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A study of wheat phenology and the factors affecting the wheat yield

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Abstract

The paper focusses on the study of Wheat Phenology and the factors affecting the Wheat yield. A study is being conducted to develop a model for prediction of wheat yield in Patiala district of Punjab, India. The prediction model has been developed based on different meteorological and agronomic factors that affect the wheat plant and hence the wheat yield. Various factors have different effects at different stages of plant growth and the yield is affected accordingly. For this, it is pertinent to understand the phenology of the wheat crop. Phenology is the study of different stages of development of a plant. The current study aims at providing an insight to the phenology of the wheat crop. The paper explains the materials used and methods adopted for the research. Wheat crop is grown in a 250 square yard plot. The agricultural practices as prescribed by Punjab Agriculture University, Ludhiana in Package of Practices for Crops of Punjab Rabi 2015-16 are followed. Different stages of the plant growth are noted and photographs are taken (or sketches are drawn) to depict the various stages. A literature survey is done to study the various factors that affect the wheat yield at different stages. Nine stages of wheat plant growth are studied which are divided into four phenological phases according to the effect of different factors. A large number of factors affect the wheat yield and they can be broadly categorised into three types – Meteorological factors such as temperature and rainfall, Agronomic factors such as soil type, seed variety, etc., and weather disturbances such as hail storm.

Keywords: Wheat phenology, tillering, jointing, booting, factors affecting wheat yield, agronomic factors affecting wheat yield

1. Introduction

Human being since day one has depended largely on food grains for its survival, either as a nomadic, a hunter-gatherer lifestyle or as a settled farmer. Settled farming can be seen as a pivotal turn in human history. The interplay between human beings and farming is multifaceted and intricate due to various human and natural factors. one such factor is the alarming increase in population, which has exacerbated pressure on agricultural land. This calls for sustainable agricultural practices and optimal land-use planning to guarantee food security for future generations. On the one hand the increased population pressure has increased the demand of food and residential area, on the other hand, it also needs industrial and development projects which shrinks the portion of agricultural land. Hence, the decreased size of agricultural land makes it pertinent to use land under optimum conditions for crop production.

Since, Wheat is the most widely consumed food grain across the world, the current paper focusses on the study of the phenology of the wheat grain and the factors affecting its yield. The research is centered on the study of the Punjab state being the major provider of the wheat grain in India.

As per the data recorded, in 2013-14 in Punjab, Wheat was grown on 35.12 lakh hectares with a production of 176.2 lakh tones and yield of 50.17 quintals per hectare (i.e. 20.07 quintals per acre) [1]. It is a well-known fact that the wheat crop needs a cool temperature during the early stage of its growth and a warm temperature during ripening. Thus, the sowing of wheat, in Punjab, starts in October and continues till as late as 1st week of December and most of wheat is harvested in April-May [2].

Since an effective and accurate prediction of the wheat yield is essential to control the forward marketing and to maintain the food security, many scientific researches have been conducted in diverse fields. However, the optimal outcomes can be attained through interdisciplinary research in the field of agriculture engineering and computer engineering. A study has been conducted to develop a model for prediction of wheat yield in Patiala district of Punjab, India [3]. As part of this study, a framework has already been proposed to develop a model for crop yield prediction [4].

To develop the wheat yield prediction model, it is pertinent to understand the morphology and the phenology of the wheat plant. A comprehensive study on the morphology of wheat in the context of developing a predictive model for wheat yield has already been conducted [5]. The paper focusses on the study of Wheat Phenology i.e., the study of different stages of development of a wheat plant and the factors affecting the Wheat yield. The study in the current paper is the pre-requisite of the study conducted to develop this model [3]. For a thorough understanding, the researcher has grown wheat crop in a 250 square yard plot and followed the agricultural practices as prescribed by Punjab Agriculture University, Ludhiana in Package of Practices for Crops of Punjab Rabi 2015-16 [1]. The different phenological stages of the wheat plant are noted.

2. Phenological Stages of Wheat

Based on the two most used methods of identification i.e. Feekes scale and Zadoks scale, the following major stages of growth of wheat plant have been identified:

2.1 Germination

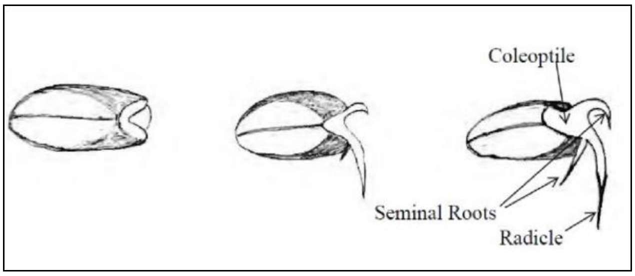

Fig 1: Germination

Germination is the process by which a plant grows from a seed. The minimum water content required in the grain for wheat germination is 35 to 45 percent by weight [6]. Though germination may occur between 4° and 37°C, the optimal temperature required is from 12° to 25°C [7]. During germination, the seedling (seminal) roots, including the primary root (radicle), emerge from the seed along with the coleoptile (leaf like structure), which encloses the primary leaves and protects the first true leaf during emergence from the soil [8]. The coleoptile extends to the soil's surface. It ceases to grow when the first true leaf emerges from its tip. The seedling emergence may occur within a week under favourable conditions. The seedling depends on energy and nutrients stored in the seed until the first leaf becomes functional.

2.2 Seedling

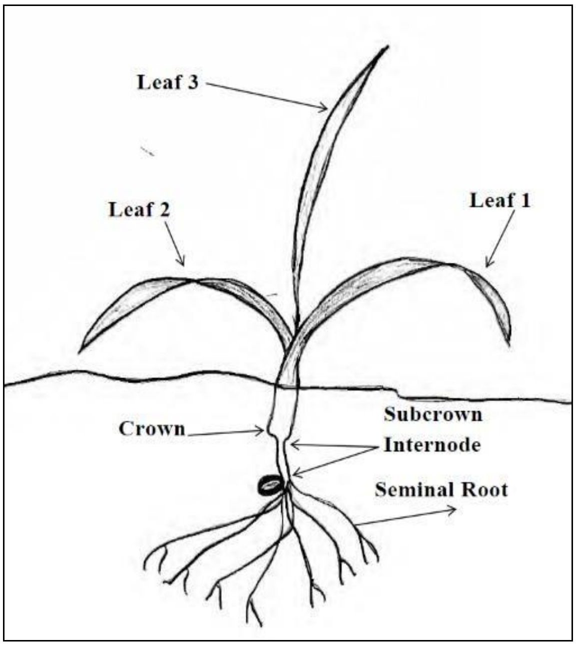

Fig 2: Seedling

The seedling stage begins with the appearance of the first leaf and ends with the emergence of the first tiller. A maximum of six seminal roots and three leaves support the plant at this stage. The crown of the plant usually becomes noticeably distinct after the third leaf has emerged. The crown is a region of lower nodes whose internodes do not elongate. It is located between the seed and the soil surface. The crown tends to develop at the same level, about onehalf to one inch below the soil surface, regardless of planting depth. Leaves, tillers and roots including the main root system develop from the crown nodes. The growing point is located at the crown until it is elevated above the soil surface at the stem elongation stage [8].

2.3 Tillering

Tillers are the secondary shoots that develop from nodal buds on the older wheat shoots. Each tiller that is produced represents the potential of wheat plant to develop an additional stem which is complete with its own leaves, roots and head [9]. Tillers depend on the main stem for nutrition during its development. The number of tillers on a given plant varies according to the seeding rate, soil moisture and fertility, temperature and the seed variety. Normally, the winter wheat generates 3 to 6 tillers. Besides emergence, tillers have all the growth stages of the main stem. Root and shoot development of the plant is synchronized so that the number of crown roots is related to the number of leaves produced. However, usually root production by a tiller is delayed until the emergence of its third leaf. Consequently, tillers that do not produce at least three leaves, are not competitive and usually die off once the stem elongation stage starts.

Fig 3: Tillering

2.4 Stem Elongation/ Jointing

During the tillering stage, the nodes from which leaves develop are telescoped at the crown. When the jointing starts, the internode region elongates which moves the nodes and the growing point upward from the crown to produce a long stiff stem that will carry the head. During stem elongation, the stem nodes and internodes emerge above the soil surface and become visible. Nodes are areas of active plant cell division from which leaves, tillers and adventitious (crown) roots originate [8].

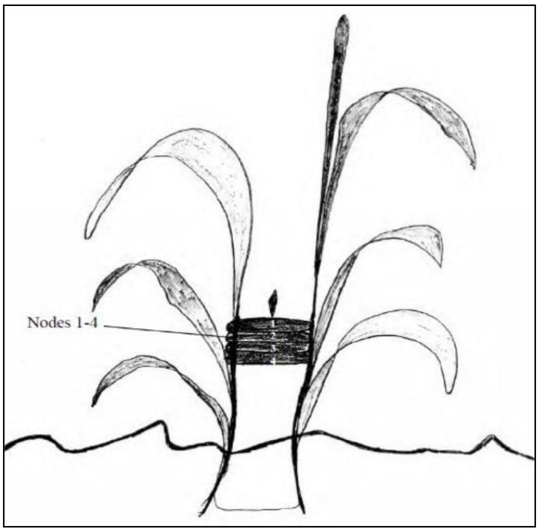

Fig 4: Pre-jointing

As the stem elongates, leaves originate and emerge from the stem nodes above the soil's surface. As the stem elongation occurs, the nodes swell, and they look and feel like bumps on the stem. An internode is the region between two successive nodes. During stem elongation, the internodes above the soil surface elongate to form the stem. The elongated internode is hollow between the nodes. During the stem elongation, the lower four nodes remain in the crown. The fifth node may remain in the crown or be elevated slightly. Nodes six, seven and possible additional nodes are elevated above the soil.

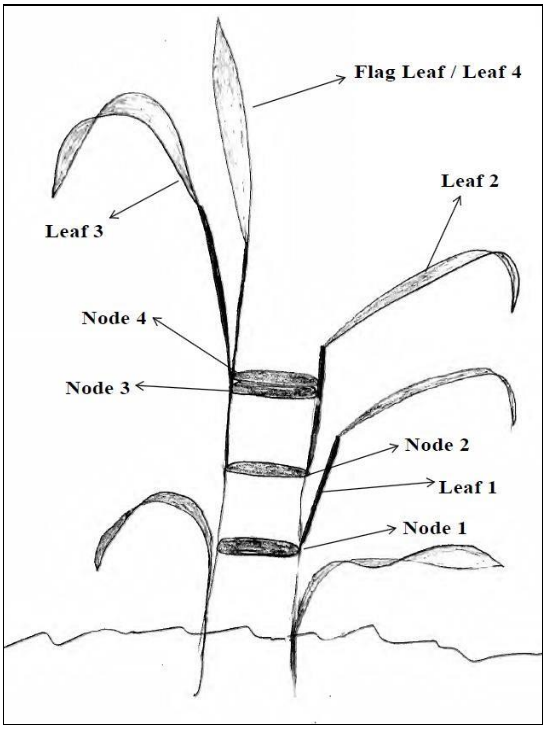

Fig 5: Flag Leaf Emergence indicating the end of Jointing

When the stem elongation is complete, most of the wheat varieties usually have three nodes visible above the soil surface, but occasionally a fourth node can be found. The stem elongation stage is complete when the last leaf, commonly called the flag leaf emerges from the whorl. On most of the wheat varieties, the flag leaf begins to emerge just after the emergence of a third node above the ground. The flag leaf stage is significant because the flag leaf produces a large proportion of the photosynthate (carbohydrates) for filling grain. It must be protected from diseases, insects, and defoliation in order for the plant to develop its full yield potential.

2.5 Booting

The boot stage occurs shortly after the emergence of flag leaf and indicates that the head is about to emerge. The boot stage initiates when the head begins to form inside the sheath of the flag leaf [10]. During the booting stage, the head begins to swell within the base of the flag leaf.

Fig 6: Booting

2.6 Heading

During this stage, the spike emerges from the flag leaf. The boot opens and the first awns are visible. The head has reached its full length when the tips of the awns emerge from the tip of the flag leaf sheath. The terminal spikelet of the head becomes visible and emergence continues until the head is completely emerged. At this stage, the yellow anthers are still within the florets [11].

Fig 7: Heading

2.7 Flowering or Anthesis

The flowering or Anthesis stage lasts from the beginning to the end of the flowering period. Pollination and fertilization occur during this period. The lodicules of each floret swell up, thus forcing apart the lemma and palea. The filaments of the stamens elongate and may eventually attain a length of about 10 mm. As the filament grows, the anther dehisces, each chamber developing a longitudinal split, starting at the tip of the anther, through which pollen is released. The stigma lobes which are pressed together before Anthesis, move apart, and the receptive branches are spread widely giving a large area for pollen interception [12].

Fig 8: Anthesis

Anthesis is a short phase lasting only a few minutes in an individual floret, a couple of hours in a head and about three to four days across a dry-land crop (White & Edwards, 2008). The wheat spike contains only one spikelet per rachis node and each spikelet has three to six potentially fertile florets [13]. The florets are self-pollinated (that is, fertilized by their own pollen) in 96 percent of the cases [14]. Anthesis begins in the central part of the spike and continues towards the basal and apical parts during a 3 to 5 day period [12]. After fertilization, the empty anthers appear on the outside of the head [11]. Figure 8 shows how the empty anthers dangle from the spikelets when Anthesis is over.

2.8 Grain Development

Grain Development begins after flowering and continues till physiological maturity. Within a few hours of pollination, the embryo (rudimentary, undeveloped plant in a seed) and endosperm (area of starch and protein storage in the seed) begin to form; and photosynthates (products of photosynthesis) are transported to the developing grain from leaves (primarily the flag leaf). In addition, starches, proteins, and other compounds previously produced and stored in leaves, stems, and roots are also transferred to the developing grain [8]. The grain has three growth stages:

1. **Grain Enlargement:** The grain begins growing immediately after flowering and reaches its maximum size (not weight) within about 2 weeks [15]. In the first 4 days after flowering, the seed increases rapidly in size as the cells that enclose the embryo sac divide and expand [11]. The Kernel size is established during this stage, though there is little increase in kernel weight. A clear fluid oozes out, when the kernel is pressed. This stage is called the watery ripe stage. The developing grain is still green in colour.
2. **Grain Fill:** During this stage, carbohydrates and proteins are transported into the grain from other parts of the plant and the grain starts to gain weight at a constant rate. The kernel enters the milk stage. During this stage, there is a noticeable increase in solids of the liquid endosperm as nutrients in the plant are redistributed to the developing kernels [8]. When the kernel is squeezed, a milk-like fluid oozes out. After this, the water concentration in the kernel starts decreasing and the material in the grain gains soft dough-like consistency. The kernel is said to move into soft dough state. By the end of this stage, the green color of the kernel begins to fade. Then the kernel enters hard dough stage and it becomes hard and firm. It is difficult to crush it between fingers though it can still be dented with finger nails.
3. **Physiological Maturity:** The kernel is said to have attained physiological maturity when the vascular system supplying the grain with water and nutrients is blocked by a waxy substance. At this stage, the grain stops growing and turns brown [11]. When the grain reaches this stage, the tillers die off. At this stage, kernel moisture content is between 30 and 40 percent [8].

2.9 Ripening Stage

During this stage, the plant turns to straw color and the kernel becomes very hard. It is difficult to divide the kernel with a thumbnail. It cannot be crushed between fingernails and can no longer be dented by a thumbnail. The moisture content of the grain decreases from 3035 percent to 12-13 percent [15]. Now the wheat is ready to be harvested.

Fig 9: Ripening

From the above phenological understanding of the wheat plant, it is derived that the growth of wheat plant can be divided into four phenological phases:

1. The Pre-establishment phase which consists of Germination stage.
2. The Vegetative phase which consists of the Seedling, the Tillering and the Jointing stages.
3. The Reproductive phase which consists of the Booting, the Heading and the Anthesis stage.
4. The Grain Development phase which consists of the Grain Development and the Ripening stages.

This pre-hand knowledge of the morphology and phenology of the wheat plant, is pertinent to derive an understanding of the factors that affect its yield. The identification of yield-affecting factors is essential to build and design a model for the prediction of wheat yield.

3. Factors Affecting the Wheat Yield

To determine the factors that affect wheat yield, a detailed literature survey is carried out. The present section presents the literature review, on the basis of which the researchers have shortlisted the factors which significantly affect the wheat yield.

(Landau, *et al*., 2000) developed a model of effects of weather on wheat yield in UK from a database of nearly 2000 field observations. The observations reflected negative effects of rainfall during the estimated early-productive phase, the Anthesis phase and the grain filling phase. Yield is less if there is rainfall in the week before the harvest. The model predicts that longer the duration of grain filling phase, the higher is the yield. The yield is reduced if the sowing is delayed. Late harvesting may have a negative effect on yield because of the risk of shedding and risk of harvesting under adverse conditions increase [16].

(Jalota, *et al*., 2010) studied the effect of sowing date, soil texture and irrigation on grain yield in the rain fed maize-wheat cropping system in Punjab. They found that wheat sown around November 5 gives maximum yield while there is reduction of 20% to 30% with the delay in sowing from November 1 to16 and from November 1 to 30, respectively. The simulated yields are higher in silt loam than sandy loam and loamy sand soil. The yield is higher when irrigation is applied at crown root initiation [17].

(Singh, Singh, Kang, & Aggarwal, 2011) discuss various management practices to mitigate the impact of high temperature on late sown wheat, and to increase the wheat yield. They found that planting of wheat with zero tillage, bed planting and conventional tillage with mulching produce higher grain yield than conventional tillage. The use of organic mulches provides better soil water status and improves plant canopy in terms of biomass, root growth, leaf area index and grain yield. The foliar spray of KNO3 (0.5%) at 50 percent flowering stage, 1.0 per cent KNO3 during Anthesis stage, 2.5 mm of arginine, spray of zinc, extra irrigation water during grain filling stage, use of potassium fertilizers with municipal waste water increases the productivity of wheat under high temperature conditions [18].

(Leona & Jalao, 2013) created a framework for crop yield prediction. They concluded that climate related variables such as rainfall and temperature are not the main determinants of corn yield rather the yield is affected by the planting practices such as pest management, weed management, land preparation, seed rate, cropping pattern and in particular, the application of right amount of fertilizer [19].

(Gill, Kaur, & Babuta, 2013) studied the effect of the four irrigation levels on two wheat varieties – PBW 343 and PBW 621 under three sowing dates – November 15, November 25 and December 5 in the central (Ludhiana) and south western zone (Bathinda) of Punjab. They concluded that the timely sown wheat i.e. on November 15 gives the best yield. The irrigation treatment with five levels of irrigation (irrigation at Crown Root Initiation, Tillering, Jointing, Booting and Milking) exhibits maximum heat use efficiency in both Ludhiana and Bathinda for both grain and biomass. Among the varieties, PBW 621 exhibits significantly higher heat use efficiency as compared to PBW 343 for grain and biomass for both Ludhiana and Bathinda [2].

(Zheng, *et al*., 2014) discuss the effects of five tillage practice treatments – strip rotary tillage, strip rotary tillage after subsoiling, rotary tillage, rotary tillage after subsoiling, and plowing tillage – on water use efficiency and grain yield for wheat in North China Plain. They found that the soils become compact with high bulk density after many years of traditional tillages (that is rotary or plowing tillage), adversely affecting the root growth, uptake of water and nutrients, and crop yield. Thus, the 1-year subsoiling tillage and then 2-years of strip rotary planting operation can be an efficient measure to increase both the wheat yield and the water use efficiency [20].

(Krupnik, *et al*., 2015) observed that nitrogen rate is the most important factor affecting the wheat yield. They found that zero-Nitrogen treatment has the lowest yield while the highest yields are found at 100 kg N Ha^{-1} and 133 kg N Ha^{-1}. They found that the ideal sowing date for that region is mid-December and yield has negative correlation with sowing days before or after December 15, though generally the early sown wheat gives higher yield than the late sown wheat. The number of irrigations also affects the yield, though the late sowers used more number of irrigations. The median range with farmers who weeded the field at least once is much higher than those who didn't. They observe that the other significant factors affecting the yield are cultivar, electric conductivity of soil, plant population and the depth of ground water [21].

(Gouache, Bouchon, Jouanneau, & Bris, 2015) analysed agrometeorological factors that affect the wheat yield in France. They recognized heat stress during grain filling as a key factor which influences wheat yield. Crop water balance during stem extension is also seen as an important cause of yield variation. The yield is also affected by the balance between incoming radiation and temperature during stem extension, excess rain during grain filling and water logging [22].

(Ahmad & Kumar, 2015) found the effect of irrigation scheduling on growth and yield of wheat. They concluded that irrigating the wheat crop at all the critical stages of crown root initiation, tillering, jointing, flowering, milking and dough produces higher grain yield and net returns. Under scarcity of water, four irrigation schedules at crown root initiation, tillering, flowering and milking also give on par-yields [23].

(Imran, Ayaz, & Noureen, 2015) conducted a study at RAMC, Faislabad, Pakistan to investigate the impact of weather conditions on different phenological phases and hence on final wheat yield. They found rainfall as one of the most important factors that affect annual wheat production. Rainfall before sowing, and rainfall from shooting to grain formation stage are greatly beneficial. Similarly, rainfalls after sowing and before germination and at the time of full maturity negatively affect crop growth and ultimately reduce the yield. They also identified air temperature as important climatic variable that affects the plant life. The most optimum temperature for wheat plant is 25^0C. The growth of wheat plant stops when the temperature is below

5^0C and above 32^0C. Soil moisture is pivotal in the growth of the plant and eventually the yield. Soil moisture is proportional to rainfall and intake of irrigational water. It is inversely proportional to evapotranspiration from the plant and its surroundings. Highest amount of soil moisture is required during flowering stage followed by grain formation and vegetative stages. According to (Imran *et al*., 2015), the most important parameter that effects the plant growth is soil temperature. It effects the germination of seeds, the functional activity of the root system, the incidence of plant diseases, and the rate of plant growth. During the vegetative stage, the optimal soil temperature for the growth of wheat plant is below 20^0C. A gentle wind is necessary for the movement of carbon dioxide to plant canopy so that a normal rate of photosynthesis continues in day time. Strong wind accompanied by a severe weather event like heavy shower or hail storm, affects the crop, especially during the grain filling stage [24].

(Kumar, Singh, Kalhapure, & Pandey, 2015) studied the effect of tillage, time of first irrigation and application of Nitrogen on wheat plant growth and yield. They found that growing wheat with residue retention under zero tillage, applying first irrigation at 20 days after sowing and application of 150 kg/Ha nitrogen give the best crop yield [25].

From the above literature survey, it is inferred that most of the researchers find irrigation, date of sowing and rainfall as the most important factors. Apart from these, soil texture, soil moisture and soil temperature, climatic conditions such as temperature, hail storm and wind, and management practices such as tillage, use of fertilizers and pesticides, mulching, weeding, seed rate, cropping pattern and land preparation play vital role in achieving a good yield.

Krupnik *et al*., Jalota *et al*., Ahmad & Kumar, Gill *et al*., Singh et.al and Kumar *et al*. lay emphasis on the number of irrigations as an important factor. Besides irrigation, Krupnik *et al*., Jalota *et al*., and Gill *et al*. find sowing date as another important factor; Landau *et al*. also find substantial impact of sowing date, harvesting date and rainfall on the yield of wheat. Rainfall is also considered an effective factor in the study of Imran *et al*. and Rossana *et al*. Zheng *et al*., Singh *et al*. and Kumar *et al*. examines the impact of tillage practices on the yield; Kumar *et al*. finds that besides tillage practices, other management practices such as observing temperature and managing the date of sowing accordingly, the use of organic mulches, foliar sprays and use of fertilizers increases the productivity of wheat.

Besides these, most of the researchers find that climatic conditions have a great impact on the wheat yield. From the above survey, the following factors have been shortlisted that significantly affect the wheat yield:

Table 1: Factors Affecting Wheat Yield

S. No	Meteorological Factors	Agronomic Factors	Weather Disturbance
1.	Air Temperature	Date of Sowing	Hail
2.	Soil Temperature	Soil Type	Excessive Rain
3.	Rainfall	Soil Texture	Rain and Storm
4.	Precipitation	Electrical Conductivity of soil	
5.	Relative Humidity	C%, N%, pH	
6.	Reference Crop Evaporation (Transpiration)	Seed Variety	
7.	Soil Moisture	Seed Rate	
8.		Fertilizer Type (Organic/Inorganic/Combined)	
9.		N-Fertilization Rate	
10.		Weed Management	
11.		Pest Management	
12.		Land Preparation	
13.		Cropping Pattern	
14.		Plant Spacing	
15.		Planting Depth	
16.		Irrigation Schedule	

4. Conclusion

Thus, it can be summed up that the stages of wheat plant growth can be divided into four phenological phases according to the effect of various factors. These factors can be broadly categorised into three types – Meteorological factors such as temperature and rainfall, Agronomic factors such as soil type, seed variety, etc., and weather disturbances such as hail storm. Wheat being the most consumed crop, plays an essential role in the economy as well as the social security of the country; an effective and accurate prediction of the wheat yield is pivotal to control the forward marketing and maintain the food security. Hence, Prediction Models with higher accuracy and low error results, need to be developed; the current study is the part of one such research. It is found that the thorough understanding of the morphology and the phenology of the wheat plant, and the accurate selection of the factors significantly affecting the wheat yield, is the utmost important initial step in the development of the prediction model.

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