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Effects of magnetic field on seed germination

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Abstract
Plants are the producers in the food chain of Ecosystem. Plants perpetuate itself by two main ways *viz*. vegetative propagation and seed germination. Germination is always influenced by many factors and favourable conditions. Proper seed maturity, adequate water or humidity, temperature, light or darkness, sufficient aeration and fertile soil are the factors which influence healthy seed germination. But apart from all the above factors it has been scientifically proved that natural earth geomagnetism also plays a vital role in proper seed germination. In the current experiment the effect of artificially influenced magnetic field on seed germination has been studied on four different seeds namely two monocot seeds i.e., (i) *Sorghum vulgare* L., (ii) *Zea mays* L. and two dicot seeds i.e., (iii) *Vigna radiata* (L.) R. Wilczek, (iv) *Trigonella foenum-graecum* L. The magnetic field from simple Bar magnets is used throughout the experiment set. Length of plumule and radicle were recorded and weight of seeds were noted from starting to end of 0-5 days of germination.

Keywords: magnetic field, monocot seeds and dicot seeds, seed germination, length of plumule and radicle

Introduction

The use of magnets to induce magnetic field has been a key technique to influence germination. Generally, the natural earth's geomagnetic field is changed by using natural magnets of different strength but the range of effects depends on quality of magnets. The effects of magnetic field on living systems, particularly on seed germination and plant growth have been reported by many researchers. Due to world's population rise and climate change, it has become necessary to increase agricultural food production around 50% by the year 2050 to avoid world famine (Murchie H. E. *et al*., 2009) [12]. Chemical methods can improve crop production. However, besides being expensive they cause environmental pollution (Rochalska M. *et al*., 2011) [16]. Physical methods have shown to improve seed germination and early growth (Tahir N. A. R. *et al*., 2010; Matwijczuk A. *et al.*, 2012; Paniagua P. G. *et al.*, 2013; Rico M. F. *et al.*, 2014) [18, 10, 13, 15] which makes them more suitable alternative to replace chemicals (Bilalis D. *et al*., 2012) [4]. Among these, a technique which has proved to be environment friendly, easy to use and economically cheaper is the pre-sowing treatment with magnetic field (MF) (Aladjadjiyan A. *et al*., 2010) [1].

Numerous authors have reported the positive influence of the stationary magnetic field on the plant seeds. The treatment fastens plants development, improves germination and seedling growth and activates protein formation and enzymes activity (Aladjadjiyan A. *et al*., 2010) [1].

The objective of the current study was to investigate the effect of magnetic field on germination of monocot as well as dicot seeds.

Methodology

Effects of Magnetic Field on Seed Germination project was carried out by using two types of seeds *viz*. monocot and dicot (M. E. S. M. Ahmed *et al.*, 2013) [8]. From monocot seeds *Sorghum vulgare* L., *Zea mays* L. and from dicot seeds *Vigna radiata* (L.) R. Wilczek, *Trigonella foenum-graecum* L. were taken for the experiment.

First of all, strength of all the magnets was measured using paper, scale and compass method. This method was adopted as it is user friendly to calculate without standard scientific instrument *viz.* Gauss meter (Hirota N. *et al*., 1999) [5]. Plain white paper was selected in which magnet was kept vertically, from North pole markings which were made by using measuring scale. On those markings compass was kept at one feet distance from magnet facing North Pole. Slowly and gradually the Compass was pushed in the direction of North Pole. The moment where the needle of Compass starts to attract the magnet, that distance signifies the strength of magnet. This process was repeated for both the poles of each and every magnet chosen for the experiment.

Using this method, the strength of magnets was found to be within the range of 25 cm. As the diameter of Petri plates was only 10 cm, this magnetic field was enough to create impact on germinating seeds (Belyavskaya N. A. *et al.*, 2004) [2]. The Petri plates were sterilized and cotton was evenly spread in the Petri plates. Further the cotton was moisturized using clean potable water and the seeds were evenly spread on the Petri plates. The closed Petri plates were kept inside large vessels of metallic steel so as to create dark conditions for healthy germination.

Dicot seeds *viz*. ten *Vigna radiata* (L.) R. Wilczek seeds were taken in each Petri plate. Total four Petri plates were used in this set of experiment. In the first set i.e., controlled set in which no magnets were used. In the second set North pole - South pole facing magnets were placed under the Petri plate. In the third set North pole - North pole facing magnets were placed under the Petri plate and in the last set South pole - South pole facing magnets were placed under the Petri plate. First of all, the seeds which were large in size and glossy in appearance were selected. Using weight balance the weight of ten seeds were taken for each set of experiment. They were washed with clean water for 4 to 5 times and finally soaked in water for 5 to 6 hours. Then they were taken out from water and ten seeds were kept in pre-soaked cotton layers in Petri plates. These steps were repeated in all the sets of experiment. All these Petri plates were kept in closed dark place. After every 24 hours length of plumule and radicle was measured using thread and measuring scale. After 4th day Petri plates were kept open in the room where some amount of sunlight was entering. Then on 5th day parameters like weight and length of plumule and radicle of seeds were recorded. This procedure was repeated for all the other three seeds i.e., *Trigonella foenum-graecum* L. seeds, *Sorghum vulgare* L. seeds and *Zea mays* L. seeds.

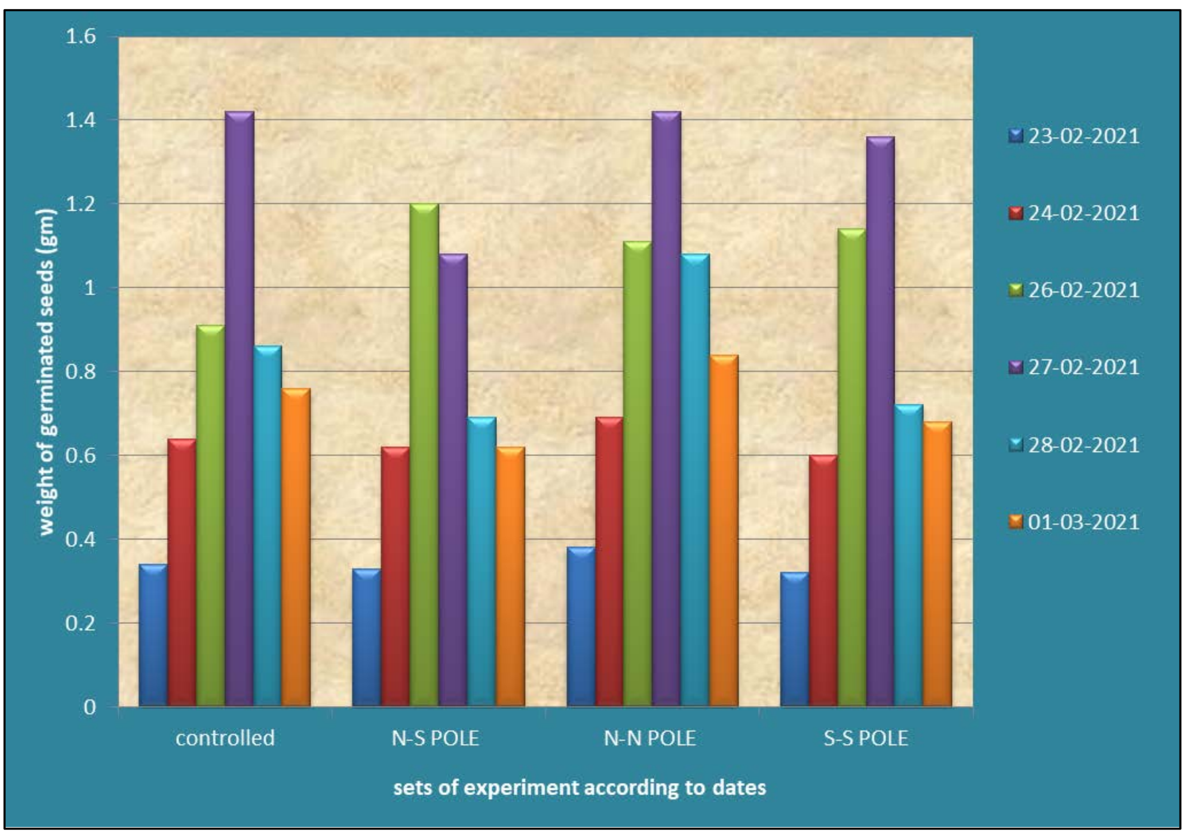
Results

In this study two types of monocot and dicot seeds were selected for carrying out the experiment under the effect of magnetic field. *Vigna radiata* (L.) R. Wilczek and *Trigonella foenum-graecum* L. were selected as an example of dicot seeds, whereas *Sorghum vulgare* L. and *Zea mays* L. were selected from monocots. In each set of experiment uniformity was maintained in number of seeds, types of magnets *viz.* shape, size, strength and position of magnets, type of water, number of days to carry out measurements. Ten seeds were selected in each set of experiment. On day-1 no emergence of plumule or radicle was observed. The data of the study has been noted in tabular and graphical form.

Table 1: Weight of ten seeds of *Vigna radiata* (L.) R. Wilczek in each set of experiment during germination under the effect of Magnetic field.

Sets of Experiment	Dry weight (gm) 23/02/21	Wet Weight (gm) 24/02/21	Wet Weight (gm) 26/02/21	Wet weight (gm) 27/02/21	Wet Weight (gm) 28/02/21	Wet weight (gm) 01/03/21
Controlled	0.34	0.64	0.91	1.42	0.86	0.76
N-S Pole	0.33	0.62	1.20	1.08	0.69	0.62
N-N Pole	0.38	0.69	1.11	1.42	1.08	0.84
S-S Pole	0.32	0.60	1.14	1.36	0.72	0.68

From the above Table, it is observed that there was increase in weight of seeds for first 3 - 4 days. Then there was reduction in seed germination due to an aerobic condition in Petri plates (Lowell W. Woodstock *et al.*, 1965) [7]. Maximum weight was recorded in N-N Pole set. This data has been analyzed in graphical mode which is represented in Graph - 1 as below.



Graph 1: Weight of *Vigna radiata* (L.) R. Wilczek seeds in each set of experiment during germination.

From the above Graph, it is observed that weight of seeds in N-S and S-S Poles was comparatively less than in controlled and N-N Pole set. Weight of seeds in N-N Pole was more compared to the controlled set, whereas weight of seeds in N-S and S-S Poles was more or less same.

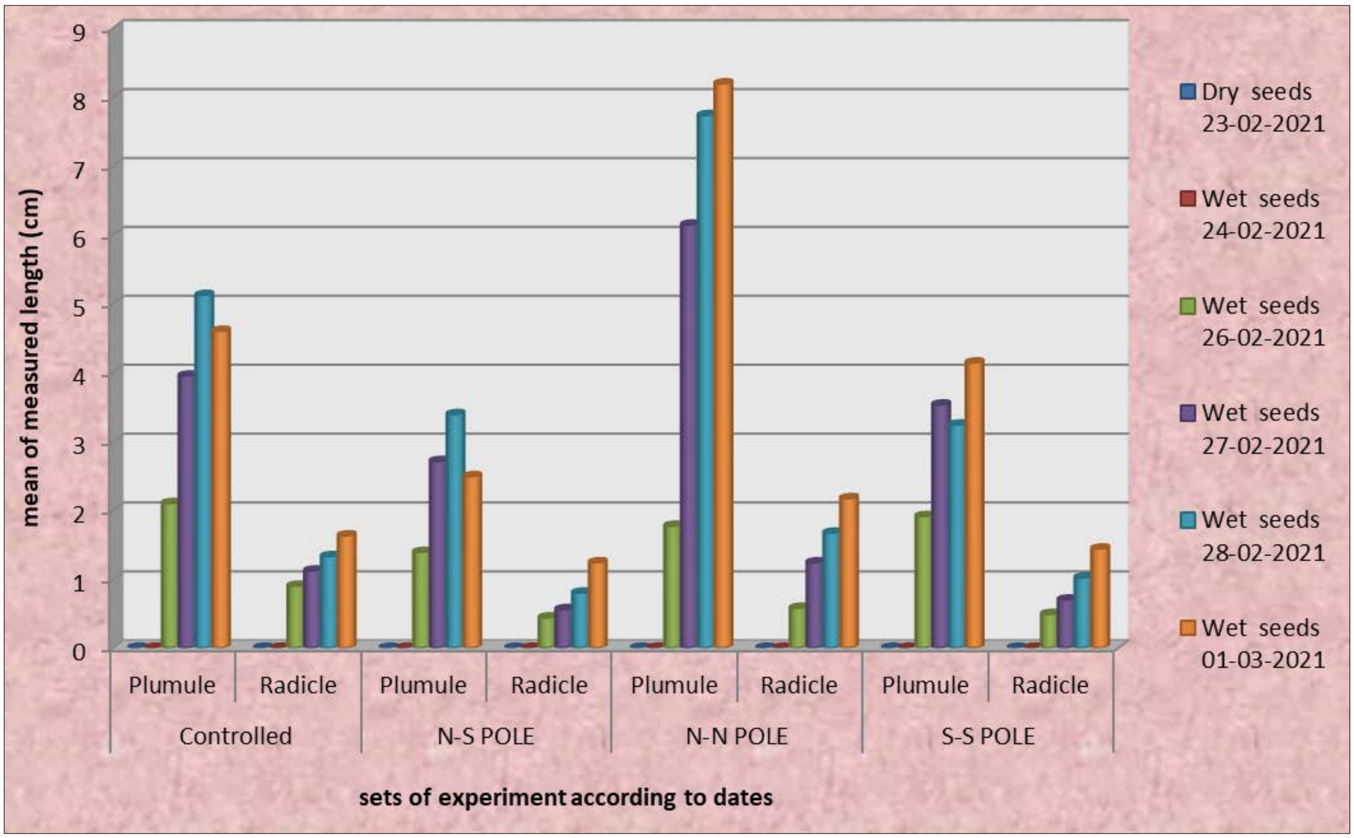
Mean of the measured values for the length of plumule and radicle was taken for the experiment.

Formula for, Mean = $\frac{\sum_{i=1}^{n} X_i}{n}$

Table 2: Day wise value of mean of measured length of plumule and radicle during the germination of *Vigna radiata* (L.) R. Wilczek seeds under the effect of Magnetic field.

Sets of Experiment	*Vigna radiata* (L.) R. Wilczek seeds	Mean of measured Length (cm)					
		Dry seeds 23/02/21	Wet seeds 24/02/21	Wet seeds 26/02/21	Wet seeds 27/02/21	Wet seeds 28/02/21	Wet seeds 01/03/21
Controlled	Plumule	0.0	0.0	2.1	3.95	5.12	4.6
	Radicle	0.0	0.0	0.9	1.12	1.33	1.63
N-S Pole	Plumule	0.0	0.0	1.39	2.71	3.39	2.49
	Radicle	0.0	0.0	0.44	0.56	0.8	1.24
N-N Pole	Plumule	0.0	0.0	1.77	6.14	7.73	8.19
	Radicle	0.0	0.0	0.58	1.24	1.67	2.17
S-S Pole	Plumule	0.0	0.0	1.91	3.53	3.24	4.14
	Radicle	0.0	0.0	0.49	0.7	1.02	1.44

Above Table represents the mean values of length of plumule and radicle of *Vigna radiata* (L.) R. Wilczek seeds during germination stages under different Magnetic effect. In N-N Pole set the length of both plumule and radicle was recorded maximum, whereas in N-S Pole set both the lengths were least.



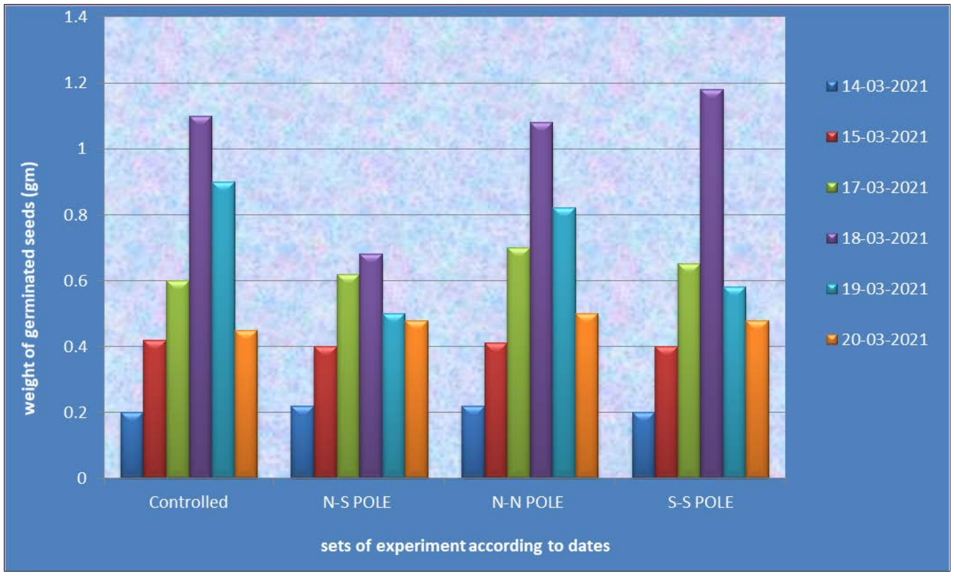
Graph 2: Mean of measured length of plumule and radicle during the germination of *Vigna radiata* (L.) R. Wilczek seeds.

From the above Graph, it is observed that at N-N Pole set increase in length of plumule and radicle was maximum.

Table 3: Weight of ten seeds of *Trigonella foenum-graecum* L. in each set of experiment during germination under the effect of Magnetic field.

Sets of Experiment	Dry weight (gm) 14/03/21	Wet weight (gm) 15/03/21	Wet weight (gm) 17/03/21	Wet Weight (gm) 18/03/21	Wet Weight (gm) 19/03/21	Wet Weight (gm) 20/03/21
Controlled	0.20	0.42	0.60	1.10	0.90	0.45
N-S Pole	0.22	0.40	0.62	0.68	0.50	0.48
N-N Pole	0.22	0.41	0.70	1.08	0.82	0.50
S-S Pole	0.20	0.40	0.65	1.18	0.58	0.48

From the above Table, it is observed that increase in weight of seeds in controlled and N-N Pole set were more or less same. But in N-S Pole set increase in weight of seeds was very less. This data has been analyzed in graphical mode which is represented in Graph- 3 as below.



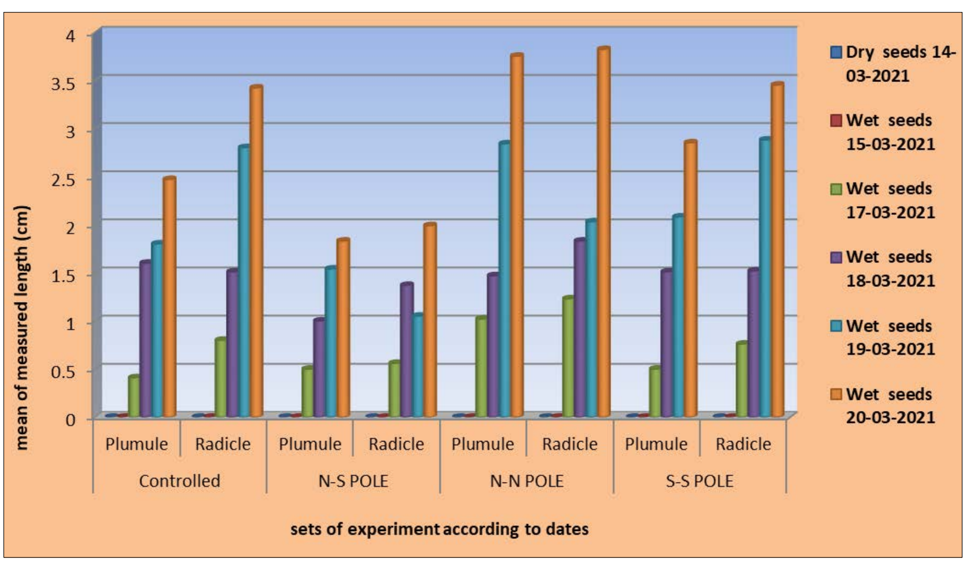
Graph 3: Weight of *Trigonella foenum-graecum* L. seeds in each set of experiment during germination.

From the above Graph, it is observed that increase in weight of seeds at controlled and N-N Pole set was more or less same. After third day the weight of seeds was maximum in N-N and S-S Poles.

Table 4: Day wise value of mean of measured length of plumule and radicle during the germination of *Trigonella foenum-graecum* L. seeds under the effect of Magnetic field.

Sets of Experiment	*Trigonella foenum-graecum* L. seeds	Mean of measured Length (cm)					
		Dry Seeds 14/03/21	Wet seeds 15/03/21	Wet seeds 17/03/21	Wet seeds 18/03/21	Wet seeds 19/03/21	Wet seeds 20/03/21
Controlled	Plumule	0.0	0.0	0.41	1.6	1.8	2.47
	Radicle	0.0	0.0	0.8	1.51	2.8	3.42
N-S Pole	Plumule	0.0	0.0	0.5	1.0	1.54	1.83
	Radicle	0.0	0.0	0.56	1.37	1.05	1.99
N-N Pole	Plumule	0.0	0.0	1.02	1.47	2.84	3.75
	Radicle	0.0	0.0	1.23	1.83	2.03	3.82
S-S Pole	Plumule	0.0	0.0	0.5	1.51	2.08	2.85
	Radicle	0.0	0.0	0.76	1.52	2.88	3.45

According to the above Table, the data suggests that length of plumule and radicle of *Trigonella foenum-graecum* L. seeds was maximum under N-N Pole magnetic field effect during germination.



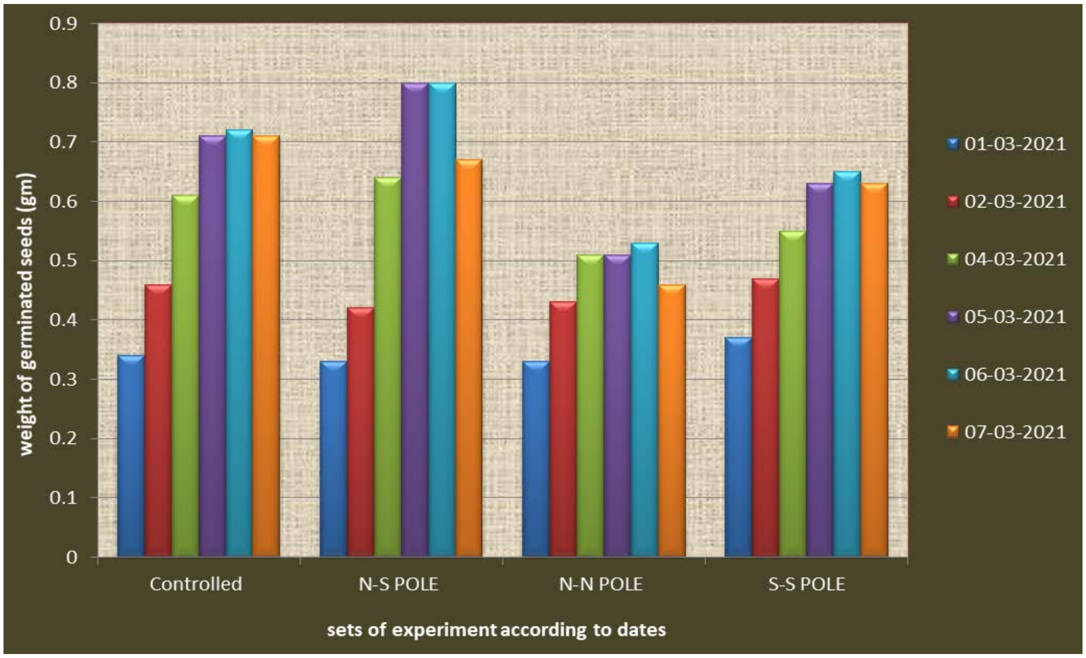
Graph 4: Mean of measured length of plumule and radicle during the germination of *Trigonella foenum-graecum* L. seeds.

From the above Graph, it is observed that increase in length of plumule and radicle was greatly influenced by magnetic field effect. The length of plumule and radicle of *Trigonella foenum-graecum* L. seeds was maximum under N-N Pole magnetic field effect during germination, whereas in N-S Pole set the increase in length of plumule and radicle of *Trigonella foenum-graecum* L. seeds was highly restricted.

Table 5: Weight of ten seeds of *Sorghum vulgare* L. in each set of experiment during germination under the effect of Magnetic field.

Sets of Experiment	Dry weight (gm) 01/03/21	Wet weight (gm) 02/03/21	Wet weight (gm) 04/03/21	Wet Weight (gm) 05/03/21	Wet weight (gm) 06/03/21	Wet Weight (gm) 07/03/21
Controlled	0.34	0.46	0.61	0.71	0.72	0.71
N-S Pole	0.33	0.42	0.64	0.80	0.80	0.67
N-N Pole	0.33	0.43	0.51	0.51	0.53	0.46
S-S Pole	0.37	0.47	0.55	0.63	0.65	0.63

From the above Table, it is seen that increase in weight of seeds in controlled and N-S Pole set was same and increase in weight of seeds at N-N Pole set was very less. This data has been analyzed in graphical mode which is represented in Graph - 5 as below.



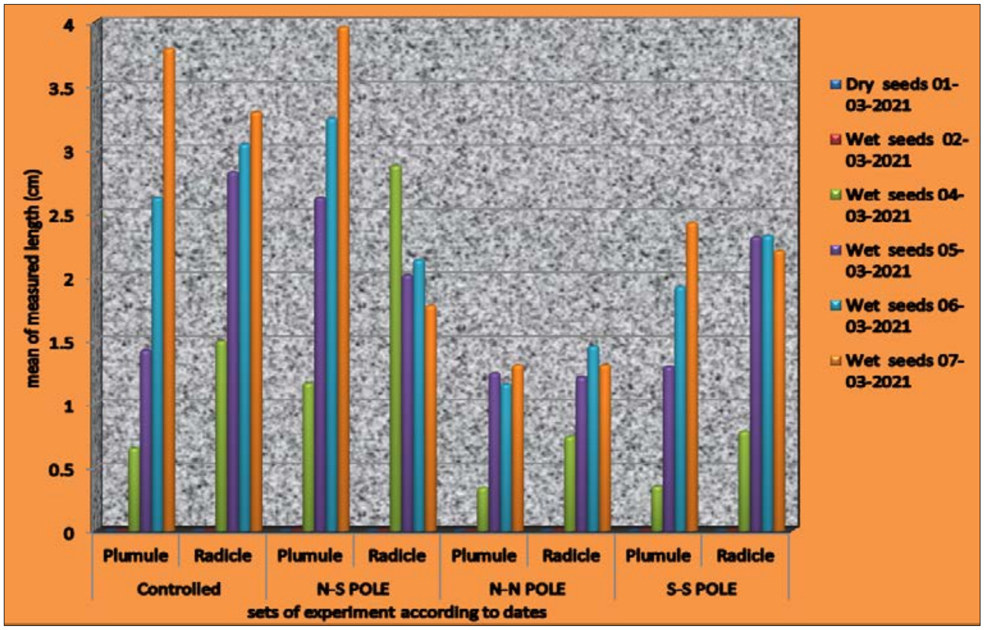
Graph 5: Weight of *Sorghum Vulgare* L. seeds in each set of experiment during germination.

From the above Graph, maximum increase in weight of seeds was noticed in N-S Pole set.

Table 6: Day wise value of mean of measured length of plumule and radicle during the germination of *Sorghum vulgare* L. seeds under the effect of Magnetic field.

Sets of Experiment	*Sorghum vulgare* L. seeds	Mean of measured Length (cm)					
		Dry seeds 01/03/21	Wet seeds 02/03/21	Wet seeds 04/03/21	Wet seeds 05/03/21	Wet seeds 06/03/21	Wet seeds 07/03/21
Controlled	Plumule	0.0	0.0	0.65	1.42	2.62	3.79
	Radicle	0.0	0.0	1.49	2.82	3.04	3.29
N-S Pole	Plumule	0.0	0.0	1.16	2.62	3.24	3.96
	Radicle	0.0	0.0	2.87	2.01	2.13	1.77
N-N Pole	Plumule	0.0	0.0	0.34	1.24	1.15	1.3
	Radicle	0.0	0.0	0.74	1.21	1.45	1.3
S-S Pole	Plumule	0.0	0.0	0.35	1.29	1.92	2.42
	Radicle	0.0	0.0	0.78	2.31	2.32	2.2

The above Table represents that increase in length of plumule and radicle was restricted due to magnetic field in which N-N Pole and S-S Pole were used during germination of *Sorghum vulgare* L. seeds. This shows negative effect of magnetic field on germination.



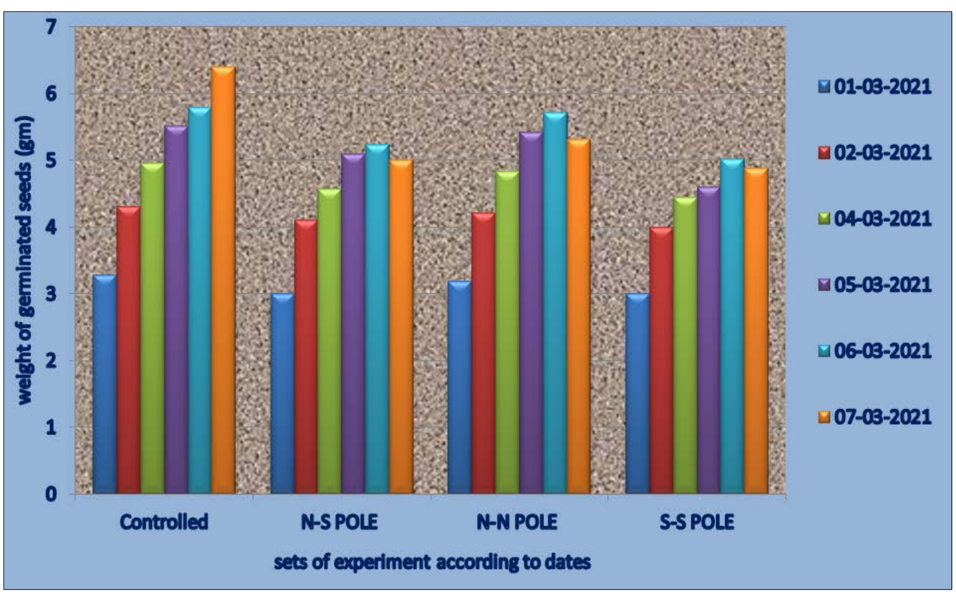
Graph 6: Mean of measured length of plumule and radicle during the germination of *Sorghum vulgare* L. seeds.

Above Graph indicates the negative effect of magnetism on *Sorghum vulgare* L. seeds. N-N Pole set signifies the greatest negative influence on length of plumule and radicle, whereas effects on N-S Pole set were similar to controlled set.

Table 7: Weight of ten seeds of *Zea mays* L. in each set of experiment during germination under the effect of Magnetic field.

Sets of Experiment	Dry weight (gm) 01/03/21	Wet weight (gm) 02/03/21	Wet weight (gm) 04/03/21	Wet weight (gm) 05/03/21	We weight (gm) 06/03/21	We weight (gm) 07/03/21
Controlled	3.28	4.31	4.96	5.51	5.79	6.40
N-S Pole	3.00	4.10	4.57	5.09	5.23	5.00
N-N Pole	3.19	4.22	4.83	5.43	5.71	5.32
S-S Pole	3.00	4.00	4.45	4.60	5.02	4.88

From the above Table, it is seen that increase in weight of seeds at N-S Pole and N-N Pole set was more or less same, whereas at S-S Pole set increase in weight of seeds was very less. This data has been analyzed in graphical mode which is represented in Graph - 7 as below.



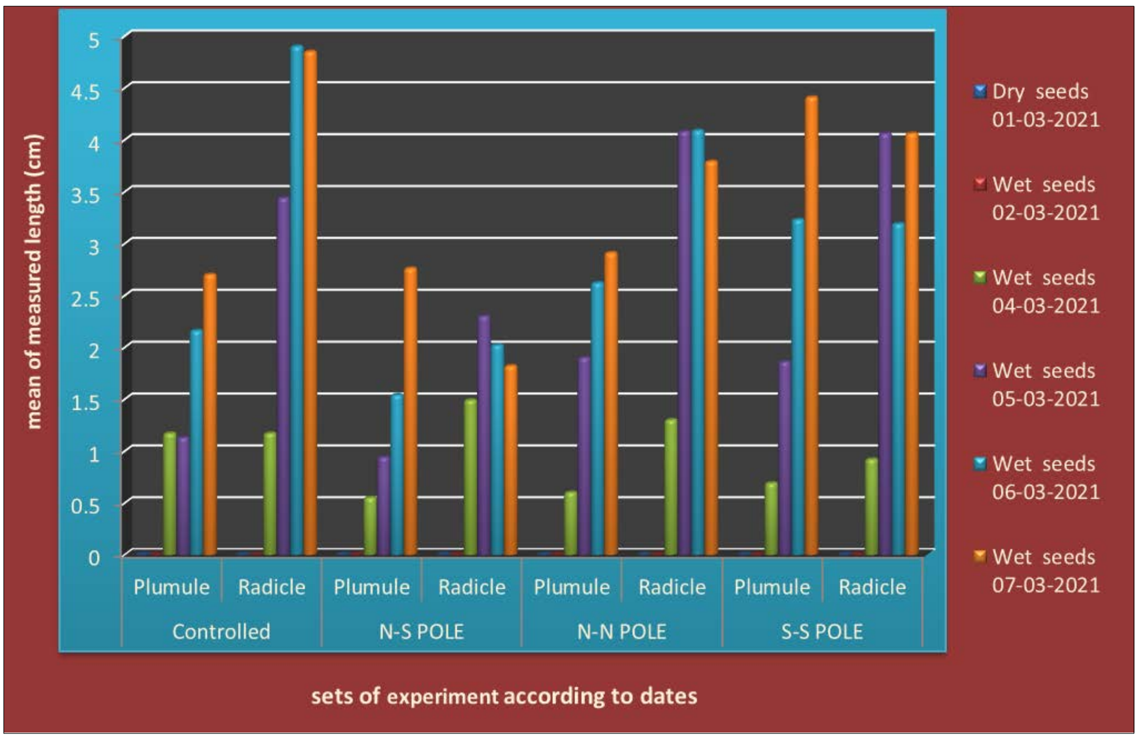
Graph 7: Weight of *Zea mays* L. seeds in each set of experiment during germination.

The above Graph represents the constant growth of weight in N-S and N-N Pole set.

Table 8: Day wise value of mean of measured length of plumule and radicle during the germination of *Zea mays* L. seeds under the effect of Magnetic field.

Sets of Experiment	*Zea mays* L. seeds	Mean of measured Length (cm)					
		Dry Seeds 01/03/21	Wet seeds 02/03/21	Wet seeds 04/03/21	Wet seeds 05/03/21	Wet seeds 06/03/21	Wet seeds 07/03/21
Controlled	Plumule	0.0	0.0	1.17	1.13	2.16	2.7
	Radicle	0.0	0.0	1.17	3.44	4.9	4.85
N-S Pole	Plumule	0.0	0.0	0.55	0.94	1.54	2.76
	Radicle	0.0	0.0	1.49	2.3	2.02	1.82
N-N Pole	Plumule	0.0	0.0	0.6	1.9	2.62	2.91
	Radicle	0.0	0.0	1.3	4.08	4.09	3.79
S-S Pole	Plumule	0.0	0.0	0.69	1.86	3.23	4.41
	Radicle	0.0	0.0	0.92	4.06	3.19	4.06

From the above Table, it is seen that the increase in length of plumule and radicle of *Zea mays* L. seeds was more or less same at controlled and N-N Pole set. The increase in length of plumule was recorded maximum under S-S Pole set.



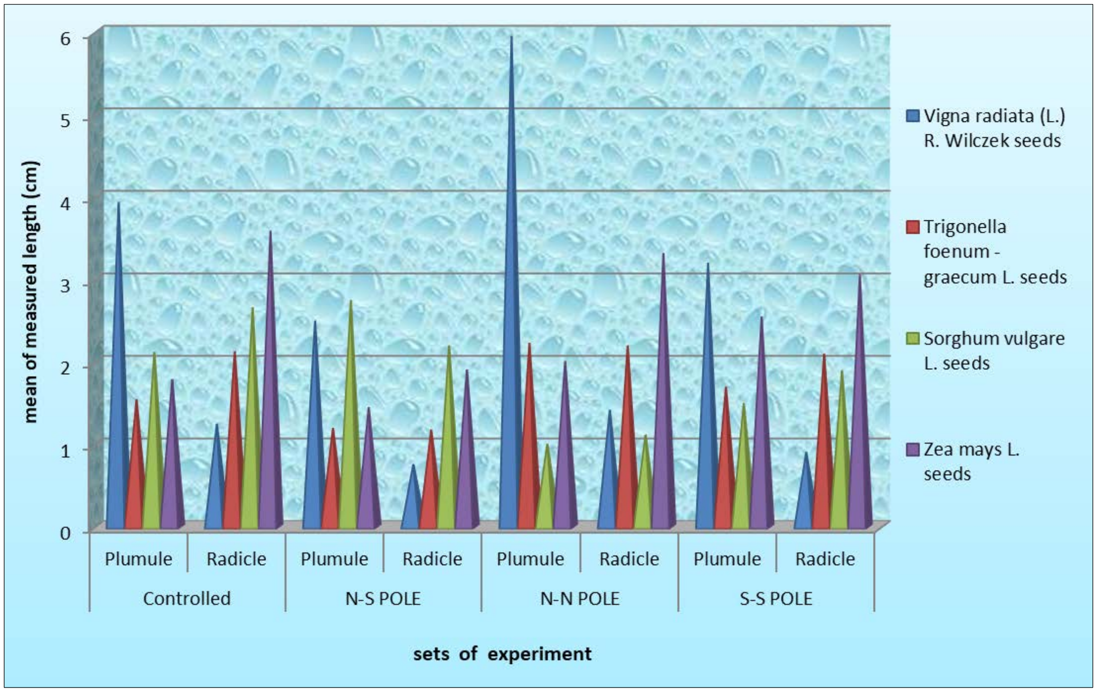
Graph 8: Mean of measured length of plumule and radicle during the germination of *Zea mays* L. seeds.

From the above Graph, it is observed that in N-S Pole set growth of radicle was highly restricted, whereas in S-S Pole set the effect was positive in growth of plumule.

The mean values of the lengths of the plumule and radicle of all the seeds has been represented in Table - 9 and Graph - 9.

Table 9: Mean of measured length of germinated seeds. (cm)

Sets of Experiment	Dicot seeds				Monocot seeds			
	Vigna radiata (L.) R. Wilczek seeds		*Trigonella foenum-graecum* L. seeds		*Sorghum vulgare* L. seeds		*Zea mays* L. seeds	
	Plumule	Radicle	Plumule	Radicle	Plumule	Radicle	Plumule	Radicle
Controlled	3.94	1.25	1.55	2.13	2.12	2.66	1.79	3.59
N-S Pole	2.5	0.76	1.2	1.18	2.75	2.2	1.45	1.91
N-N Pole	5.95	1.42	2.23	2.2	1.01	1.12	2.01	3.32
S-S Pole	3.20	0.91	1.7	2.1	1.5	1.90	2.55	3.06



Graph 9: Mean of measured length of germinated seeds. (cm)

From the above Table and Graph, it is observed that in *Vigna radiata* (L.) R. Wilczek seeds the increase in length of plumule and radicle was recorded maximum at N-N Pole set, whereas in N-S Pole set the increase in length of plumule and radicle was least. Similarly, in *Trigonella foenum-graecum* L. seeds the length of plumule and radicle was recorded maximum under N-N Pole set, whereas in N-S Pole set the increase in length of plumule and radicle was highly restricted. In *Sorghum vulgare* L. seeds the increase in length of plumule and radicle was recorded at N-N Pole set, whereas in N-S Pole set effect was similar to the controlled set. In *Zea mays* L. seeds the increase in length of plumule and radicle was more or less same at controlled and N-N Pole set and the increase in length of plumule was recorded maximum under S-S Pole set. Different seeds on interaction with magnets showed different results.

Discussion

From the above results, it has been confirmed that magnetic field influences seed germination. The results indicate that magnetism had a significant positive effect on plant growth. Plant seeds under the influence of the magnetic field had a higher germination rate compared to the controlled set. In the present study, Bar magnets were used for generating a magnetic field and two monocot seeds i.e., *Sorghum vulgare* L.; *Zea mays* L. and two dicot seeds i.e., *Vigna radiata* (L.) R. Wilczek; *Trigonella foenum-graecum* L. were used for performing the experiment. It was observed that *Zea mays* L. seeds showed better result in terms of gaining weight and *Vigna radiata* (L.) R. Wilczek seeds showed better result in terms of growth.

Similar experiments were performed by Mohammad S. *et al*., 2020 [11], Bhardwaj j. *et al*., 2012 [3] and Vashisth A. *et al*., 2008 [20]. According to Mohammad S. *et al*., 2020 [11], it was observed that on plants like *Vigna radiata* L., *Zea mays* L., *Cicer arietinum* L. and *Glycine max* (Linn.) Merr. magnetic field provided positive result in terms of increase in the roots and shoots, increase in plant biomass, increase in photosynthetic rate and increase in efficiency of PSII. No negative impact of the magnetic field was observed in the experiment. Similarly in the present study the positive impact of the magnetic field was observed in terms of plumule and radicle growth. But in contrast to the experiment performed by Mohammad S. *et al*., 2020 [11], it was observed that some of the seeds faced negative impact of the magnetic field like radish, tomatoes, grapes and watermelon.

In similar experiments conducted by Bhardwaj *et al*., 2012 [3] it was observed that the seeds of cucumber which were exposed to static magnetic field strength from 100 to 250 mT for 1, 2 and 3 h, germination percentage, rate of germination, length of seedling and dry weight increased by 18.5, 49, 34 and 33% respectively in magneto primed seeds compared to unexposed seeds. Here the factors like length of plumule and radicle were not taken in consideration, whereas whole plant germination behavior was recorded. This study also supports the current experiment that positive effects are observed in the plants treated with the magnetic field. Experiment conducted by Vashisth A. *et al*., 2008 [20] supports the current experiment. In the study conducted by Vashisth A. *et al*., 2008 [20], it was observed that the seeds of chickpea(*Cicer arietinum* L.) when exposed in batches to static magnetic fields of strength from 0 to 250 mT showed that magnetic field application enhanced seed performance in terms of laboratory germination, speed of germination, seedling length and seedling dry weight significantly compared to unexposed control.

Despite of all these advantages of the magnetic treatments in the plant characteristics, chemical composition and availability of nutrients in the soil, the mechanism of action of magnetic field treatment in the plants is still unknown until now but several theories had been proposed to explain this action (Phirke *et al.*, 1996, Turker *et al.*, 2007, Hozayn *et al.*, 2015; Maheshwari B. L. *et al.*, 2009) [14, 19, 9]. The electromagnetic fields modify the rate of ion transport across the plasma membrane or otherwise affect the structure of cell membrane lipid protein dynamics, this may cause the alteration in the permeability of the plasma membrane of plant roots (Stange *et al.*, 2002) [17].

Conclusion and Future Perspectives

In this study, influence of magnetic field effects has been observed in the germination process of the monocot and dicot seeds and for different seeds the effects of magnetic field are different. It can be concluded that the process of germinating seeds by giving required quantity of magnetic field at initial stage of germination is eco-friendly rather than using growth promoting synthetic nutrients in field of agriculture, horticulture and forestry. Moreover, this process is cheap rather than other techniques with zero percent side effects if it is confined to use proper magnetic field in right period and position during initial stage of healthy germination.

But, the mechanism by which plants perceive magnetic field and regulate the signal transduction pathway is not fully understood. The aspect of magneto biology still deserves in-depth investigation, as well as the potential genotoxic side effects of magnetic field. Further experiments are needed to understand the molecular mechanisms involved in fastening seed germination, higher seedling vigor and enhancing plant growth using magnetic field.

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