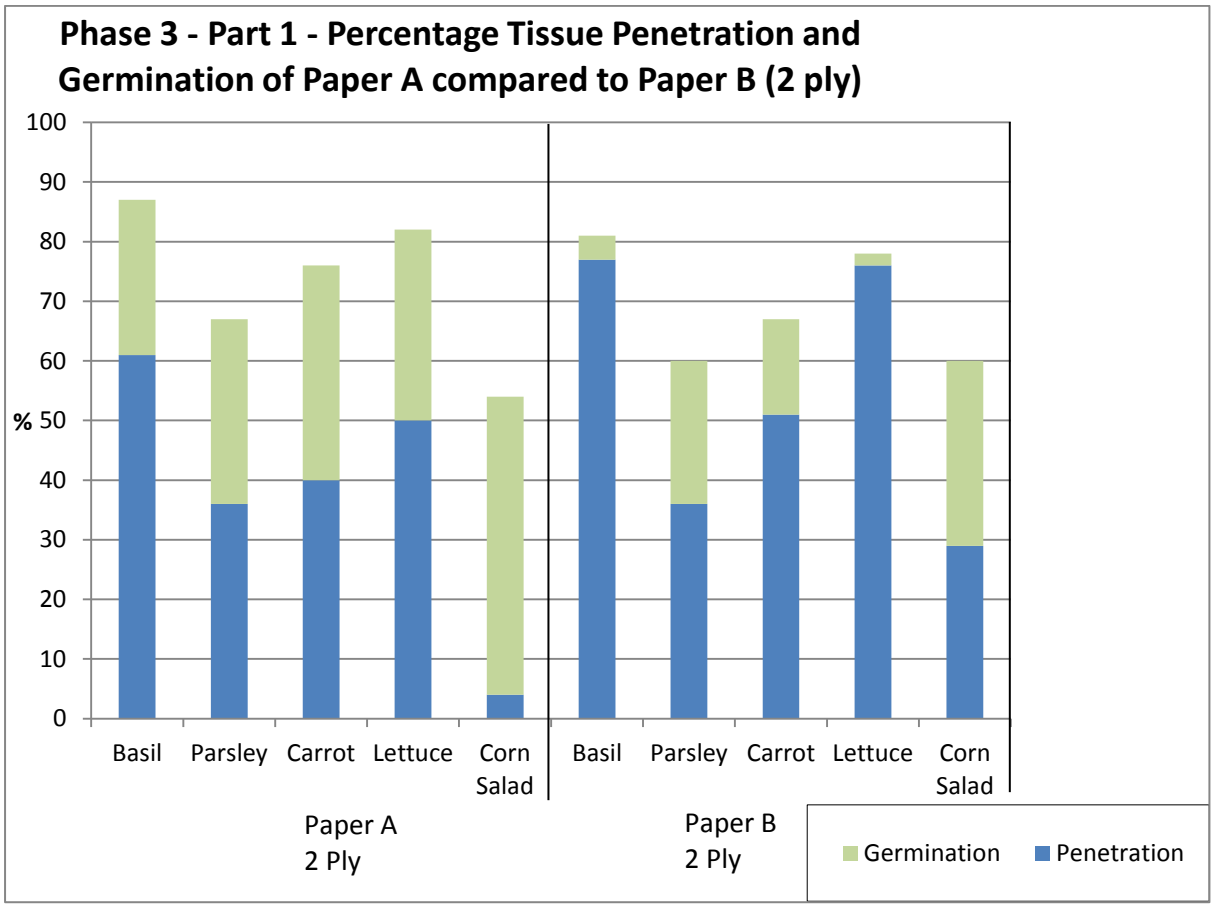


Figure 7.2, Comparing the differences of percentage germination and penetration rates between Paper A and Paper B in 2 ply samples during Phase 3 (part 2). Consistent with part 1, percentage penetration rates are higher for each seed variety for Paper B than Paper A, with the exception of Sunflower seeds.

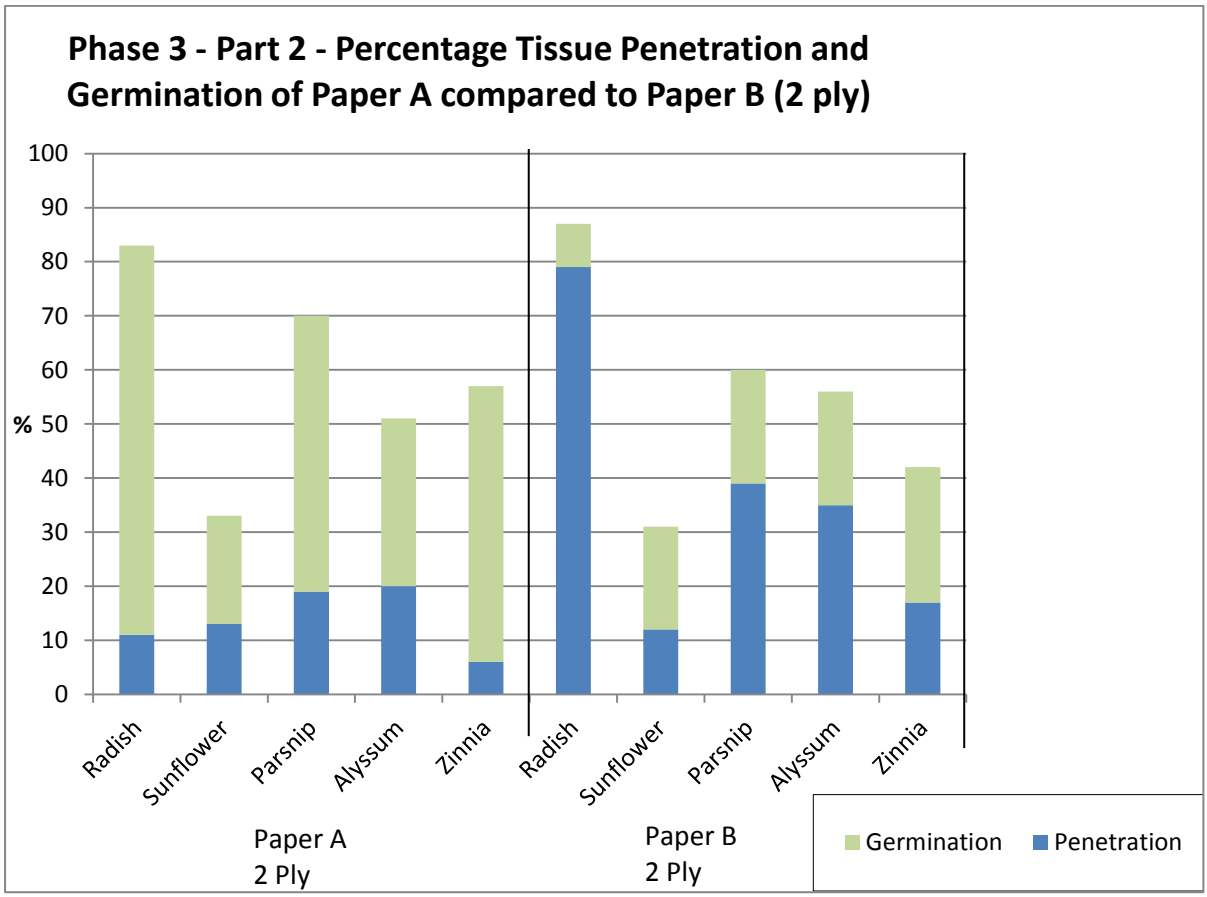


Figure 7.3, Comparing the differences of percentage germination and penetration rates between Paper A and Paper B in 4 ply samples during Phase 3 (part 1). Similar to 2 ply specimens, percentage germination rates do not correlate between Paper A and Paper B, and the percentage penetration rate again shows a marked improvement in Paper B.

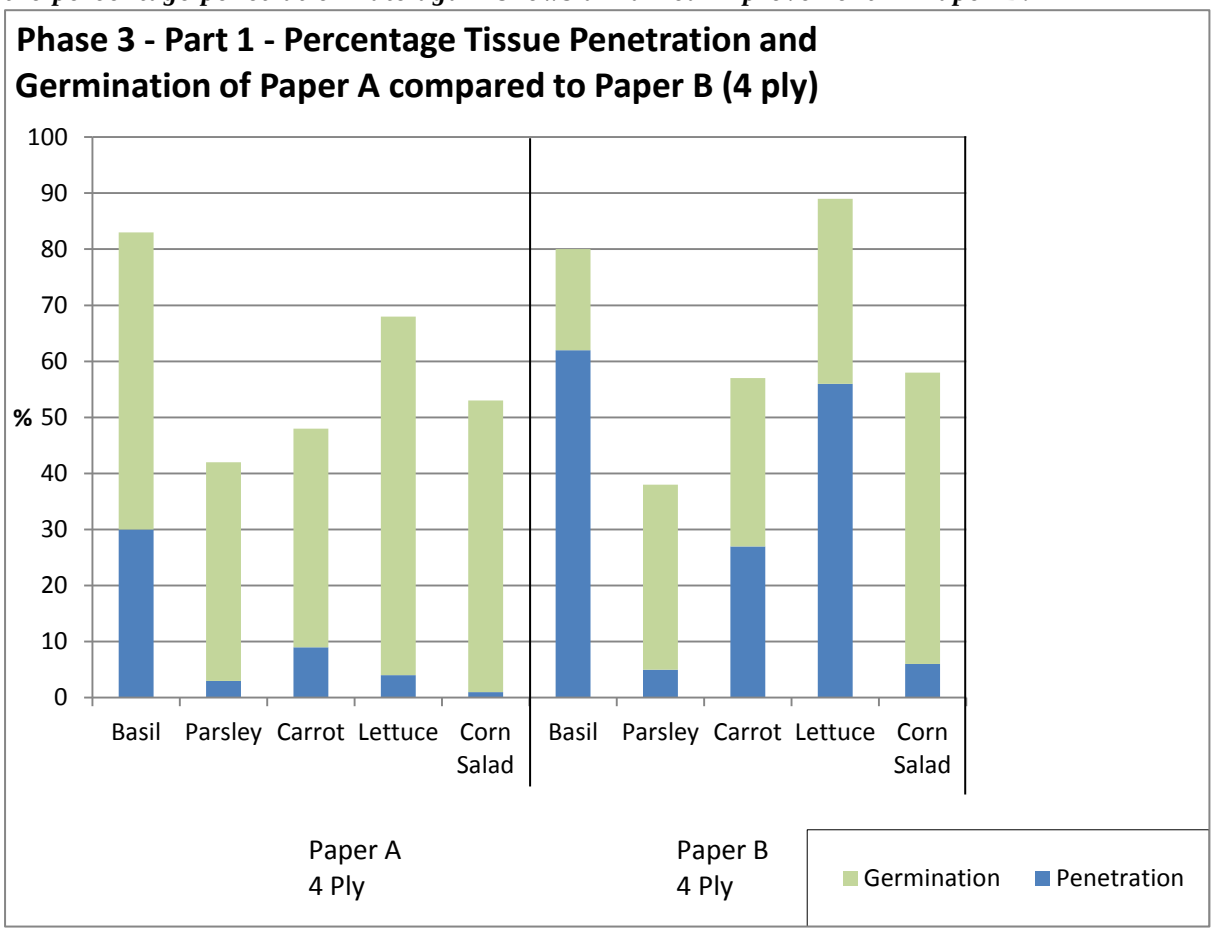
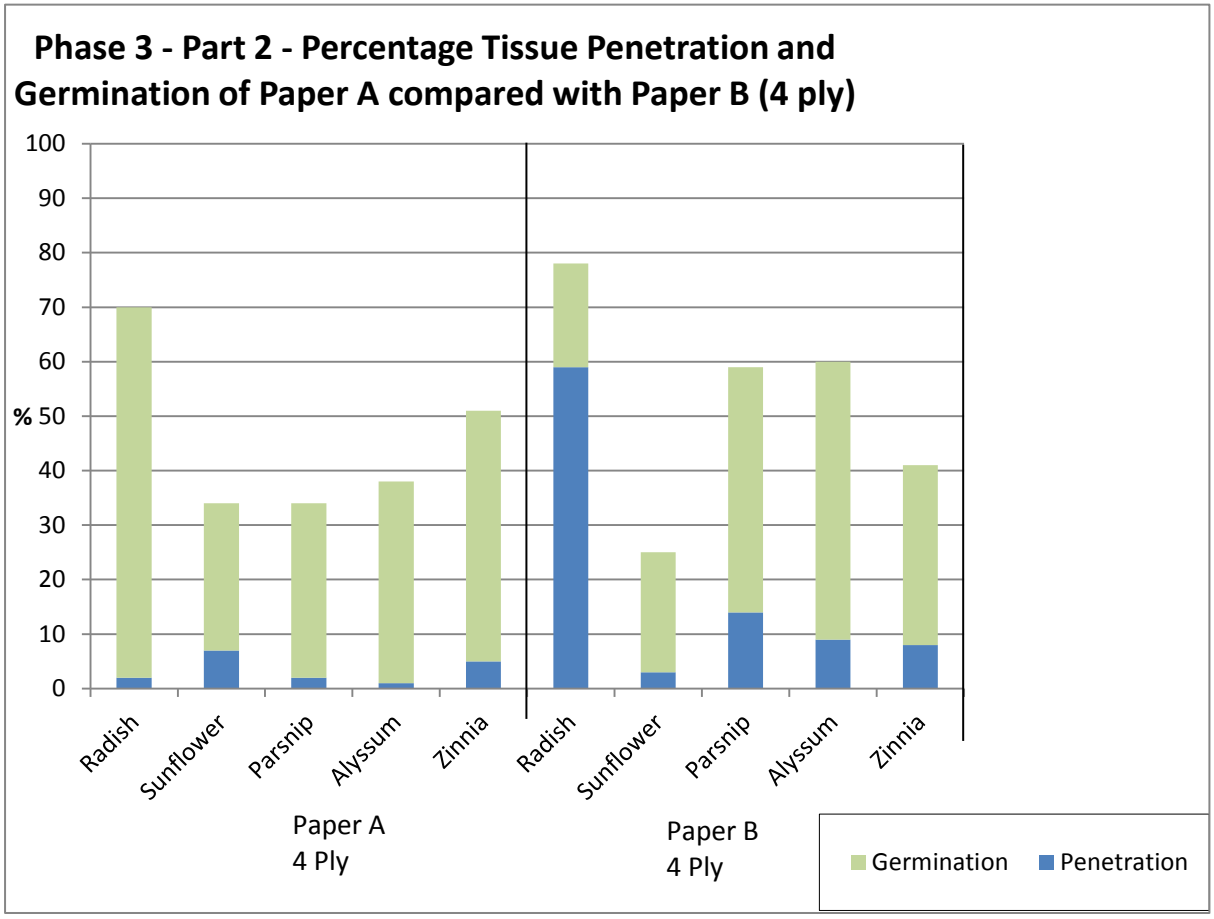


Figure 7.4, Comparing the differences of percentage germination and penetration rates between Paper A and Paper B in 4 ply samples during Phase 3 (part 2).



Germination Count Analysis

Regarding the 2 ply specimens, the mean germination count for Paper A was marginally higher than for Paper B, as seen in Table 7.1. In the 4 ply specimens, Paper B had a slightly higher performance in the majority of the mean percentage germination results, in comparison to Paper A. However, there were no outstanding differences between the germination counts of Paper A and Paper B. This strongly suggests that the germination count was not affected by the change in seed tape material. This is supported by the varying germination counts seen in Figure 7.1, Figure 7.2, Figure 7.3 and Figure 7.4.

Table 7.1, Displaying the average percentage germination count for each tissue paper during Phase 3.

Paper	Overall Mean % Germination Count During Phase 3	
A 2 ply	66	59.05
A 4 ply	52.1	
B 2 ply	62.2	60.35
B 4 ply	58.5	

The range of germination counts in Paper A, compared to the range of germination counts in Paper B, offers further detail of the results.

Table 7.2, Displaying the range of percentage germination counts and standard deviations for the seed species in each tissue paper during Phase 3.

Paper	Range of % Germination During Phase 3	Standard Deviation
A 2 ply	54	17.1
A 4 ply	49	16.7
B 2 ply	56	17.2
B 4 ply	64	20.2

The range and standard deviation of the germination data again proves that the two tissue paper samples have little influence on the germination count of seeds within the seed tape, as seen in Table 7.2. There was a difference of 15 seeds between the highest range (Paper B 4 ply) and the lowest range (Paper A 4 ply); this demonstrates a relatively high level of consistency across all specimens.

Germination Rate

The figures in Appendix 2 demonstrate that the germination rate was similar for seeds of a specific species in each material. Similar trajectories for the germination rate of each material suggest that the germination rate is not affected by the tissue paper material.

There is no trend with regard to an individual material producing superior germination rates across all of the seed species. The lack of a trend again advocates the hypothesis that the choice of tissue paper material does not significantly influence the rate of germination.

Penetration Count Analysis

To provide a rounded view of the figures, it is beneficial to analyse the average penetration count in Paper A, in comparison to the average penetration count in Paper B.

Table 7.3, Displaying the average percentage penetration count for each tissue paper during Phase 3.

Paper	Overall Mean % Penetration Count During Phase 3
A 2 ply	26
A 4 ply	6.4
Average A	16.2
B 2 ply	45.1
B 4 ply	24.9
Average B	35

The mean penetration count highlights the general performance of the tissues' papers across the range of seed species, as displayed in Table 7.3. There is a clear distinction between the average percentage penetration of Paper A and Paper B in both 2 ply and 4 ply formats. The difference between the penetration count in 4 ply formats was particularly extensive with almost four times better performance. It is also clear from these figures that overall the 4 ply format of Paper B was relatively close to the performance of the 2 ply format of Paper A. The performance of the 2 ply format of Paper B was 1.73 times more advantageous than the 2 ply format of Paper A. These figures provide an extensive margin to verify the improved performance that Paper B can offer in comparison to Paper A.

The range of penetration counts in Paper A, compared to the range of penetration counts in Paper B, offers further detail and is shown in Table 7.4.

Table 7.4, Displaying the range of percentage and standard deviations penetration counts for the seed species in each tissue paper during Phase 3.

Paper	Range of % Penetration During Phase 3	Standard Deviation
A 2 ply	57	19.6
A 4 ply	29	8.7
B 2 ply	67	24.8
B 4 ply	59	22.9

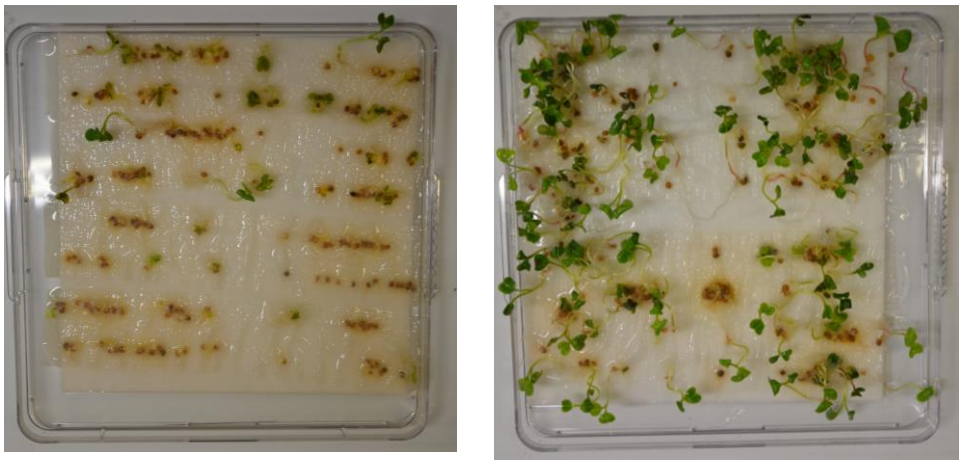
A higher standard deviation for both 2 ply and 4 ply Paper B, in comparison to Paper A products, reinforces the mean penetration statistical data and refutes Hypothesis B – The Paper A produces maximum seedling penetration rates. The standard deviation also highlights a significant difference between the two Paper A formats, compared to the relatively minimal difference in Paper B formats.

The range of the percentage penetration counts for each tissue paper shows the level of consistency between the samples. Both Paper A samples had more consistent penetration counts than Paper B, especially in 4 ply samples. The high penetration count range in Paper B specimens is the outcome of significantly better results for species such as Radish and Lettuce, however average penetration results were produced for species such as Sunflower and Parsley. The range of the penetration counts can be seen visually in Figure 7.1, Figure 7.2, Figure 7.3 and Figure 7.4. The relatively small range of the penetration results for Paper A 4 ply is clear. In comparison, Paper B has a wider range of penetration counts. A consistent product across the range of seed species will be a benefit to the consumer, and so offers an

advantage to Paper A, however, in achieving a consistent product, penetration count in some species will be compromised.

The penetration count can be seen visually in images captured at the end of the experiment. When visually comparing the two paper specimens in Figure 7.5 it is clear that the penetration count is greatly improved with the use of Paper B.

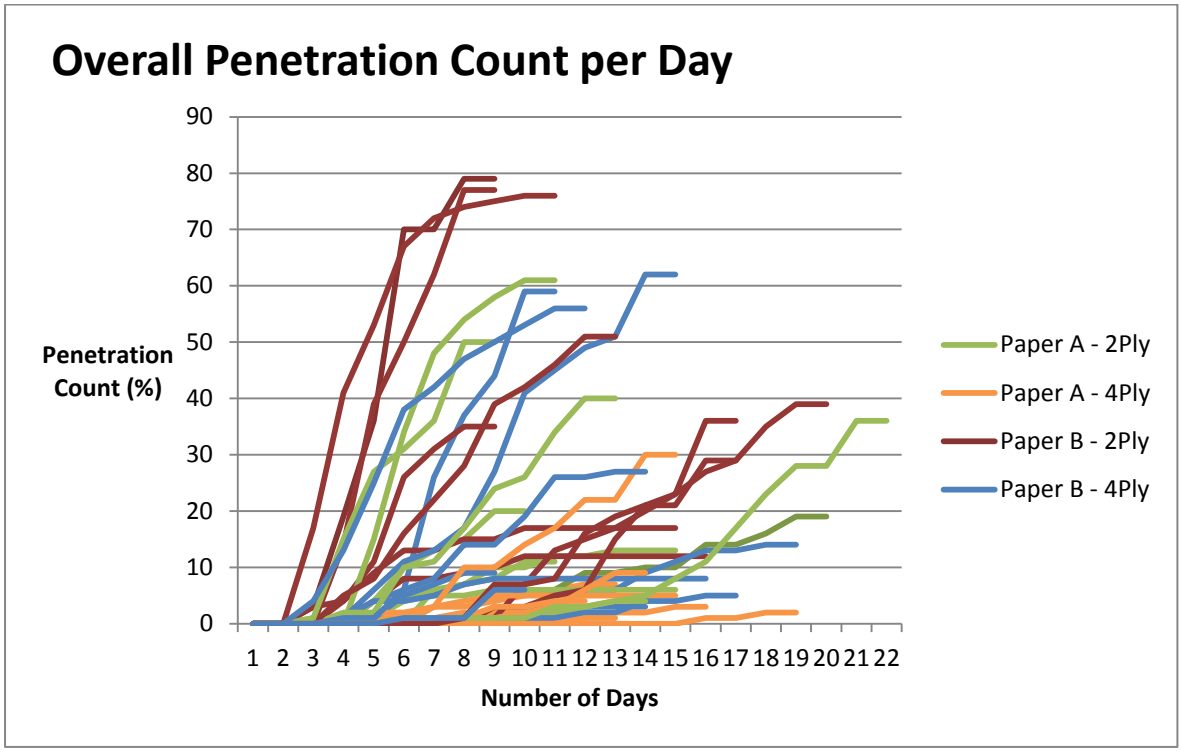
Figure 7.5, Two images comparing the penetration and growth rates on day 11 of Phase 3.Left: Radish Paper A, Right: Radish Paper B. These images visually demonstrate the stark difference between the seed growth in Paper A and Paper B.



Penetration Rate

In relation to time, on average both 2 ply and 4 ply specimens of Paper B penetrated at a much greater rate than the equivalent specimens of Paper A. The penetration rate of 4 ply Paper B was relatively similar to the 2 ply specimen of Paper A, and in some places took place at a quicker rate. The penetration rates for each paper specimen are presented in Figure 7.6. The highest rate of penetration took place between day three and day ten of the experiment for all four material samples. This is most likely due to the growing cycle of the seed species used in the experiment. At day 14 the rate of new tissue penetration was almost none, this data can be used to provide an estimated growth time for seed tape products.

Figure 7.6, The percentage penetration count per day, for each Paper specimen. All specimens for each Paper type are represented by the same colour, highlighting the trend for each material. The concentration of orange in the lower portion of the graph compared with the spread of blue across the graph, highlights the difference between penetration rates of the 4 ply samples. Similarly the differences between 2 ply specimens are also evident.



Effect of 4 ply in comparison to 2 ply

The penetration results show that extra layers of tissue paper act as a restraint during early plant growth. In each specimen, the 2 ply samples produced higher penetration rates than the 4 ply samples of the same tissue paper. This supports Hypotheses C - Penetration rates will be greater in 2 ply format seed tapes than 4 ply format seed tapes of the same material. Therefore, in the manufacturing process of seed tape products, in the interest of plant penetration, it is preferable to use a 2 ply format rather than a 4 ply format.

It is also seen that in samples of Basil, Lettuce, Corn Salad, Radish and Zinnia, 4 ply Paper B samples demonstrate better penetration results than the 2 ply Paper A samples of the same

seed species. The overlap of results highlights the vast difference in the penetration counts in Paper A in comparison to Paper B.

With regard to germination, the difference in 2 ply or 4 ply paper created little effect on the germination rate or germination count results. Therefore, the main advantage of the use of a 2 ply format is due to an improvement in penetration results.

Penetration significance, in comparison to Germination

It is necessary to question the importance of the germination metrics in comparison to the penetration metrics. As a consumer product, the purchaser is predominantly concerned by the amount of plants that grow to the surface of the soil. The metric that is a close measure of the amount of plants that will grow to the surface is the penetration count. The penetration count is influenced by the germination count, and is a more accurate measure of crop yield. If the seedlings fail to penetrate within three days, the warm temperatures and damp and humid conditions cause plant death. Thus, the success of a seed tape material must be measured on the penetration count achieved. For this reason, the penetration rate is of greater significance than the germination count.

Statistical Leader

The germination count and the germination rates, shows that none of the tissue papers have an advantage with regard to germination count or rate, compared to each other.

The penetration rates were strongly influenced by the tissue papers. The 2 ply Paper B format proved to be the most successful material in terms of the overall penetration count and produced the fastest penetration rate. As these are the two principle metrics that are of concern to the consumer, the 2 ply Paper B material is the most appropriate material tested for the use in seed tape products, for the range of seed species used in this experiment.

Paper B produced the best penetration results out of the two 4 ply formats with a mean of over three times the penetration count of Paper A. The 4 ply format of Paper B had a similar penetration count to the 2 ply format of Paper A, however the range of the penetration counts for Paper B (4 ply) was the highest. It can be reasoned that if consumers prioritise high penetration results over consistency, Paper B is recommended.

5. Reliability and Accuracy of Data

Every effort was made to maximise the accuracy and reliability of the data collected during each experiment; producing results that would be repeatable. There were a number of aspects that were monitored to maintain credibility: seed counting, spacing of the seed, sample size, seeds that fell out of the seed tape and continued plant growth.

Seed counting accuracy

Due to the nature of the experiments, the accuracy of counting the number of seeds germinated or penetrated is not guaranteed to be one hundred percent. Overlapping seeds, very small seeds and miscounting errors can be attributed to the reduction in accuracy. To minimise the effect of these inaccuracies, each reading was counted three times and the mean of these three counts were used in the results. The data collection charts, as seen in Appendix 1, have been analysed to gauge the accuracy of counting. Across the data for all of the phases, there is an overall variance of ±3 seeds to that of the mean. The majority of the data has a variance of ±2 seeds, with the accuracy decreasing to ±3 seeds in four instances. Considering the marked differences in the results, a variance of ±3 percent is negligible and does not alter the conclusions that can be drawn.

Spacing of the seeds

The samples that were produced during the Phase 3 experiment were manufactured in a way so that the seeds within the seed tapes were relatively close together, but still within the normal spacing range used in seed tapes. The reason for the small spacing between the seeds was to minimise the space used inside the test chamber, whilst maximising the amount of samples that could be examined simultaneously. Simultaneously analysing more samples allowed for all ten seed species to be tested, therefore, seed spacing was compromised for larger sample numbers. The effect of smaller spaces between the seeds is likely to have

minimal effect on the penetration count, however, it was observed that seeds found inside the seed tape in clusters often all grew through the tissue paper; once one seed in the cluster had penetrated through to make the initial opening (and in this case all of the seedlings were counted as penetrating through the tissue paper).

During the manufacture of the specimens, the spacing of the seeds did not change from sample to sample. It must be noted, however, that there were random differences in the spacing, as this is the nature of the product, but this also occurred in most of the samples and were indiscriminate. As the spacing used in the samples was within the range used in commercial seed tape production, the results are reliable.

Sample size

There is a large distinction between the results of Paper A and Paper B, because of the marked difference between the two Papers, it can be reasoned that the reliability of the results is high. During Phase 3, 4000 seeds were analysed, taken from 10 different species and batches of seed, this increasing the reliability of the results. However, these experiments were conducted under laboratory conditions, therefore, it is recommended that tests are conducted to more closely match the conditions used by seed tape consumers. The conclusions from this research will be further supported if the results can be replicated in future research experiments with the inclusion of soil.

Seeds departed from seed tape

Due to the nature of the seed tape products, during the experiments there were a number of seeds that were unintentionally released from the seed tape. This occurred on four occasions, as seen in Table 8.1.

Table 8.1, Displaying the number of seeds dis-counted from the data due to absence from seed tape samples.

Paper	Seed Variety	Number of seeds
A	Carrot	1
B	Parsnip	2
E	Cucumber	1

To maintain the reliability of the results, the seeds that were no longer contained within the seed tapes were not counted in the data collection process. It is not known if the loose seeds would have penetrated through the tissue paper (if they had not evaded the seed tape), therefore these seeds must be discounted. Due to the rarity of this occurrence, its effect on the overall results of the experiments is negligible.

Continued plant growth

It is reasonable to hypothesise that if the specimens are allowed to continue to grow, then the plants that originally failed to penetrate through the paper will eventually have the strength required to penetrate the tissue paper, however this is not the case. In reality, if the specimens are given extended periods of time, the tissue paper continues to restrict the plant growth, leading to a relatively small amount of growth within the channel before the fairly high water content and humidity cause the plant to die and rot. The beginning of this process can be seen with the Zinnia variety of specimens in Figure 8.1.

Figure 8.1, An image of the Zinnia Paper A specimen, captured on day 15.The dark patches around the seeds are the beginning of the rotting process.

6. Additional Recommended Research

This research project has significantly contributed to the knowledge of seed tape performance. Nonetheless, there is further work that is required by future research projects. Throughout this research project, a number of questions were generated that it was not possible to answer given the time and resources available. This section poses the questions raised throughout the research project and formulates recommendations for further work.

Does the addition of soil affect seed tape performance?

It is important that the results generated in this research are representative of the plant growth as seen by the consumer. In order to see if the hypotheses are also true in 'real life' situations, it is recommended that further experiments are conducted in soil. The inclusion of soil is predicted to simulate many additional parameters that would be difficult to analyse individually. The additional parameters include the effect of soil weight, water retention and light exposure. For example, the weight of soil may affect the growth, acting as a support for the seedling to push against as it forces through the tissue paper membrane. With regard to irrigation, the soil is likely to provide a more realistic level of water retention and distribution. Water will percolate rapidly through the soil if it is very sandy, or water retention will be much higher if the soil is constructed from fine textured and organic particles with smaller pore spaces (Fitzpatrick, 1986), therefore, analysing the germination and penetration results in various soil types will provide a representative range of data. Finally, an experiment with the addition of soil would provide a more realistic representative of light exposure to the seeds. To initiate germination, many seeds require light levels to be above a particular threshold; testing within soil will accurately simulate light levels when sown.

Conversely, the addition of soil in the experiment introduces the possibility of many other influential variables which must be controlled; such as pests, diseases and varying amounts of nutrients provided to the plants. In order to control the variables, the soil must be sterilised and uniform.

It is expected that the addition of soil will not provide an advantage to either of the tissue papers over the other; if the results of one tissue paper are affected then so will the results of the other. However, the addition of soil may affect the relative crop size of loose seeds in comparison to seed tapes.

Could the tissue paper reduce light exposure to the seedlings?

It is expected that the tissue paper would reduce light exposure to the seedlings at a negligible level. When sowed by the consumer, the seeds are likely to be covered by a thin layer of soil, which itself would reduce light exposure to the seed. It must also be considered that both tissue papers have a relatively similar opacity, which, due to the fibrous nature of tissue paper, allows a reasonable amount of light to pass through. A method for analysing the amount of light that is blocked by tissue paper could be used to identify which tissue paper is advantageous in terms of the amount of light that can pass through. It is expected that this will have a negligible effect on plant growth, but this is a possible avenue for further research.

Could the tissue paper act as a protective membrane against disease or pests?

It is not known if the tissue paper of seed tapes could effectively act as a protective membrane to prevent against damage by disease or pests. It may be possible to manufacture seed tapes to improve disease or pest resistance, and the selection of tissue paper is likely to influence this. Therefore, there is a significant importance for further research to investigate the effects of alternative tissue papers on the resistance to pests or disease.

Are the material properties directly proportional to the penetration count?

It is quite likely that a number of the material properties may be proportionally linked to the penetration count. It would be commercially beneficial to identify specific material properties that are influential on the penetration count, and to what extent they are influential. If this can be measured, then a model can be created and used to design the ideal seed tape material.

Can the penetration rates be predicted based upon a common characteristic found in successful plant species?

Basil, Lettuce and Radish plant species were particularly successful for both tissue samples with regard to the penetration results. In contrast, Corn Salad, Sunflower and Zinnia plant species were particularly unsuccessful. There may be particular strengths that can be identified within the plant that could be used to predict the penetration rates within a known seed tape material. If so, a model can be created to forecast the success of plant growth.

Does the behaviour of seedlings root systems restrict penetration rates?

Further investigation of the behaviour of root systems in seed tapes is recommended for future research, as this could demonstrate the advantages of a weaker tissue paper on the underside of the seed tape. It was observed in this research that the root systems suppressed the early growth of neighbouring seedlings. It is unknown if this occurrence is promoted by seed tapes in comparison to loose seeds, or if its effect differs between alternative seed tape materials.

7. Summary & Conclusions

Literature

Prior to the experimentation phases, a review of the literature was conducted in two core areas of research: literature related to tissue paper and work connected to seed germination and early plant growth. The literature review highlighted numerous influential characteristics affecting the performance of seed tape products.

A primary factor affecting performance was found to be the manufacturing process of the tissue paper from which the seed tape is constructed; for example, a tissue paper can be manufactured with various stretch properties, dependant on the length of fibres used. Other properties such as tensile strength and multidirectional stretch can be controlled during the manufacturing process of the tissue paper, to produce a raw material ideal for the seed tape application.

Another principal factor affecting seed tape performance was found to be the conditions required to trigger the exit from the seeds' dormancy phase. To ensure that all specimens throughout the experiments had an unbiased opportunity to exit the dormancy phase, consistent conditions were maintained in accordance with recommendations from The International Seed Testing Association (2014).

During each experiment, four metrics were monitored: germination count, germination rate, penetration count and penetration rate. These four metrics have been analysed to test the following fundamental hypotheses:

Hypothesis A

The crop size produced from loose seed will be higher than the crop size produced from seed tape products.

Hypothesis B

The tissue paper material currently used by Seed Developments Limited (Paper A), produces maximum seedling penetration rates.

Hypothesis C

Penetration rates of seedlings through the seed tape material will be greater in 2 ply format seed tapes than 4 ply format seed tapes of the same material.

The series of experiments provided scientific grounding to evaluate each of the hypotheses.

Results

In Phase 1 of the experiment, the advantage of loose seed in comparison to 2 ply and 4 ply seed tapes with regard to crop size was clearly defined. There was a distinct difference in crop size between loose seed and a 2 ply seed tape, and a dramatic difference in crop size of loose seeds and 4 ply seed tape specimens. The results produced from Phase 1, provided evidence that supports both Hypothesis A - The crop size produced from loose seed will be higher than the crop size produced from seed tape products, and Hypothesis C - Penetration rates will be greater in 2 ply format seed tapes than 4 ply format seed tapes of the same material.

It was also discovered in Phase 1 that a similar germination performance was achieved for all specimens of the same plant species, suggesting that the seed tapes have negligible effect on germination.

Despite optimum conditions for growth, there was a major irregularity with the germination rate of the Red Beet Detroit seeds, therefore, the seed variety was omitted from the analysis and the remaining experiments. In Phase 2 of the experiment, two seed species were tested with eight variations of materials. The seed species used in this phase were ‘Cress’ and ‘Cucumber Tendergreen’, sourced from the same batch as the seeds in Phase 1.

The best penetration results during Phase 2 were produced by Paper D specimens, however, after the initial germination of the seedling, it was observed that the Paper D specimens demonstrated a much slower growth in comparison to other samples. The difference in early plant growth was so significant, that further work with Rice Paper materials is recommended. The results of the remaining specimens in Phase 2, concluded that Paper A, Paper C and Paper B produced the most advantageous crop sizes. Paper A and Paper B were further investigated in Phase 3 due to superior penetration results produced in Phase 2, thus demonstrating appropriateness for manufacture as well as fitting the criteria of other consumer needs. Paper A also provided a point of reference to measure the performance against a current seed tape material.

Overall, there was a negligible difference between the germination counts of Paper A and Paper B, and a similar gradient for the germination rate for each material. This supports data collected during Phase 1, reinforcing the conclusion that the germination performance was not affected by the change in seed tape material.

There is a clear distinction between the average percentage penetration of Paper A and Paper B in both 2 ply and 4 ply formats. The difference between the penetration counts was very significant, with Paper B producing 1.73 times greater performance in 2 ply formats and 3.89 times greater performance in 4 ply formats, compared to the equivalent Paper A specimens. These figures provide an extensive margin to verify the improved performance that Paper B

can offer in comparison to Paper A; disproving Hypothesis B - The tissue paper material currently used by Seed Developments Limited (Paper A), produces maximum seedling penetration rates.

Both Paper A samples had more consistent penetration counts than Paper B; a consistently performing seed tape product will be a benefit to the consumer. However in achieving a consistent product, the penetration count will be significantly compromised. It can be reasoned that if consumers prioritise high penetration results over consistency, Paper B is recommended, although the converse is also the case.

In relation to time, on average both 2 ply and 4 ply specimens of Paper B penetrated at a much greater rate than the equivalent specimens of Paper A. The penetration rate of 4 ply Paper B was relatively similar to the 2 ply specimen of Paper A, and in some places took place at a quicker rate. The penetration results show that extra layers of tissue paper act as a restraint during early plant growth. In each specimen, the 2 ply samples produced higher penetration rates than the 4 ply samples of the same tissue paper. This supports Hypotheses C - Penetration rates will be greater in 2 ply format seed tapes than 4 ply format seed tapes of the same material.

In summary, the data produced in Phase 1 of the experiment confirmed that loose seed produces a larger crop than seed tape products, supporting Hypothesis A; the results of Phase 3 of the experiment show that the 2 ply Paper B format is the most successful material in terms of the overall penetration count and fastest penetration rate, thus not supporting Hypothesis B; and the combined results of each experiment conclude that penetration performance is superior in 2 ply format seed tapes than 4 ply format seed tapes, supporting Hypothesis C.

Reliability

The reliability of the conclusions is significantly increased due to the quantity of seeds examined throughout the experiments. Data was analysed from 6200 seeds over the three the experiments, comprising of 12 different species and batches of seed, providing a reputable sample size.

During the experiments, there were a number of seeds that were unintentionally released from the seed tapes; however, due to the rarity of this occurrence, the effect on the overall results of the experiments is negligible. Similarly, during the course of the data collection process, a variance of ±3 percent was detected in the counting process, again inflicting a negligible effect upon the results.

These experiments were conducted under laboratory conditions; therefore, it is recommended that tests are conducted to more closely match the conditions used by seed tape consumers. However, considering the marked differences in the results between specimens, the conclusions drawn from the data analysis are robust.

Recommendations

It is recommended that further experiments are conducted in soil to provide confirmation that the conclusions are common in 'real life' situations. The effects of soil weight, water retention and light exposure on seed tapes in comparison to loose seed is unknown, for this reason, there is a requirement to conduct further research experimentation in this area.

There is also an opportunity to investigate the differences in root system performance in seed tapes in comparison to loose seeds. It was observed during this research that the root systems suppressed the early growth of neighbouring seedlings, it is unknown if this occurrence is promoted by seed tapes in comparison to loose seeds, or if its effect differs between alternative seed tape materials.

Seed Tape Industry

Knowledge gained from this research can be used by the seed tape industry to provide scientific grounding to previously anecdotal theories. For example, this research provides evidence supporting previous theories of seedlings dying and rotting if they fail to penetrate the seed tape material. Another fundamental fact illustrated by this research is that the number of tissue paper plys has a direct effect on the percentage penetration and penetration rate, whilst having negligible influence on the percentage germination and germination rate.

This research also eliminates previous misconceptions, such as the belief that seed tapes have an equal crop size to loose seeds; showing that seed tapes produce reduced penetration results in comparison to loose seeds. This information has the ability to further stimulate developments in seed tape materials.

The data generated and analysed in the research has provided initial scientific evidence that has been used to support or refute three primary hypotheses for the seed tape industry, in addition to building an understanding of the relationship between seed penetration performance and seed tape materials. The experimentation in this research has also led to the creation of a template for a proposed standard process for testing alternative seed tape materials. This proven method can be used by the seed tape industry as a template for future seed tape growth experiments.

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Appendices

Appendix 1

Phase 1 Data Collection Chart, Specimens Planted on 19/08/2014

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count									Penetration (Through tissue) Count					
			Cress			Cucumber			Beet			Cress		Cucumber		Beet	
			2Ply	Loose	4Ply	2Ply	Loose	4Ply	2Ply	Loose	4Ply	2Ply	4Ply	2Ply	4Ply	2Ply	4Ply
07:07	20/8/14	1st	94	98	95	77	87	82	0	0	0	15	0	0	0	0	0
		2nd	93	98	95	76	87	82	0	0	0	15	0	0	0	0	0
		3rd	94	98	95	76	87	82	0	0	0	15	0	0	0	0	0
		Mean	94	98	95	76	87	82	0	0	0	15	0	0	0	0	0
07:21	21/8/14	1st	97	97	96	90	99	82	1	11	1	60	5	39	4	0	0
		2nd	97	97	95	90	99	82	1	11	1	61	5	39	4	0	0
		3rd	97	97	96	90	99	82	1	11	1	60	5	39	4	0	0
		Mean	97	97	95	90	99	82	1	11	1	60	5	39	4	0	0
07:50	22/8/14	1st	97	97	95	90	99	90	1	13	1	83	11	39	7	0	0
		2nd	97	97	95	90	99	90	1	13	1	82	11	39	7	0	0
		3rd	97	97	95	91	99	90	1	13	1	82	11	38	7	0	0
		Mean	97	97	95	90	99	90	1	13	1	82	11	39	7	0	0
08:25	26/8/14	1st	97	97	95	90	99	90	6	16	10	89	26	69	28	2	3
		2nd	97	97	95	90	99	90	6	18	10	89	26	70	28	2	3
		3rd	98	97	95	90	99	90	6	18	10	89	26	69	28	2	3
		Mean	97	97	95	90	99	90	6	18	10	89	26	[illegible]	28	2	3
08:08	27/8/14	1st						90	7	19	11	89	26	78	33	2	5
		2nd						90	7	19	11	87	26	79	33	2	5
		3rd						90	7	19	11	87	26	78	33	2	5
		Mean						90	7	19	11	89	26	78	33	2	5
08:13	28/8/14	1st							9	19	12	89	30	83	33	3	7
		2nd							9	19	12	89	30	83	33	3	7
		3rd							9	19	12	89	30	83	33	3	7
		Mean							9	19	12	89	30	83	33	3	7
08:18	29/8/14	1st							12	20	12		30	83	35	4	8
		2nd							12	20	12		30	83	35	4	8
		3rd							12	20	12		30	83	35	4	8
		Mean							12	20	12		30	83	35	4	8
08:25	1/9/14	1st							12	20	13		30	83	43	4	8
		2nd							12	20	13		30	83	43	4	8
		3rd							12	20	13		30	83	43	4	8
		Mean							12	20	13		30	83	43	4	8
08:24	2/9/14	1st							12	26	13				43	4	8
		2nd							12	26	13				44	4	8
		3rd							12	26	13				43	4	8
		Mean							12	26	13				43	4	8
08:25	3/9/14	1st								26	15				43		
		2nd								26	15				43		
		3rd								26	15				43		
		Mean								26	15				43		
08:30	4/9/14	1st								26	15						
		2nd								26	15						
		3rd								26	15						
		Mean								26	15						
08:24	5/9/14	1st									15						
		2nd									15						
		3rd									15						
		Mean									15						
/	6/9/14	1st															
		2nd															
		3rd															
		Mean															

Phase 2 Cress Data Collection Chart, Specimens Planted on 23/09/2014

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count								Penetration (Through tissue) Count							
			2 Ply				4 Ply				2 Ply				4 Ply			
			A	C	B	D	F	A	C	B	A	C	B	D	F	A	C	B
09:04	24/09/2014	1st	77	75	74	47	72	61	60	60	0	0	0	0	0	0	0	0
		2nd	77	92	75	50	71	59	60	60	0	0	0	0	0	0	0	0
		3rd	77	92	75	45	72	60	60	60	0	0	0	0	0	0	0	0
		Mean	77	93	75	47	72	60	60	60	0	0	0	0	0	0	0	0
09:08	25/09/2014	1st	91	98	92	69	89	88	90	88	1	3	4	14	3	1	1	0
		2nd	90	98	92	70	90	88	89	87	1	3	4	13	3	1	1	0
		3rd	91	98	92	70	90	87	90	87	1	3	4	14	3	1	1	0
		Mean	91	98	92	70	90	88	90	87	1	2	4	14	3	1	1	0
08:51	26/09/2014	1st	92	98	92	94	93	90	90	92	32	23	25	41	20	5	3	2
		2nd	92	98	92	92	93	90	90	92	31	13	25	34	22	5	3	2
		3rd	92	98	92	95	93	90	90	92	31	13	25	39	22	5	3	2
		Mean	92	98	92	94	93	90	90	92	31	13	25	40	22	5	3	2
09:09	27/09/2014	1st									51	38	43	82	46	13	5	7
		2nd									52	38	43	82	49	13	5	7
		3rd									52	38	43	82	48	13	5	7
		Mean									52	38	43	82	48	13	5	7
11:58	28/09/2014	1st									67	58	52	87	53	25	7	25
		2nd									68	58	54	87	53	25	7	25
		3rd									67	58	53	87	53	25	7	25
		Mean									68	58	53	87	53	25	7	25
08:48	29/09/2014	1st									68	66	56	87	53	32	10	28
		2nd									67	66	56	87	53	33	10	28
		3rd									68	66	56	87	53	33	10	28
		Mean									68	66	56	87	53	33	10	28
09:01	30/09/2014	1st									71	74	60	87	58	35	16	30
		2nd									70	74	60	87	57	35	16	30
		3rd									70	74	60	87	57	34	17	30
		Mean									70	74	60	87	57	35	16	30
08:21	01/10/2014	1st									70	78	61		57	35	16	35
		2nd									70	76	61		57	35	16	35
		3rd									70	76	61		57	35	16	35
		Mean									70	77	61		57	35	16	35
08:46	02/10/2014	1st									73	81	65		58	35	16	36
		2nd									73	78	65		56	35	16	35
		3rd									73	79	65		58	35	16	35
		Mean									73	79	65		58	35	16	35

Phase 2 Cress Data Collection Chart, continued.

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count								Penetration (Through tissue) Count							
			2 Ply				4 Ply				2 Ply				4 Ply			
			A	C	B	D	F	A	C	B	A	C	B	D	F	A	C	B
08:44	03/10/2014	1st									73	76	62		56			66
		2nd									78	79	65		55			67
		3rd									73	79	65		58			37
		Mean																
09:54	04/10/2014	1st									73	79	65		58			37
		2nd									73	79	65		55			36
		3rd									73	79	65		58			37
		Mean									73	79	65		58			37
09:30	05/10/2014	1st																
		2nd																
		3rd																
		Mean																
	06/10/2014	1st																
		2nd																
		3rd																
		Mean																
	07/10/2014	1st																
		2nd																
		3rd																
		Mean																
	08/10/2014	1st																
		2nd																
		3rd																
		Mean																
	09/10/2014	1st																
		2nd																
		3rd																
		Mean																
	10/10/2014	1st																
		2nd																
		3rd																
		Mean																
	11/10/2014	1st																
		2nd																
		3rd																
		Mean																

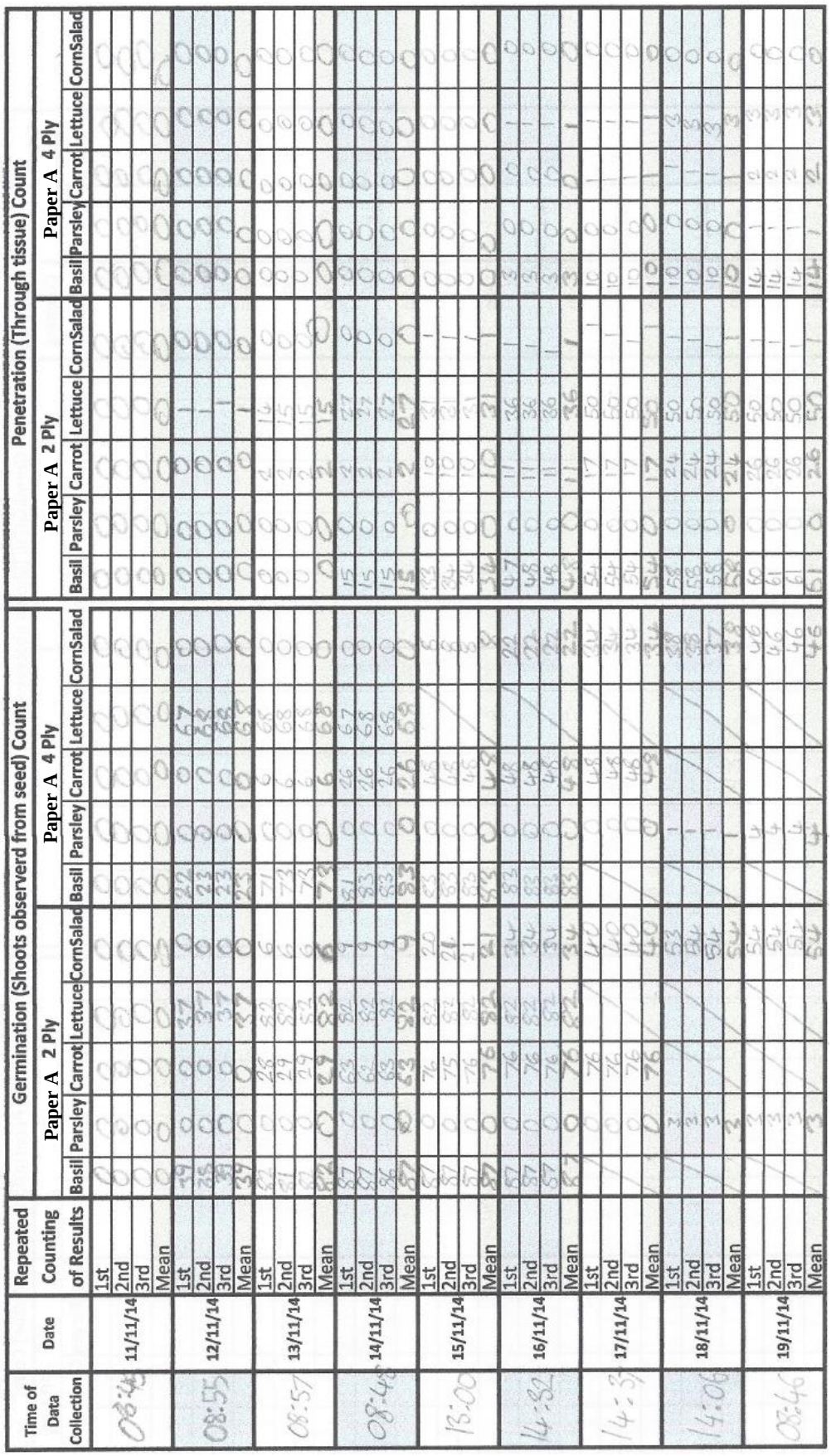
Phase 2 Cucumber Data Collection Chart, Specimens Planted on 08/09/2014

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count								Penetration (Through tissue) Count							
			2 Ply				4 Ply				2 Ply				4 Ply			
			A	C	B	D	F.	A	C	B	A	C	B	D	F.	A	C	B
08:36	09/09/2014	1st	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2nd	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		3rd	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mean	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08:50	10/09/2014	1st	67	74	74	75	65	64	82	69	0	0	0	1	0	0	0	0
		2nd	66	75	71	76	64	62	82	69	0	0	0	1	0	0	0	0
		3rd	68	75	71	75	65	63	82	69	0	0	0	1	0	0	0	0
		Mean	67	75	72	75	65	63	82	69	0	0	0	1	0	0	0	0
08:47	11/09/2014	1st	84	82	84	84	85	76	86	74	7	8	7	74	5	1	0	0
		2nd	81	82	85	86	86	71	86	76	7	8	8	75	5	1	0	0
		3rd	83	82	85	84	86	75	86	76	7	8	8	74	5	1	0	0
		Mean	83	82	85	85	86	74	86	75	7	8	8	74	5	1	0	0
08:47	12/09/2014	1st	83	84	87	86	87	79	86	78	9	15	14	86	8	2	0	2
		2nd	83	83	85	87	86	77	86	77	8	16	14	86	8	2	0	2
		3rd	83	84	87	85	88	76	86	78	8	16	14	86	8	2	0	2
		Mean	83	84	87	86	87	77	86	78	8	16	14	86	8	2	0	2
09:10	13/09/2014	1st	88	86	90	86	87	77	86	79	25	20	21	86	20	7	5	3
		2nd	86	85	90	86	86	76	87	75	24	24	21	86	22	7	5	3
		3rd	86	85	90	86	87	77	87	78	25	24	21	86	21	7	5	3
		Mean	87	85	90	86	87	77	87	78	25	23	21	86	21	7	5	3
17:20	14/09/2014	1st	86	85	90	86	87	76	87	82	36	25	21	86	28	9	8	3
		2nd	87	85	91	86	87	77	87	83	36	24	21	86	29	9	8	3
		3rd	87	86	90	86	87	77	87	82	36	25	21	86	29	9	8	3
		Mean	87	85	90	86	87	77	87	82	36	25	21	86	29	9	8	3
08:40	15/09/2014	1st	87	84	90	86	87	76	87	82	36	26	21	86	28	11	8	4
		2nd	87	85	89	86	87	77	88	82	36	25	21	86	30	12	8	4
		3rd	87	85	90	86	86	77	87	82	36	26	25	86	29	11	8	4
		Mean	87	85	90	86	87	77	87	82	36	26	25	86	29	11	8	4
08:49	16/09/2014	1st								82	43	30	30		31	11	11	5
		2nd								81	44	32	27		34	11	12	5
		3rd								82	43	32	30		32	11	11	5
		Mean	—	—	—	—	—	—	—	82	44	31	30	—	32	11	11	5
08:52	17/09/2014	1st									50	35	33		31	12	11	6
		2nd									47	35	33		33	13	11	7
		3rd									50	34	33		33	12	11	6
		Mean								—	49	35	33	—	32	12	11	6

Phase 2 Cucumber Data Collection Chart, continued.

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count								Penetration (Through tissue) Count							
			2 Ply				4 Ply				2 Ply				4 Ply			
			A	C	B	D	E	A	C	B	A	C	B	D	E	A	C	B
09:02	18/09/2014	1st									52	46	33	-	35	14	11	6
		2nd									53	45	34	-	36	14	12	7
		3rd									52	46	34	-	35	14	12	6
		Mean									52	45	34	-	35	14	12	6
09:07	19/09/2014	1st									55	46	34	-	36	14	12	8
		2nd									56	47	34	-	37	14	12	7
		3rd									56	47	34	-	36	14	12	8
		Mean									56	47	34	-	36	14	12	8
13:01	20/09/2014	1st									62	51	36	-	42	15	13	8
		2nd									61	50	36	-	40	15	12	8
		3rd									62	50	36	-	40	15	13	7
		Mean									62	50	36	-	40	15	13	8
15:36	21/09/2014	1st									63	48	37	-	39	15	13	9
		2nd									62	50	36	-	40	15	13	8
		3rd									62	50	37	-	40	16	13	9
		Mean									62	50	37	-	40	15	13	9
09:02	22/09/2014	1st									62	55	37	-	41	16	13	9
		2nd									62	53	37	-	42	15	13	9
		3rd									62	55	37	-	43	15	13	9
		Mean									62	54	37	-	42	15	13	9
08:57	23/09/2014	1st										54	37	-	43			9
		2nd										54	37	-	42			9
		3rd										54	37	-	42			9
		Mean										54	37	-	42			9
08:53	24/09/2014	1st										54			42			
		2nd										54			42			
		3rd										54			42			
		Mean										54			42			
	25/09/2014	1st																
		2nd																
		3rd																
		Mean																
	26/09/2014	1st																
		2nd																
		3rd																
		Mean																

Phase 3 Part 1, Data Collection Chart, Specimens Planted on 10/11/2014



Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper A 2 Ply				Paper A 4 Ply						Paper A 2 Ply				Paper A 4 Ply					
			Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad
08:40	11/11/14	1st	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2nd	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		3rd	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mean	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08:55	12/11/14	1st	39	0	0	37	0	22	0	0	67	0	0	0	0	1	0	0	0	0	0	0
		2nd	35	0	0	37	0	23	0	0	68	0	0	0	0	1	0	0	0	0	0	0
		3rd	33	0	0	37	0	23	0	0	66	0	0	0	0	1	0	0	0	0	0	0
		Mean	34	0	0	37	0	23	0	0	68	0	0	0	0	1	0	0	0	0	0	0
08:57	13/11/14	1st	31	0	28	80	6	71	0	2	68	0	0	0	2	14	0	0	0	2	0	0
		2nd	31	0	29	80	6	73	0	2	68	0	0	0	2	15	0	0	0	2	0	0
		3rd	32	0	29	82	6	73	0	2	68	0	0	0	2	15	0	0	0	2	0	0
		Mean	31	0	29	82	6	72	0	2	68	0	0	0	2	15	0	0	0	2	0	0
08:45	14/11/14	1st	87	0	63	82	9	81	0	26	67	0	15	0	2	27	0	0	0	2	0	0
		2nd	87	0	63	82	9	83	0	26	68	0	15	0	2	27	0	0	0	2	0	0
		3rd	86	0	63	82	9	83	0	26	66	0	15	0	2	27	0	0	0	2	0	0
		Mean	87	0	63	82	9	83	0	26	69	0	15	0	2	27	0	0	0	2	0	0
13:00	15/11/14	1st	87	0	76	82	20	83	0	45	67	6	34	0	10	31	1	0	0	2	0	0
		2nd	87	0	75	82	21	83	0	46	68	6	34	0	10	31	1	0	0	2	0	0
		3rd	87	0	76	82	21	83	0	46	68	6	34	0	10	31	1	0	0	2	0	0
		Mean	87	0	76	82	21	83	0	45	68	6	34	0	10	31	1	0	0	2	0	0
14:82	16/11/14	1st	87	0	76	82	34	82	0	48	68	20	47	0	11	36	1	3	0	2	1	0
		2nd	87	0	76	82	34	83	0	48	68	20	48	0	11	36	1	3	0	2	1	0
		3rd	87	0	76	82	34	83	0	48	68	20	46	0	11	36	1	3	0	2	1	0
		Mean	87	0	76	82	34	83	0	48	68	20	48	0	11	36	1	3	0	2	1	0
14:35	17/11/14	1st		0	76		40		0	48		34	51	0	17	50	1	10	0	1	1	0
		2nd		0	76		40		0	48		34	54	0	17	50	1	10	0	1	1	0
		3rd		0	76		40		0	48		34	54	0	17	50	1	10	0	1	1	0
		Mean		0	76		40		0	48		34	54	0	17	50	1	10	0	1	1	0
14:06	18/11/14	1st		3			53		1			38	58	0	24	50	1	10	0	1	2	0
		2nd		3			54		1			38	58	0	24	50	1	10	0	1	3	0
		3rd		3			54		1			37	58	0	24	50	1	10	0	1	3	0
		Mean		3			54		1			38	58	0	24	50	1	10	0	1	3	0
08:40	19/11/14	1st		3			54		4			46	60	0	25	50	1	14	1	2	3	0
		2nd		3			54		4			46	61	0	26	50	1	14	1	2	3	0
		3rd		3			54		4			46	61	0	26	50	1	14	1	2	3	0
		Mean		3			54		4			46	61	0	26	50	1	14	1	2	3	0

Phase 3 Part 1, Data Collection Chart, continued.

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper A 2 Ply					Paper A 4 Ply					Paper A 2 Ply					Paper A 4 Ply				
			Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad
09:04	20/11/14	1st		17			54		5			53	61	2	34		3	17	1	3	4	0
		2nd		17			54		5			53	61	2	33		3	17	1	3	4	0
		3rd		17			54		5			53	61	2	34		3	17	1	3	4	0
		Mean		17			54		5			53	61	2	34		3	17	1	3	4	0
08:48	21/11/14	1st		31					15			52	61	3	40		5	20	1	6	4	1
		2nd		31					15			53	61	3	40		3	22	1	6	4	1
		3rd		31					15			53	61	3	40		3	22	1	6	4	1
		Mean		31					15			53	61	3	40		3	22	1	6	4	1
13:07	22/11/14	1st		40					20			53		4	40		4	22	2	9	4	1
		2nd		40					21			53		4	41		4	22	2	8	4	1
		3rd		40					21			53		4	40		4	22	2	9	4	1
		Mean		40					21			53		4	40		4	22	2	9	4	1
14:40	23/11/14	1st		43					35					5	40		4	30	2	9		1
		2nd		45					34					5	40		4	28	2	9		1
		3rd		45					35					5	40		4	30	2	9		1
		Mean		45					35					5	40		4	30	2	9		1
14:51	24/11/14	1st		66					42					2			4	20	3	9		
		2nd		67					42					9			4	30	3	9		
		3rd		68					42					8			4	30	3	9		
		Mean		67					42					8			4	30	3	9		
08:43	25/11/14	1st		67					40					11				28	3			
		2nd		68					42					11				30	3			
		3rd		67					42					11				30	3			
		Mean		67					42					11				30	3			
08:37	26/11/14	1st		67					42					16					3			
		2nd		67					41					17					3			
		3rd		67					42					17					3			
		Mean		67					42					17					3			
8:54	27/11/14	1st												23								
		2nd												23								
		3rd												23								
		Mean												23								
07:49	28/11/14	1st												28								
		2nd												27								
		3rd												28								
		Mean												28								

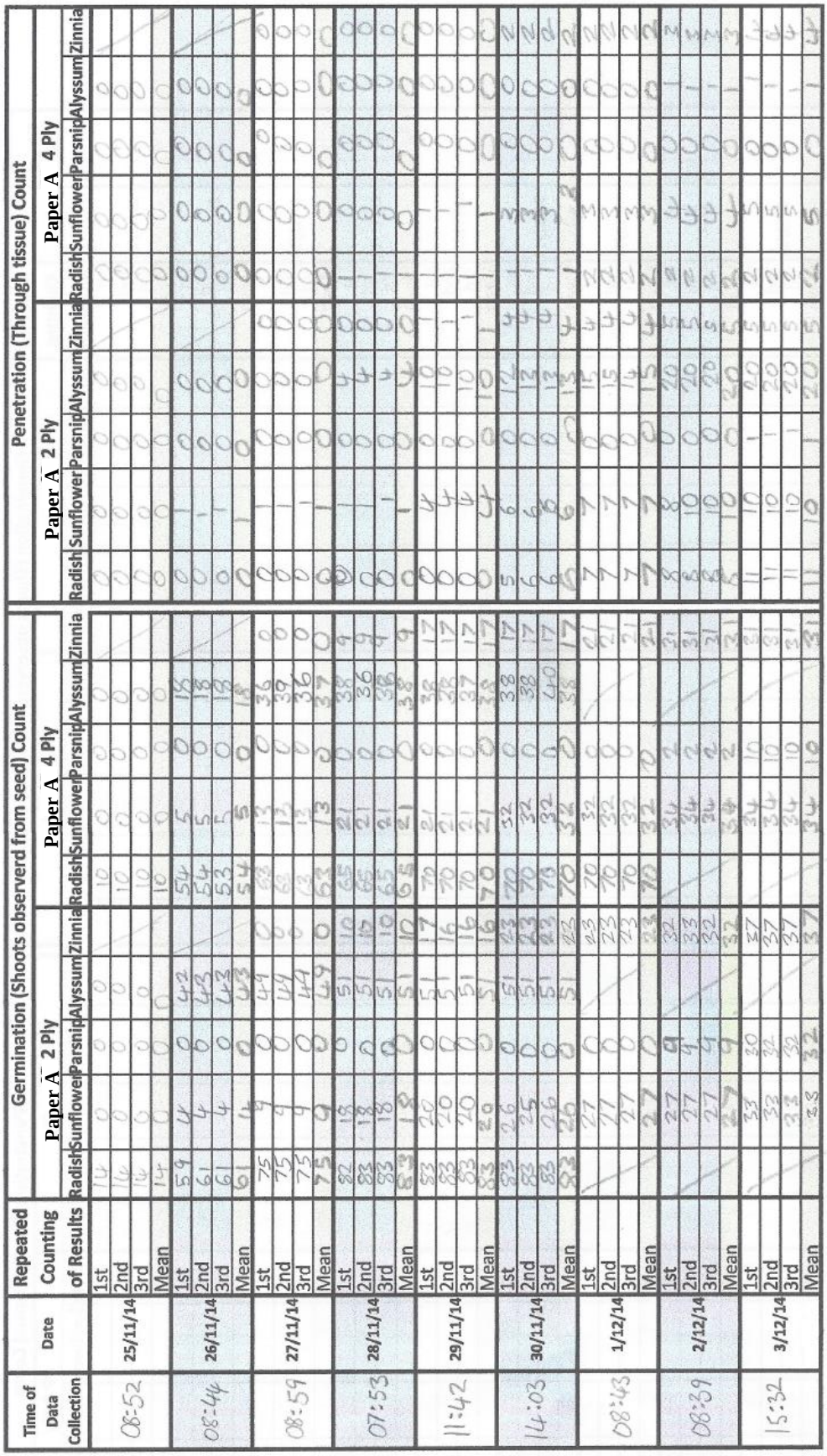
Phase 3 Part 1, Data Collection Chart, continued.

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper A 2 Ply					Paper A 4 Ply					Paper A 2 Ply					Paper A 4 Ply				
			Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad
11:38	29/11/14	1st												27								
		2nd												28								
		3rd												28								
		Mean												28								
13:58	30/11/14	1st												35								
		2nd												36								
		3rd												37								
		Mean												36								
08:37	1/12/14	1st												36								
		2nd												36								
		3rd												36								
		Mean												36								
08:35	2/12/14	1st												36								
		2nd												36								
		3rd												35								
		Mean												36								
	3/11/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	4/11/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	5/11/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	6/11/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	7/11/14	1st																				
		2nd																				
		3rd																				
		Mean																				

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper B 2 Ply					Paper B 4 Ply					Paper B 2 Ply					Paper B 4 Ply				
			Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad
08:45	11/11/14	1st	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2nd	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		3rd	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mean	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08:55	12/11/14	1st	37	0	0	77	0	35	0	0	75	0	0	0	0	16	0	0	0	0	4	0
		2nd	37	0	0	77	0	34	0	0	75	0	0	0	0	17	0	0	0	0	4	0
		3rd	37	0	0	77	0	33	0	0	74	0	0	0	0	17	0	0	0	0	4	0
		Mean	37	0	0	77	0	34	0	0	75	0	0	0	0	17	0	0	0	0	4	0
08:57	13/11/14	1st	74	0	22	76	7	70	0	14	85	3	14	0	5	41	0	1	0	1	12	0
		2nd	73	0	22	77	7	72	0	14	89	3	13	0	5	41	0	1	0	1	13	0
		3rd	74	0	22	78	7	72	0	14	89	3	14	0	5	41	0	1	0	1	13	0
		Mean	74	0	22	78	7	72	0	14	89	3	14	0	5	41	0	1	0	1	13	0
08:48	14/11/14	1st	81	0	44	78	8	80	0	31	89	6	37	0	8	51	0	6	0	1	25	0
		2nd	81	0	44	78	8	80	0	31	89	6	39	0	8	53	0	6	0	1	25	0
		3rd	81	0	44	78	8	80	0	31	89	6	39	0	8	53	0	6	0	1	25	0
		Mean	81	0	44	78	8	80	0	31	89	6	39	0	8	53	0	6	0	1	25	0
13:00	15/11/14	1st	81	0	67	78	31	60	0	46	89	22	45	0	16	67	0	11	0	6	37	1
		2nd	81	0	67	78	31	80	0	45	89	24	50	0	16	67	0	11	0	6	38	1
		3rd	81	0	66	78	31	80	0	46	89	24	50	0	16	66	0	11	0	6	38	1
		Mean	81	0	67	78	31	80	0	48	89	24	50	0	16	67	0	11	0	6	38	1
14:32	16/11/14	1st	81	0	67	/	36	80	0	57	/	33	61	0	22	71	0	13	0	8	41	1
		2nd	81	0	67	/	36	80	0	56	/	33	62	0	22	70	0	13	0	8	42	1
		3rd	81	0	67	/	36	80	0	57	/	31	62	0	22	72	0	13	0	8	42	1
		Mean	81	0	67	/	36	80	0	57	/	33	62	0	22	72	0	13	0	8	42	1
14:37	17/11/14	1st	/	1	67	/	43	/	0	57	/	41	77	0	25	74	1	17	0	10	46	1
		2nd	/	2	67	/	43	/	1	57	/	41	77	0	25	74	1	17	0	14	47	1
		3rd	/	2	67	/	42	/	1	57	/	41	77	0	25	73	1	17	0	14	48	1
		Mean	/	2	67	/	42	/	1	57	/	41	77	0	25	74	1	17	0	14	47	1
14:06	18/11/14	1st	/	15	/	/	46	/	2	57	/	50	77	3	39	75	7	26	1	14	52	6
		2nd	/	15	/	/	45	/	2	57	/	49	77	3	39	75	7	27	1	14	50	6
		3rd	/	15	/	/	46	/	2	57	/	50	77	3	39	75	7	27	1	14	50	6
		Mean	/	15	/	/	46	/	2	57	/	50	77	3	39	75	7	27	1	14	50	6
08:46	19/11/14	1st	/	16	/	/	57	/	4	/	/	56	77	3	42	76	7	40	1	19	53	6
		2nd	/	16	/	/	57	/	4	/	/	56	77	3	42	76	7	41	1	14	53	6
		3rd	/	16	/	/	57	/	4	/	/	56	77	3	42	76	7	41	1	19	53	6
		Mean	/	16	/	/	57	/	4	/	/	56	77	3	42	76	7	41	1	19	53	6

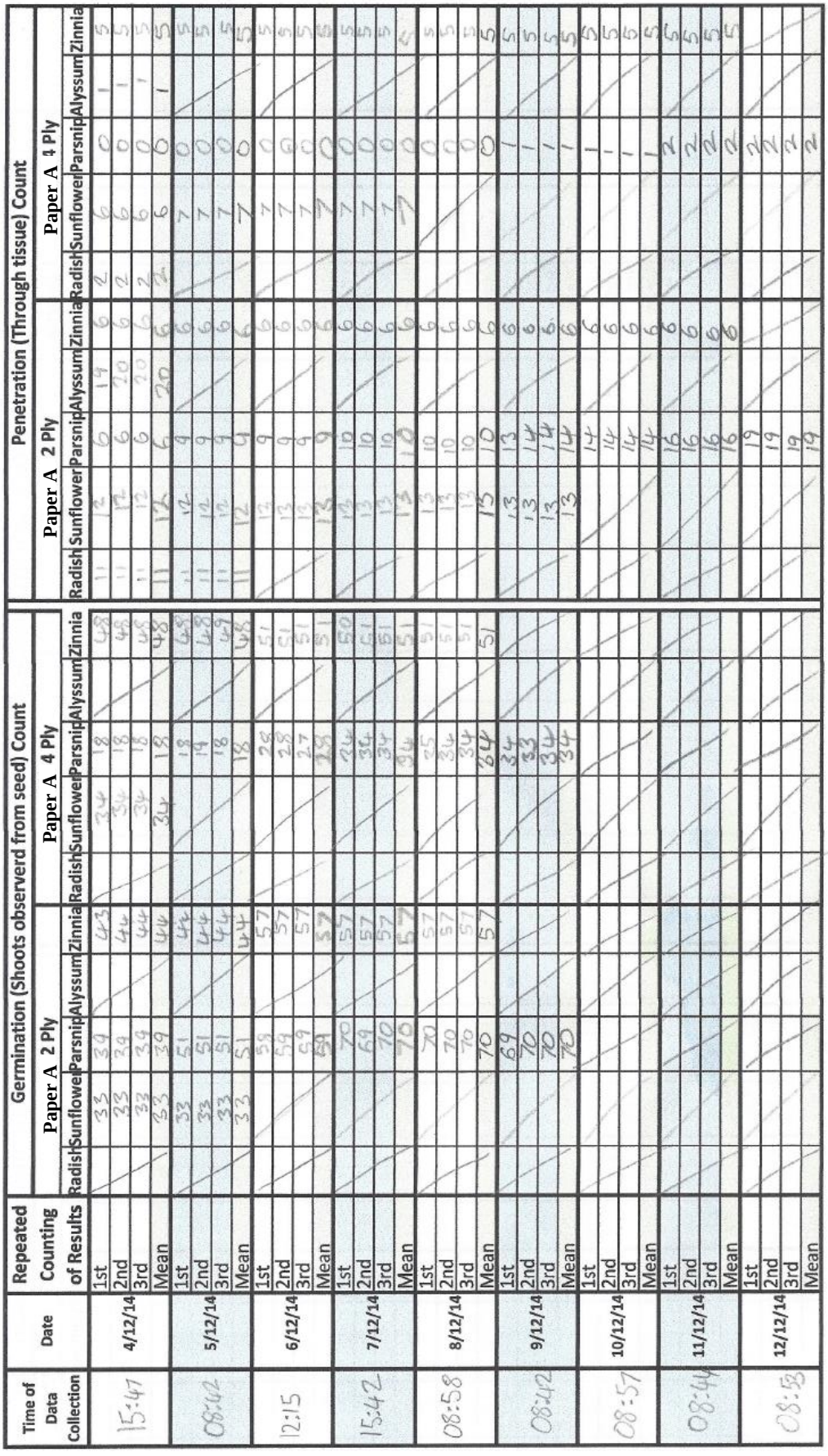
Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper B 2 Ply					Paper B 4 Ply					Paper B 2 Ply					Paper B 4 Ply				
			Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad	Basil	Parsley	Carrot	Lettuce	CornSalad
09:04	20/11/14	1st		26			59		7			55		5	46	77	8	45	1	26	56	6
		2nd		26			60		7			56		5	46	76	8	45	1	26	56	6
		3rd		26			60		7			56		5	46	76	8	45	1	26	56	6
		Mean		26			60		7			56		5	46	76	8	45	1	26	56	6
08:48	21/11/14	1st		38			60		15			58		6	50	76	14	49	2	26	56	
		2nd		38			60		16			58		6	51	76	16	49	2	26	56	
		3rd		38			59		16			58		6	51	76	16	49	2	26	56	
		Mean		38			60		16			58		6	51	76	16	49	2	26	56	
13:07	22/11/14	1st		44			60		19			58		15	51		14	50	2	27	56	
		2nd		43			60		19			57		15	50		19	51	2	27	56	
		3rd		44			60		19			58		15	51		19	51	2	26	56	
		Mean		44			60		19			58		15	51		19	51	2	27	56	
14:40	23/11/14	1st		57					36			57		21	50		21	60	4	26		
		2nd		57					38			58		21	51		21	62	4	27		
		3rd		57					38			58		21	51		21	62	4	27		
		Mean		57					38			58		21	51		21	62	4	27		
14:51	24/11/14	1st		60					38					22			21	61	4	27		
		2nd		60					38					23			21	62	4	27		
		3rd		60					38					23			21	62	4	27		
		Mean		60					38					23			21	62	4	27		
08:43	25/11/14	1st		60					38					36			28	62	5			
		2nd		60					38					36			29	62	5			
		3rd		60					38					36			29	61	5			
		Mean		60					38					36			29	62	5			
08:37	26/11/14	1st		59										36			29		5			
		2nd		60										36			29		5			
		3rd		60										36			29		5			
		Mean		60										36			29		5			
08:54	27/11/14	1st												36			29		5			
		2nd												36			27		5			
		3rd												36			29		5			
		Mean												36			29		5			
07:49	28/11/14	1st																				
		2nd																				
		3rd																				
		Mean																				

Phase 3 Part 2, Data Collection Chart, Specimens Planted on 24/11/2014 (Zinnia planted on 26/11/14).



Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper A 2 Ply					Paper A 4 Ply					Paper A 2 Ply					Paper A 4 Ply				
			Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia
08:52	25/11/14	1st	14	0	0	0		10	0	0	0		0	0	0	0		0	0	0	0	
		2nd	14	0	0	0		10	0	0	0		0	0	0	0		0	0	0	0	
		3rd	14	0	0	0		10	0	0	0		0	0	0	0		0	0	0	0	
		Mean	14	0	0	0		10	0	0	0		0	0	0	0		0	0	0	0	
08:44	26/11/14	1st	59	4	0	43		54	5	0	16		0	1	0	2		0	0	0	0	
		2nd	61	4	0	43		54	5	0	18		0	1	0	2		0	0	0	0	
		3rd	61	4	0	43		53	5	0	18		0	1	0	2		0	0	0	0	
		Mean	61	4	0	43		54	5	0	18		0	1	0	2		0	0	0	0	
08:59	27/11/14	1st	75	4	0	44		63	13	0	36		0	1	0	0		0	0	0	0	
		2nd	75	4	0	44		63	13	0	39		0	1	0	0		0	0	0	0	
		3rd	75	4	0	44		63	13	0	36		0	1	0	0		0	0	0	0	
		Mean	75	4	0	44		63	13	0	37		0	1	0	0		0	0	0	0	
07:53	28/11/14	1st	82	18	0	51		65	21	0	38		0	1	0	4		0	1	0	0	
		2nd	83	18	0	51		65	21	0	36		0	1	0	4		0	1	0	0	
		3rd	83	18	0	51		65	21	0	38		0	1	0	4		0	1	0	0	
		Mean	83	18	0	51		65	21	0	38		0	1	0	4		0	1	0	0	
11:42	29/11/14	1st	83	20	0	51		70	21	0	36		0	4	0	10		0	1	0	0	
		2nd	83	20	0	51		70	21	0	38		0	4	0	10		0	1	0	0	
		3rd	83	20	0	51		70	21	0	37		0	4	0	10		0	1	0	0	
		Mean	83	20	0	51		70	21	0	38		0	4	0	10		0	1	0	0	
14:03	30/11/14	1st	83	26	0	51		70	32	0	38		5	6	0	12		1	2	0	0	
		2nd	83	25	0	51		73	32	0	38		6	6	0	13		1	3	0	0	
		3rd	83	26	0	51		73	32	0	40		6	6	0	13		1	3	0	0	
		Mean	83	26	0	51		70	32	0	38		6	6	0	13		1	3	0	0	
08:43	1/12/14	1st		27	0			70	32	0			7	7	0	15		1	3	0	0	
		2nd		27	0			73	32	0			7	7	0	15		1	3	0	0	
		3rd		27	0			73	32	0			7	7	0	15		1	3	0	0	
		Mean		27	0			73	32	0			7	7	0	15		1	3	0	0	
08:39	2/12/14	1st		27	4			73	34	2			8	8	0	20		2	4	0	1	
		2nd		27	4			73	34	2			8	10	0	20		2	4	0	1	
		3rd		27	4			73	34	2			8	10	0	20		2	4	0	1	
		Mean		27	4			73	34	2			8	10	0	20		2	4	0	1	
15:32	3/12/14	1st		33	30			37	34	10			11	10	1	20		2	5	0	1	
		2nd		33	32			37	34	10			11	10	1	20		2	5	0	1	
		3rd		33	32			37	34	10			11	10	1	20		2	5	0	1	
		Mean		33	32			37	34	10			11	10	1	20		2	5	0	1	

Phase 3 Part 2, Data Collection Chart, continued.



Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper A 2 Ply				Paper A 4 Ply						Paper A 2 Ply				Paper A 4 Ply					
			Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia
15:47	4/12/14	1st		32	39		43		34	18		48	11	12	6	14	6	2	6	0	1	5
		2nd		33	39		44		34	18		48	11	12	6	10	6	2	6	0	1	5
		3rd		33	39		44		34	18		48	11	12	6	10	6	2	6	0	1	5
		Mean		33	39		44		34	18		48	11	12	6	20	6	2	6	0	1	5
08:42	5/12/14	1st		33	51		44			18		48	11	12	9		6		7	0		5
		2nd		33	51		44			19		48	11	12	9		6		7	0		5
		3rd		33	51		44			18		49	11	12	9		6		7	0		5
		Mean		33	51		44			18		48	11	12	9		6		7	0		5
12:15	6/12/14	1st			53		57			28		51		13	9		6		7	0		5
		2nd			59		57			28		51		13	9		6		7	0		5
		3rd			69		57			27		51		13	9		6		7	0		5
		Mean			59		57			28		51		13	9		6		7	0		5
15:42	7/12/14	1st			70		57			24		60		13	10		6		7	0		5
		2nd			69		57			35		51		13	10		6		7	0		5
		3rd			70		57			34		61		13	10		6		7	0		5
		Mean			70		57			34		51		13	10		6		7	0		5
08:58	8/12/14	1st			70		57			25		51		13	10		6			0		5
		2nd			70		57			34		51		13	10		6			0		5
		3rd			70		57			34		51		13	10		6			0		5
		Mean			70		57			34		51		13	10		6			0		5
08:42	9/12/14	1st			69					34				13	13		6			1		5
		2nd			70					33				13	14		6			1		5
		3rd			70					34				13	14		6			1		5
		Mean			70					34				13	14		6			1		5
08:57	10/12/14	1st													14		6			1		5
		2nd													14		6			1		5
		3rd													14		6			1		5
		Mean													14		6			1		5
08:44	11/12/14	1st													16		6			2		5
		2nd													16		6			2		5
		3rd													16		8			2		5
		Mean													16		8			2		5
08:53	12/12/14	1st													19					2		
		2nd													19					2		
		3rd													19					2		
		Mean													19					2		

Phase 3 Part 2, Data Collection Chart, continued.

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper A 2 Ply					Paper A 4 Ply					Paper A 2 Ply					Paper A 4 Ply				
			Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia
08:43	13/12/14	1st													19					2		
		2nd													19					2		
		3rd													19					2		
		Mean													19					2		
12:16	14/12/14	1st													18							
		2nd													19							
		3rd													19							
		Mean													19							
	15/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	16/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	17/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	18/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	19/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	20/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	21/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				

Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper B 2 Ply					Paper B 4 Ply					Paper B 2 Ply					Paper B 4 Ply				
			Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia
08:52	25/11/14	1st	12	0	0	0		11	0	0	0		0	0	0	0		0	0	0	0	
		2nd	12	0	0	0		11	0	0	0		0	0	0	0		0	0	0	0	
		3rd	12	0	0	0		11	0	0	0		0	0	0	0		0	0	0	0	
		Mean	12	0	0	0		11	0	0	0		0	0	0	0		0	0	0	0	
08:44	26/11/14	1st	62	3	0	40		53	2	0	35		3	0	0	0		0	0	0	0	
		2nd	62	3	0	40		53	2	0	36		3	0	0	0		0	0	0	0	
		3rd	62	3	0	42		53	2	0	35		3	0	0	0		0	0	0	0	
		Mean	62	3	0	40		53	2	0	35		3	0	0	0		0	0	0	0	
08:59	27/11/14	1st	85	10	0	56	2	73	6	0	63	3	19	0	0	4	0	0	0	0	0	0
		2nd	87	10	0	54	2	73	6	0	58	3	19	0	0	4	0	0	0	0	0	0
		3rd	87	10	0	53	2	73	6	0	59	3	19	0	0	4	0	0	0	0	0	0
		Mean	87	10	0	54	2	73	6	0	60	3	19	0	0	4	0	0	0	0	0	0
07:53	28/11/14	1st	87	12	0	54	15	78	9	0	57	12	36	4	0	11	3	4	0	0	1	0
		2nd	87	12	0	56	15	78	9	0	60	12	36	4	0	11	3	4	0	0	1	0
		3rd	87	12	0	58	15	78	9	0	63	12	36	4	0	11	3	4	0	0	1	0
		Mean	87	12	0	56	15	78	9	0	60	12	36	4	0	11	3	4	0	0	1	0
11:42	29/11/14	1st	87	13	0	56	20	78	11	0	60	20	70	8	0	26	4	6	0	0	5	1
		2nd	87	14	0	57	20	77	11	0	59	20	69	8	0	26	4	6	0	0	5	1
		3rd	87	13	0	54	20	78	11	0	60	20	70	8	0	26	4	6	0	0	5	1
		Mean	87	13	0	56	20	78	11	0	60	20	70	8	0	26	4	6	0	0	5	1
14:03	30/11/14	1st		21	0	57	24	78	17	0		20	70	8	0	31	9	26	0	0	7	4
		2nd		21	0	56	24	78	17	0		20	70	8	0	31	9	26	0	0	7	4
		3rd		21	0	56	24	78	17	0		20	71	8	0	31	9	26	0	0	7	4
		Mean		21	0	56	24	78	17	0		20	70	8	0	31	9	26	0	0	7	4
08:43	1/12/14	1st		21	1		24		17	1		22	77	9	0	35	13	36	0	0	9	4
		2nd		21	1		23		17	1		22	79	9	0	35	13	37	0	0	9	4
		3rd		21	1		24		17	1		22	79	9	0	35	13	37	0	0	9	4
		Mean		21	1		24		17	1		22	79	9	0	35	13	37	0	0	9	4
08:39	2/12/14	1st		21	10		26		19	7		27	79	10	1	35	13	44	0	0	9	5
		2nd		22	10		27		19	7		27	79	10	1	35	13	44	0	0	9	5
		3rd		22	10		26		19	7		27	79	10	1	35	13	44	0	0	9	5
		Mean		22	10		26		19	7		27	79	10	1	35	13	44	0	0	9	5
15:32	3/12/14	1st		24	30		35		25	18		30	79	12	7	35	15	59	2	2	9	7
		2nd		24	31		35		25	18		30	79	12	7	35	15	59	2	2	9	7
		3rd		24	31		35		24	18		30	79	12	7	35	15	59	2	2	9	7
		Mean		24	31		35		25	18		30	79	12	7	35	15	59	2	2	9	7

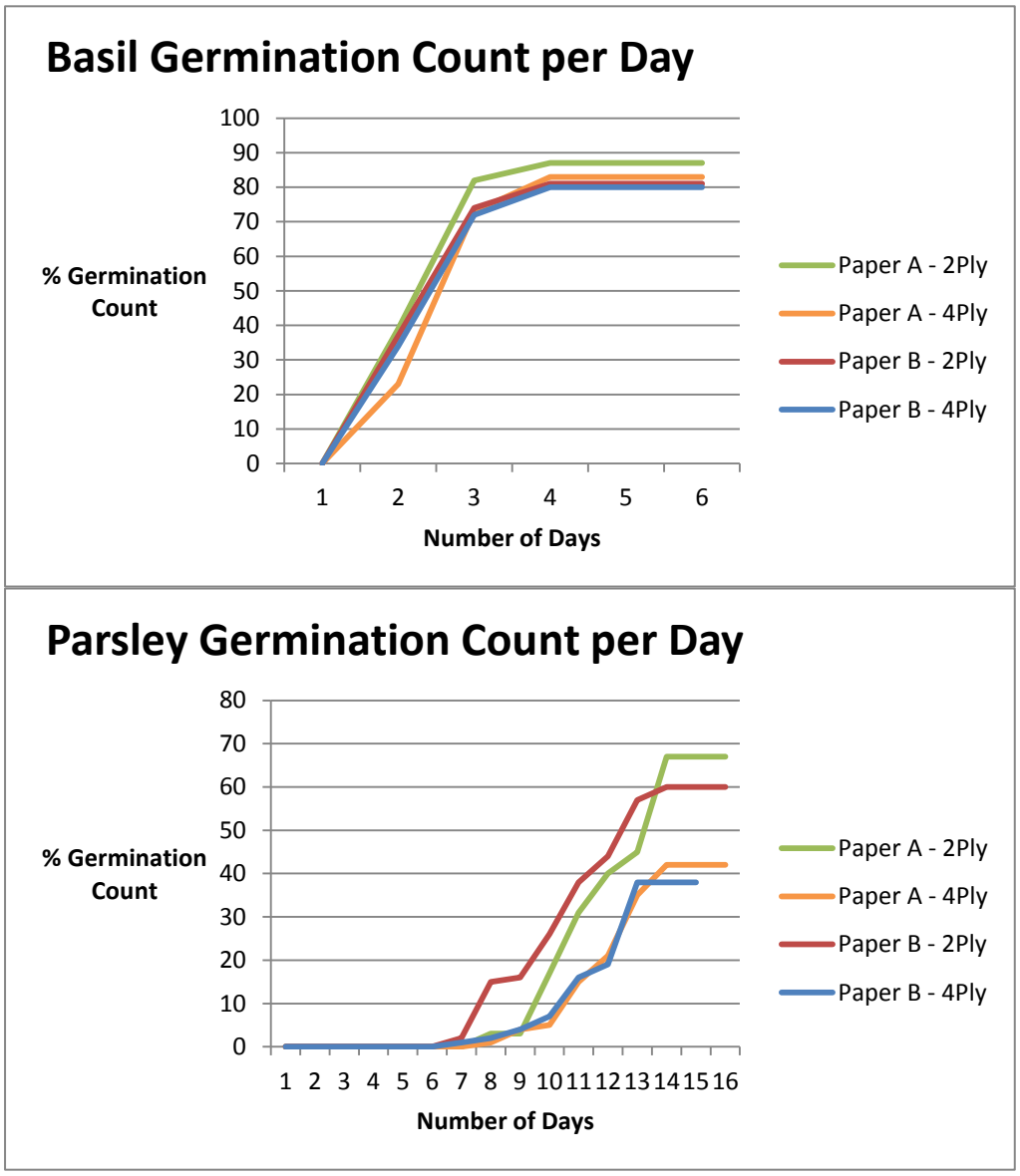
Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper B 2 Ply					Paper B 4 Ply					Paper B 2 Ply					Paper B 4 Ply				
			Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia
15:47	4/12/14	1st		24	33		35		25	29		33		12	13		15	59	2	3		7
		2nd		24	32		35		25	28		33		12	13		15	59	2	3		7
		3rd		24	33		35		25	29		33		12	13		15	59	2	3		7
		Mean		24	33		35		25	29		33		12	13		15	59	2	3		7
08:42	5/12/14	1st		31	33		38		25	32		36		12	15		17	58	3	6		8
		2nd		31	34		38		25	33		36		12	15		17	59	3	6		8
		3rd		31	35		38		25	33		36		12	15		17	59	3	6		8
		Mean		31	34		38		25	33		36		12	15		17	59	3	6		8
12:15	6/12/14	1st		31	44		41			41		40		12	17		17		3	6		8
		2nd		31	44		42			42		40		12	17		17		3	6		8
		3rd		31	44		42			42		40		12	17		17		3	6		8
		Mean		31	44		42			42		40		12	17		17		3	6		8
15:42	7/12/14	1st		31	56		42			43		41		11	18		17		3	9		8
		2nd		32	58		42			43		41		12	20		17		3	9		8
		3rd		31	58		41			43		41		12	20		17		3	9		8
		Mean		31	58		42			43		41		12	20		17		3	9		8
08:58	8/12/14	1st			59		42			56		41		12	23		17		3	11		8
		2nd			60		42			57		41		12	22		17		3	11		8
		3rd			60		42			57		41		13	24		17		3	11		8
		Mean			60		42			57		41		12	23		17		3	11		8
08:42	9/12/14	1st			60					59		41		12	26		17			13		8
		2nd			60					59		41		12	27		17			13		8
		3rd			59					60		41		12	27		17			13		8
		Mean			60					59		41		12	27		17			13		8
08:57	10/12/14	1st			60					58				12	29		17			13		8
		2nd			60					59				12	28		17			13		8
		3rd			60					59				12	29		17			13		8
		Mean			60					59				12	29		17			13		8
08:44	11/12/14	1st								59					34		17			14		8
		2nd								59					35		17			14		8
		3rd								59					35		17			14		8
		Mean								59					35		17			14		8
08:53	12/12/14	1st													39					14		8
		2nd													38					14		8
		3rd													39					14		8
		Mean													39					14		8

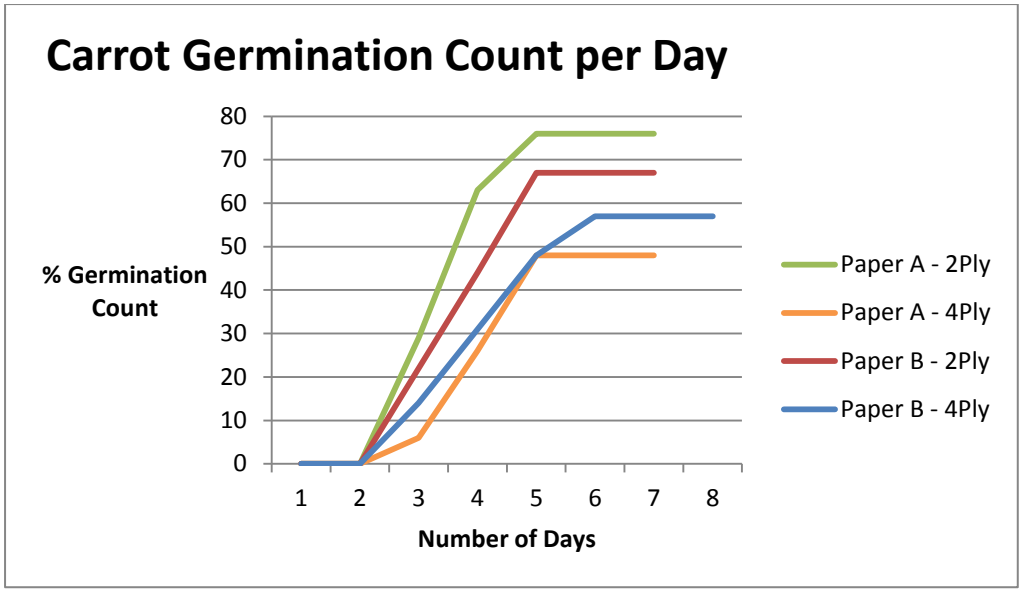
Phase 3 Part 2, Data Collection Chart, continued.

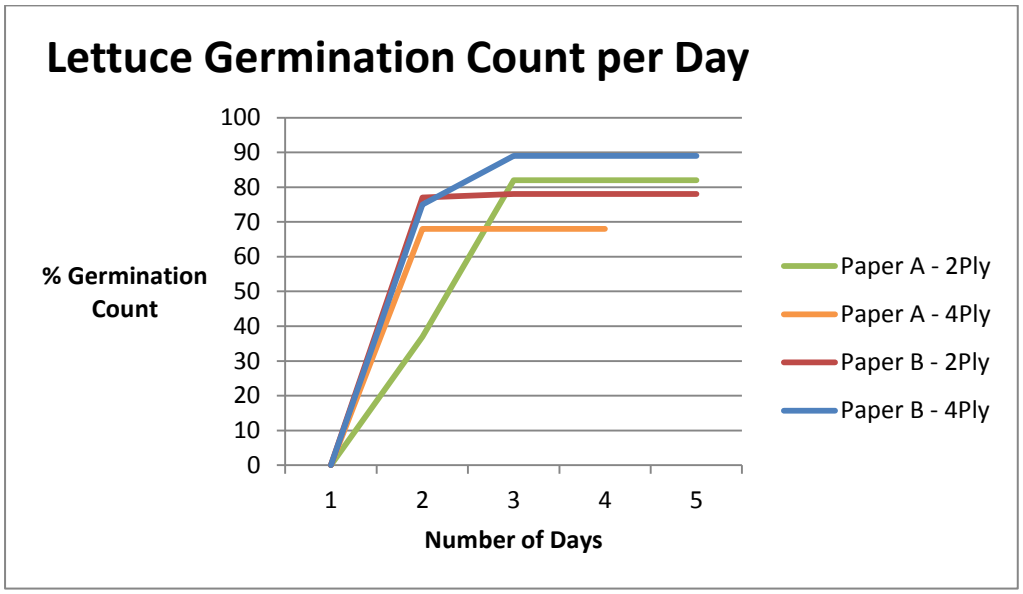
Time of Data Collection	Date	Repeated Counting of Results	Germination (Shoots observerd from seed) Count										Penetration (Through tissue) Count									
			Paper B 2 Ply					Paper B 4 Ply					Paper B 2 Ply					Paper B 4 Ply				
			Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia	Radish	Sunflower	Parsnip	Alyssum	Zinnia
08:45	13/12/14	1st													39					14		
		2nd													39					14		
		3rd													39					14		
		Mean													39					14		
12:16	14/12/14	1st													39							
		2nd													39							
		3rd													39							
		Mean													39							
	15/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	16/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	17/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	18/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	19/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	20/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				
	21/12/14	1st																				
		2nd																				
		3rd																				
		Mean																				

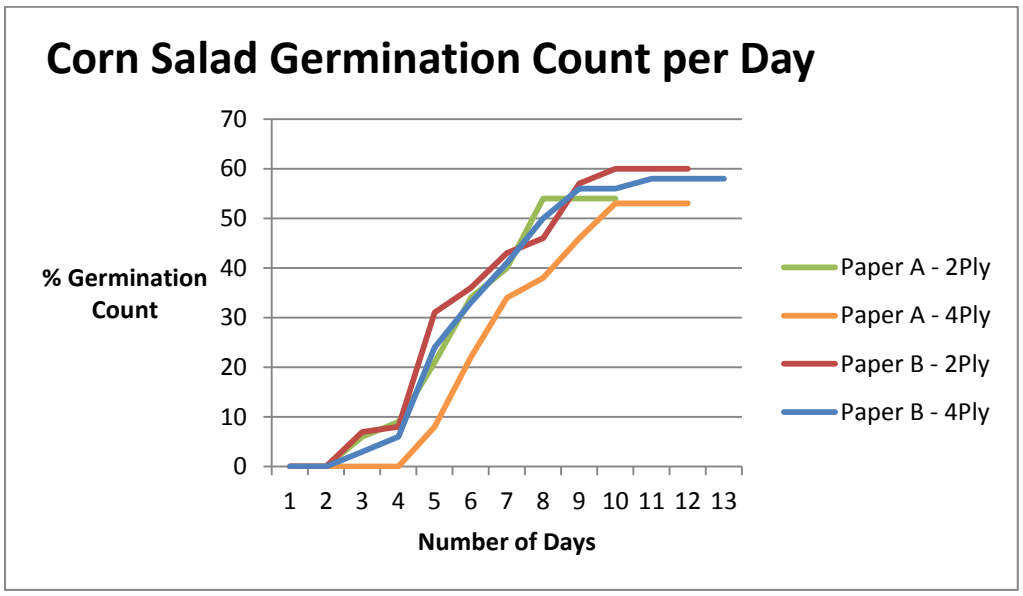
Appendix 2

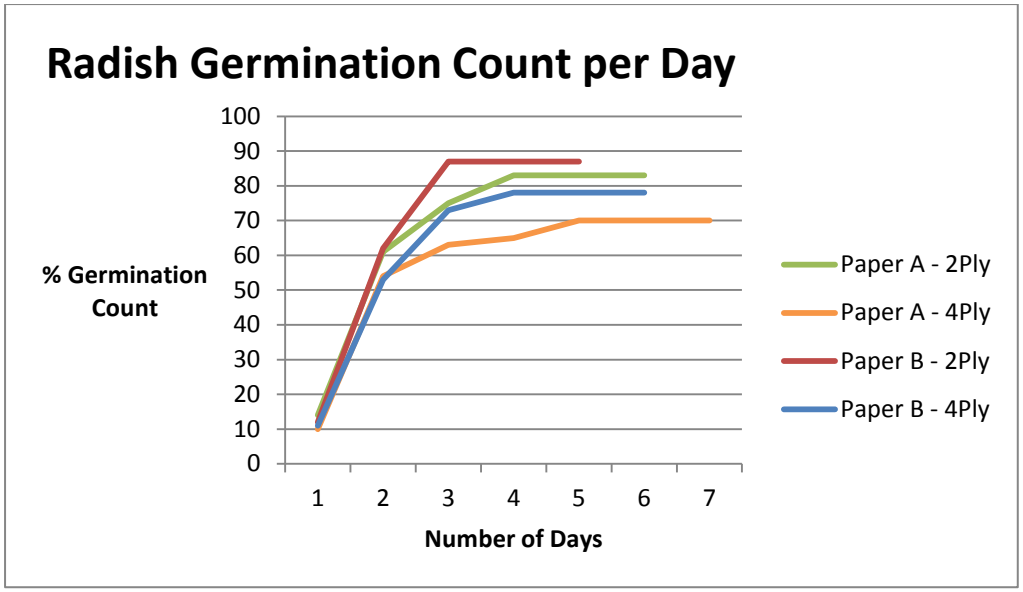
Germination rates of each seed variety during Phase 3.

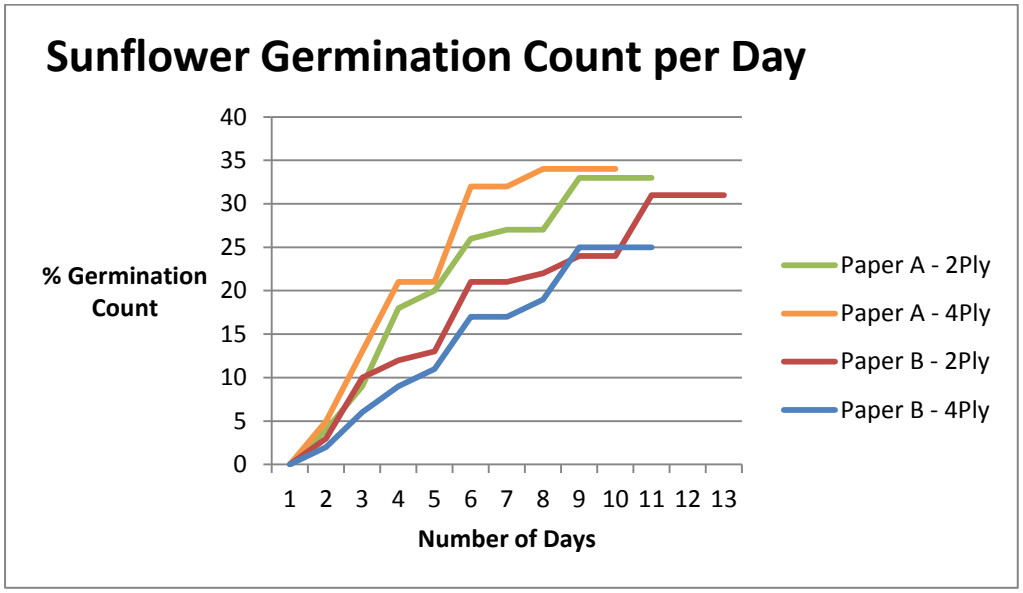


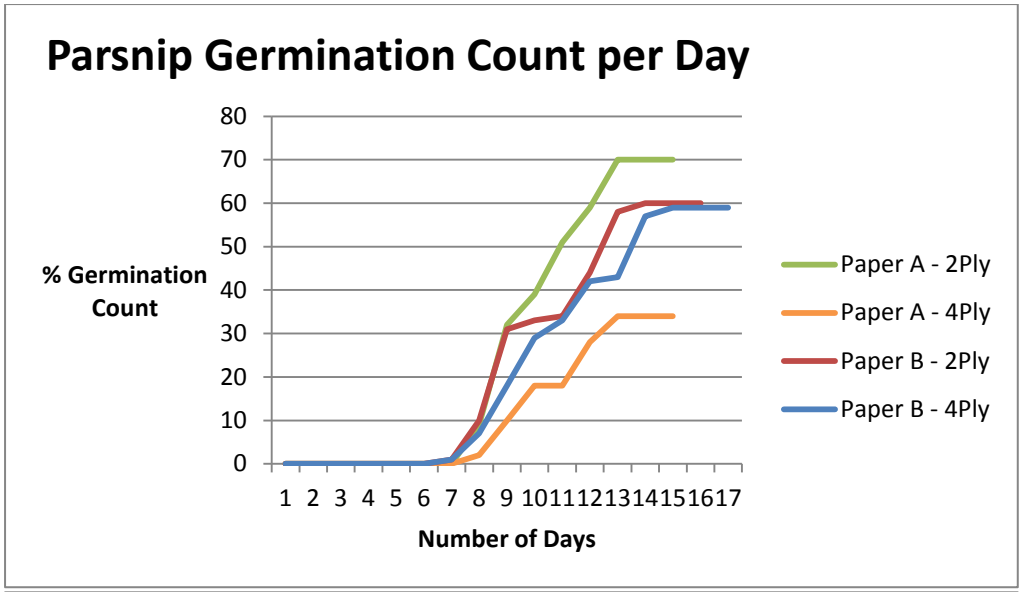

Carrot Germination Count per Day
% Germination Count
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

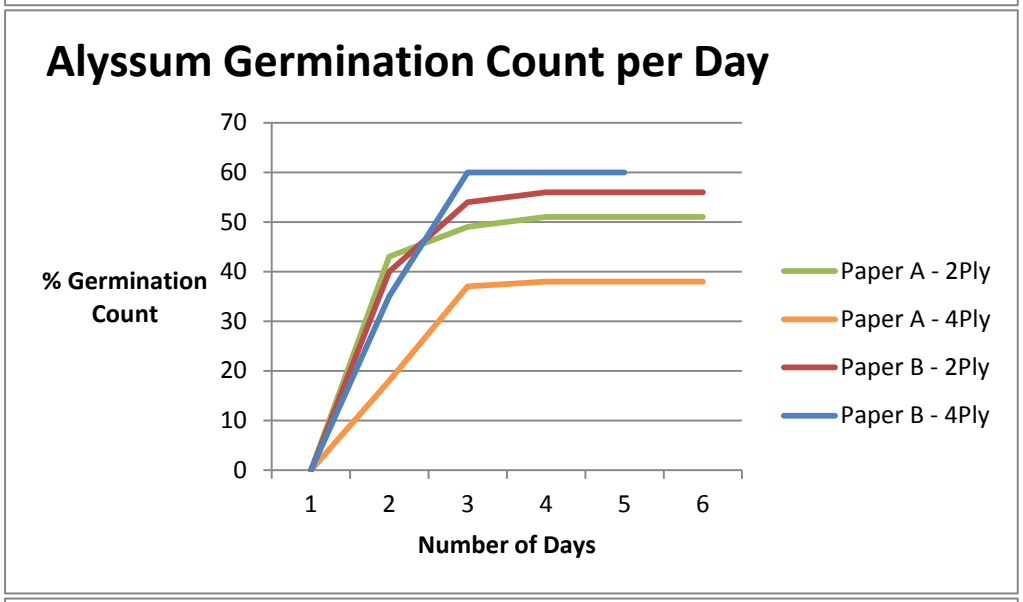

Lettuce Germination Count per Day
% Germination Count
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

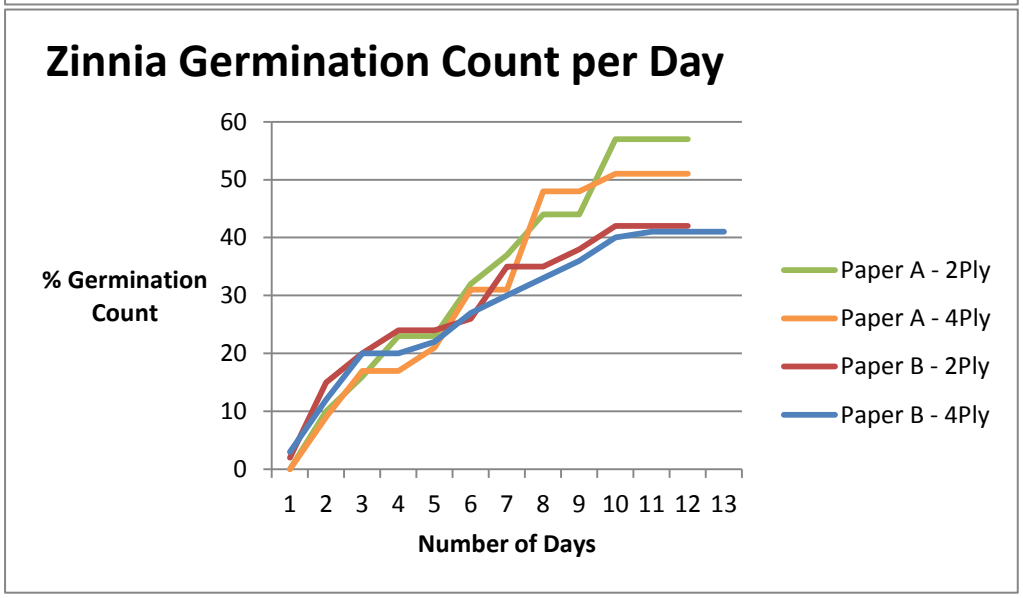

Corn Salad Germination Count per Day
% Germination Count
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

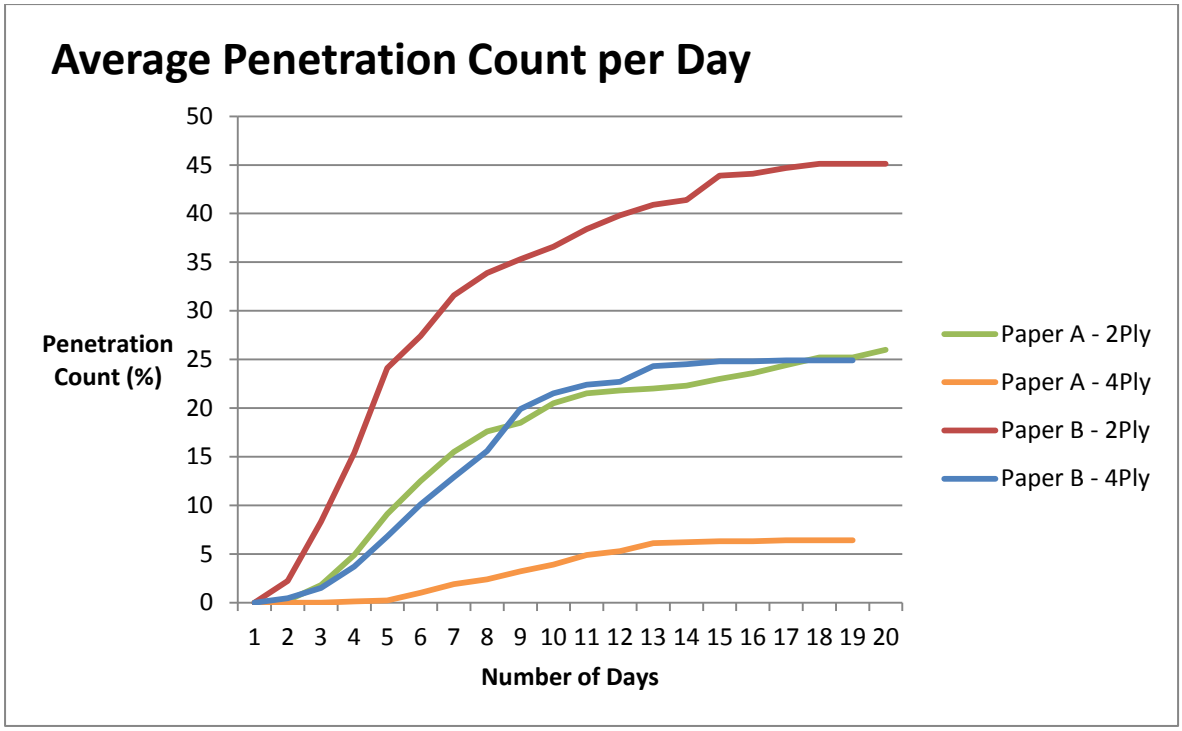

Radish Germination Count per Day
% Germination Count
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

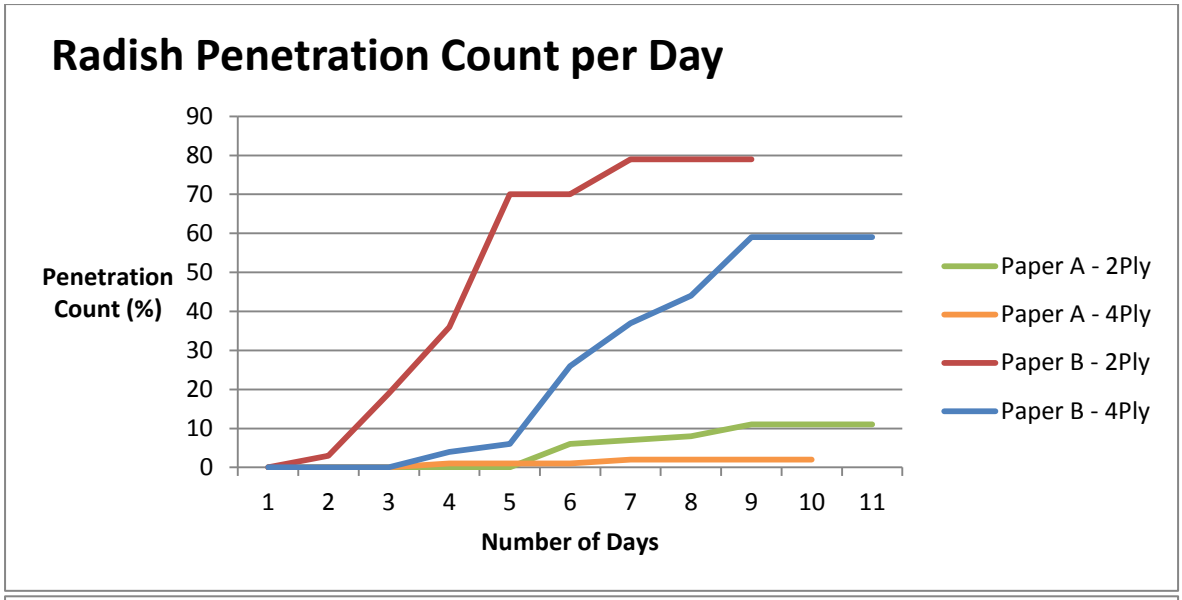

Sunflower Germination Count per Day
% Germination Count
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

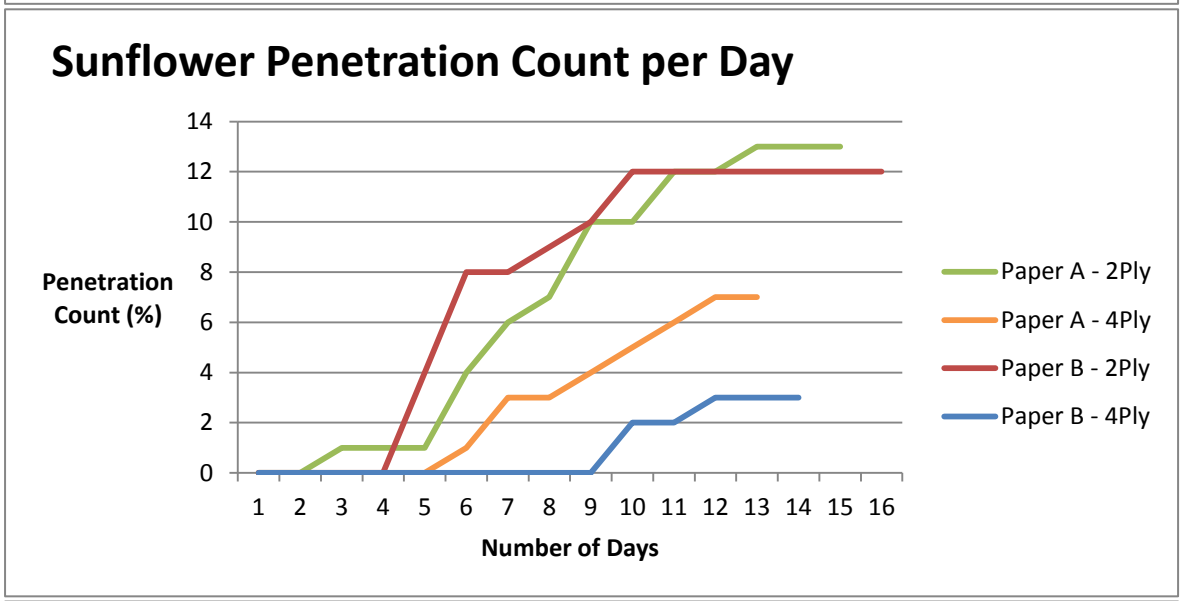

Parsnip Germination Count per Day
% Germination Count
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

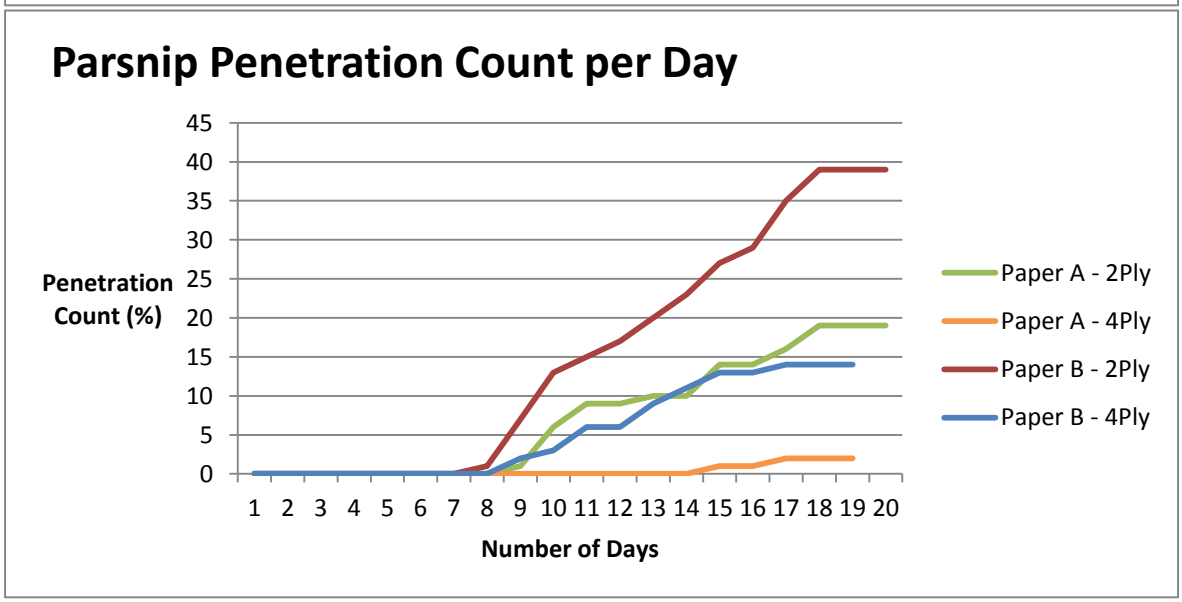

Alyssum Germination Count per Day
% Germination Count
70
60
50
40
30
20
10
0
1 2 3 4 5 6
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

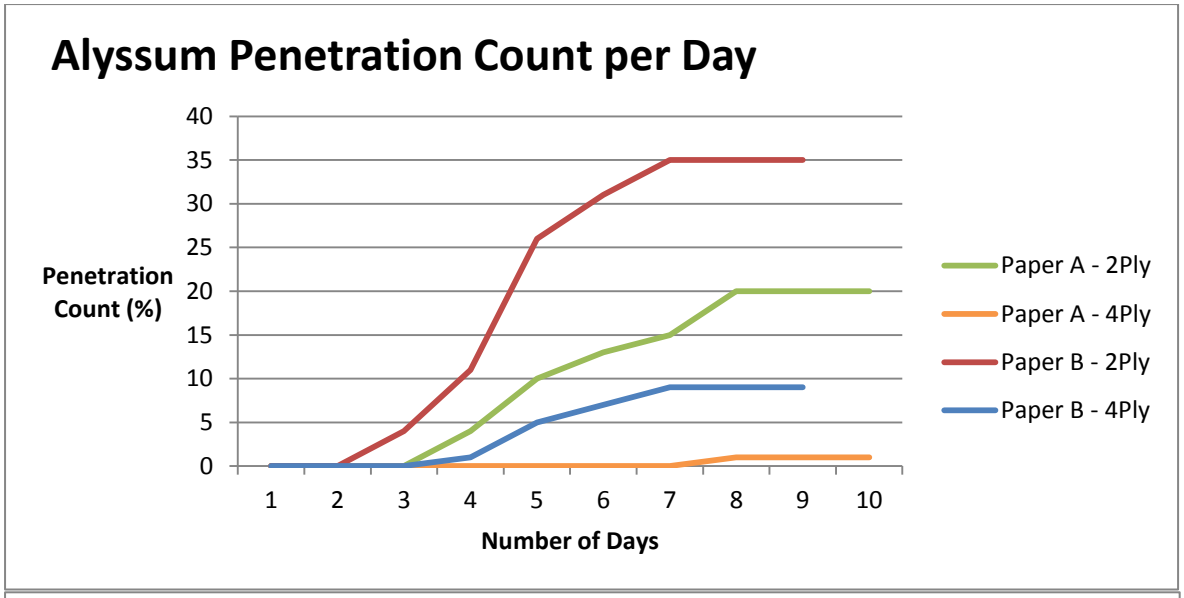

Zinnia Germination Count per Day
% Germination Count
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

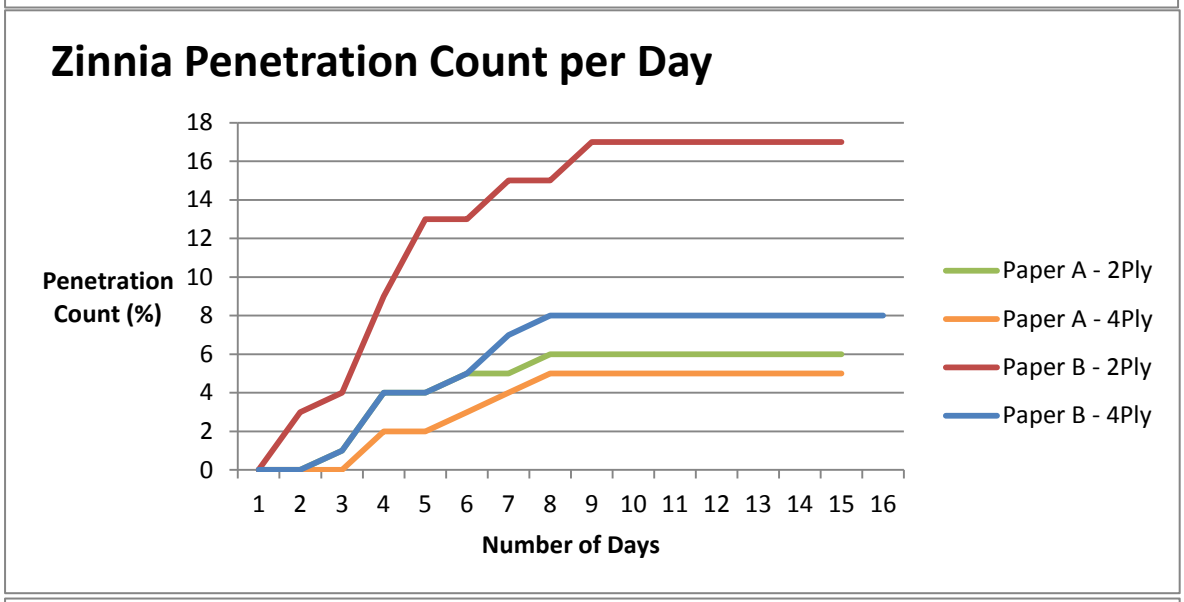

Average Penetration Count per Day
Penetration Count (%)
50
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

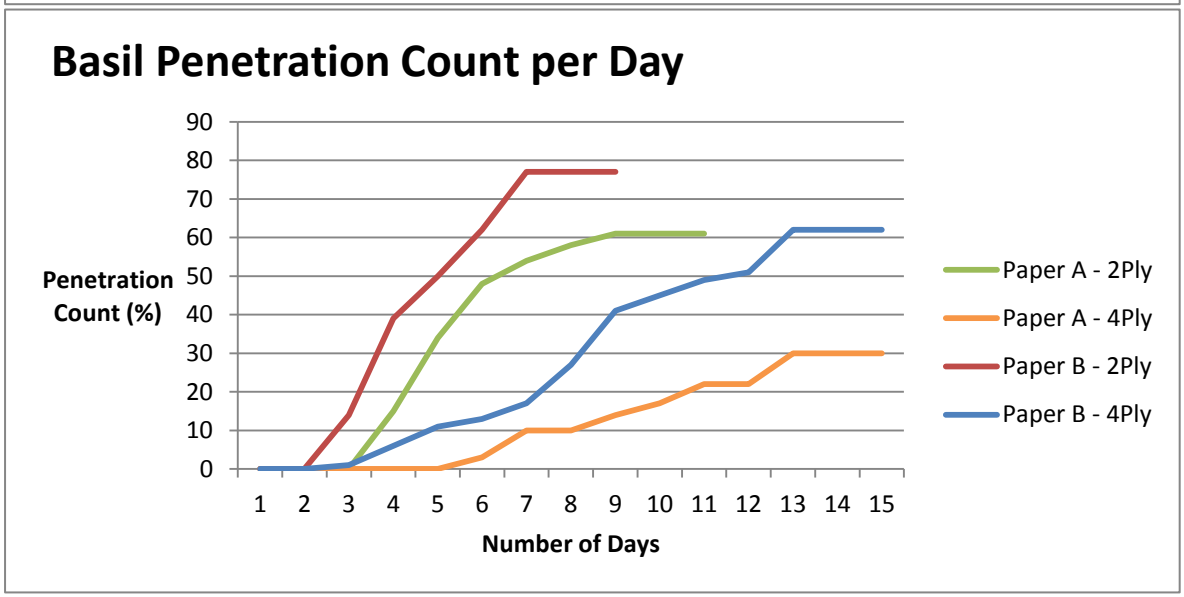

Radish Penetration Count per Day
Penetration Count (%)
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

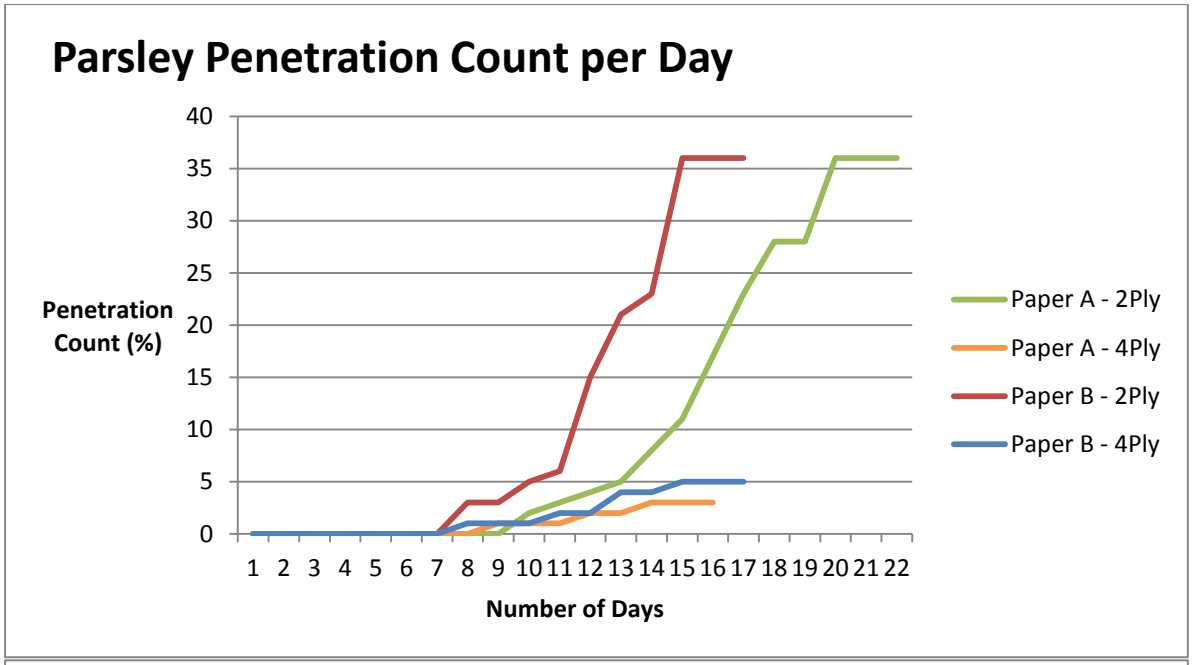

Sunflower Penetration Count per Day
Penetration Count (%)
14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

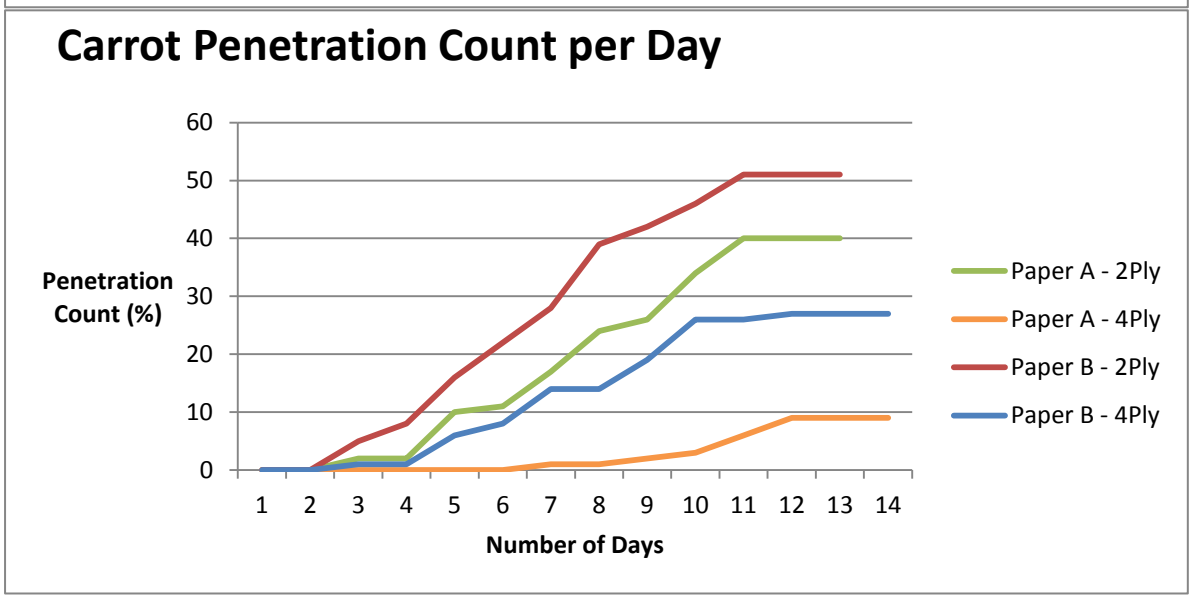

Parsnip Penetration Count per Day
Penetration Count (%)
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

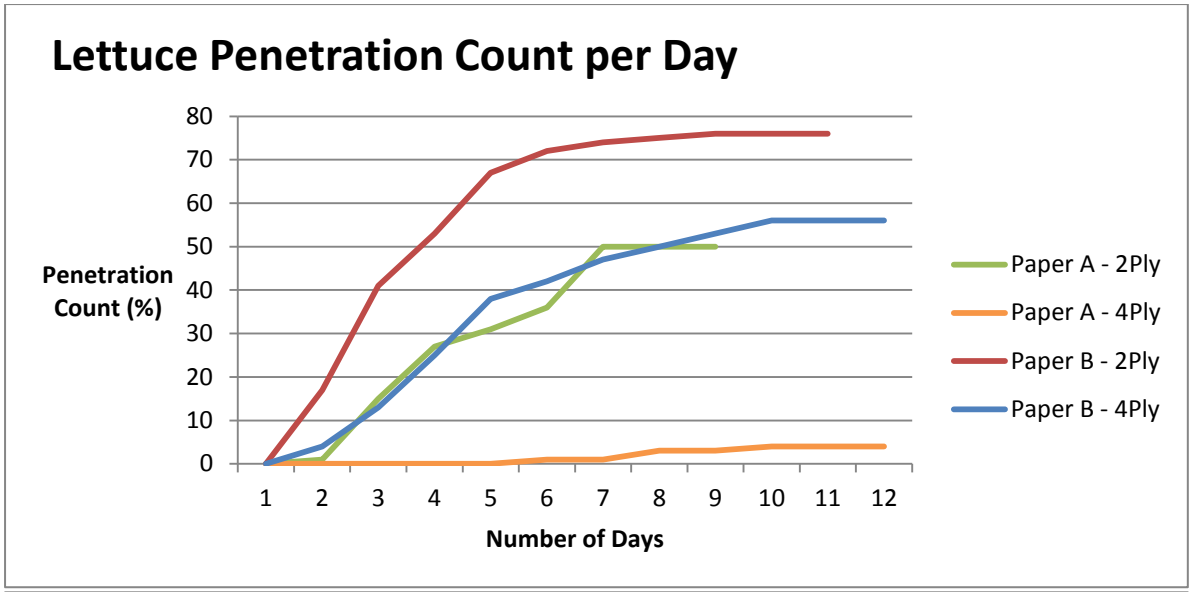

Alyssum Penetration Count per Day
Penetration Count (%)
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

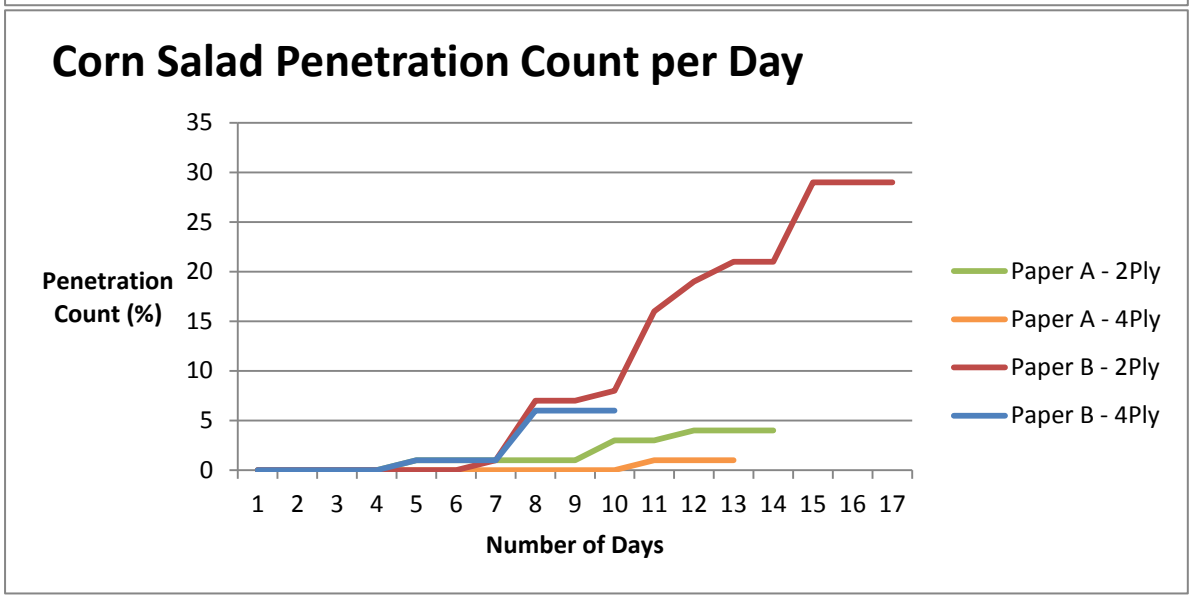

Zinnia Penetration Count per Day
Penetration Count (%)
18
16
14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply


Basil Penetration Count per Day
Penetration Count (%)
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply


Parsley Penetration Count per Day
Penetration Count (%)
0
5
10
15
20
25
30
35
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

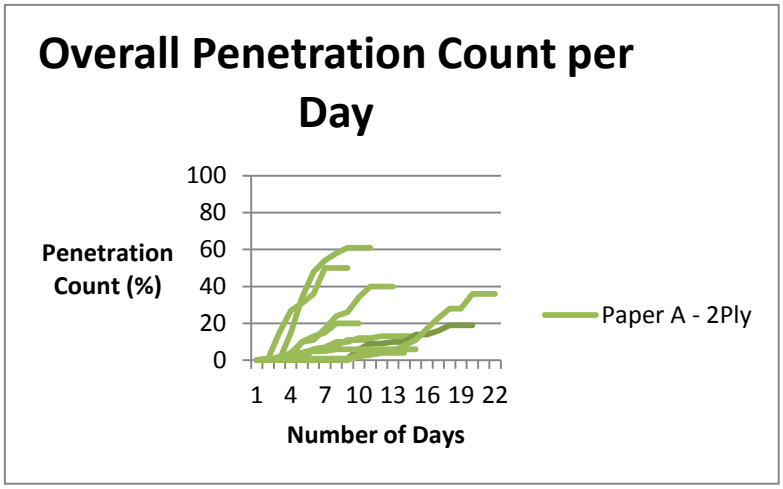

Carrot Penetration Count per Day
Penetration Count (%)
0
10
20
30
40
50
60
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

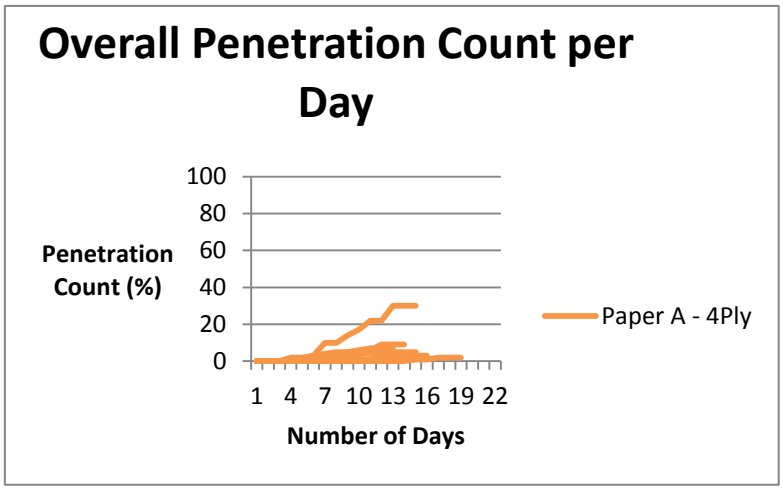

Lettuce Penetration Count per Day
Penetration Count (%)
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

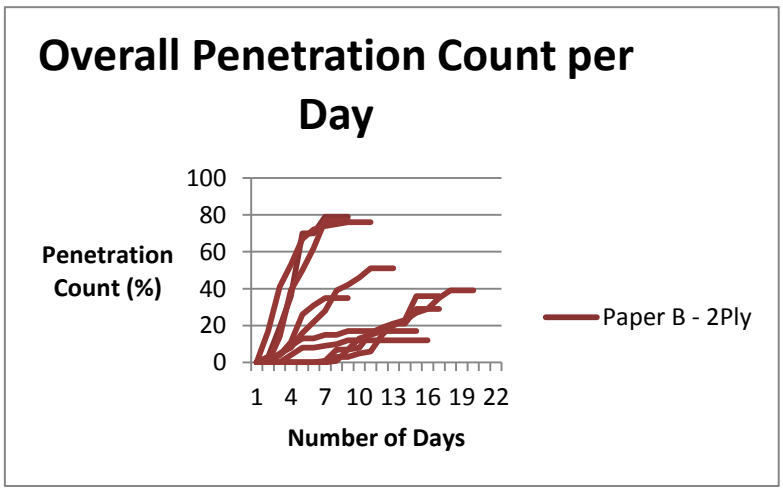

Corn Salad Penetration Count per Day
Penetration Count (%)
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Number of Days
Paper A - 2Ply
Paper A - 4Ply
Paper B - 2Ply
Paper B - 4Ply

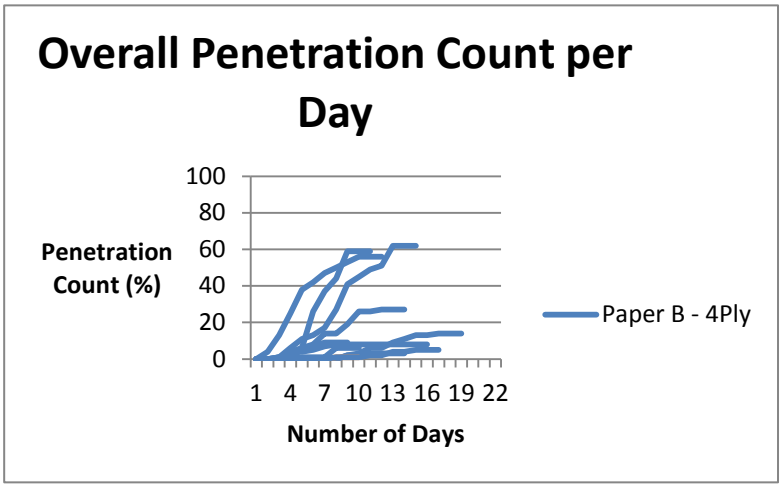
Appendix 3

Penetration rates of each paper specimen during Phase 3.








Overall Penetration Count per Day
Penetration Count (%)
100
80
60
40
20
0
1 4 7 10 13 16 19 22
Number of Days
Paper B - 4Ply