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Germinability of Film-Coated Snap Bean Seed as Affected by Oxygen Diffusion Rate under Different Soil Moisture Contents

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ABSTRACT : The film coated snap bean (*Phaseolus vulgaris*) seeds with five different coating materials treated with 3% increase in seed weight were planted at sandy loam soil controlled moisture content of 18, 19, 20 and 21%. The oxygen diffusion rate (ODR) was calculated from the different moisture content soil. The number of normal seedlings, seedling vigor, and seedling capability in field (seed vigor x dry matter weight) were observed at 9 days after planting and compared to the changes of ODR. The germination rate and ODR were sharply decreased simultaneously in the seeds planted at 21% soil moisture content. Seedling emergence did not occur at all as the soil moisture content increased above 22%. Hence this value should be considered as the threshold of soil moisture content for seedling emergence. An ODR value under 20% did not influence the percent emergence significantly. The certain difference observing in the emergence at the same ODR was not related clearly to the condition of soil. So it can be assumed that the limit of soil moisture content for the emergence of snap bean was approximately 20%. The value of 18% soil moisture content may be considered as the optimum for snap bean emergence. There was close relationship between the mean value of ODR in different soil moisture contents and the emergence. The germination rates of the seeds coated with the different materials were quite different when the seeds were planted at 21% soil moisture. Dry weight of the seedlings from film coated seeds was decreased slightly, but the germination rates were not much different from the non-treated control under relatively higher soil moisture content (21%). Major factor lowering emergence rate was oxygen stress while film coating act as a minor constraint for snap bean sown in excess soil moisture condition.

***Keywords*:** oxygen diffusion rate (ODR), soil moisture content, snap bean, seedling emergence, normal seedlings, seedling vigor, film coating

Germination has been considered largely in relation to seed viability under conditions of favorable moisture and oxygen supply. Because seeds often subjected to adverse conditions such as hypoxia/anoxia, excess or shortage of moisture, and unfavorable temperature, the response of seed to those unfavorable condition should be examined to improve the germination and seedling growth. Among the limiting factors for seed germination, oxygen deficiency is related to the condition of gaseous phase in soil in which seeds are planted.

It is generally established and accepted that a germinating seed requires moisture, a suitable temperature, and an adequate supply of oxygen. The requirement for those factors are various depending on crop species. At constant soil moisture content, seedling emergence of wheat, grain sorghum, and soybean decreased with increasing crust strength of and soils studied (Hanks & Thorp, 1956). Hanks & Thorp (1957) has indicated that the bulk density was related indirectly to seedling emergence of wheat in that any change in bulk density changed other factors such as oxygen diffusion rate and soil crust strength.

Seeds of most vegetable crops germinated more rapidly at high soil moisture content up to 18% than at low content below 9% (Doneen & MacGillivray, 1943).

The oxygen diffusion rate (ODR) has been proposed as the most reliable index of soil aeration, comprising the effects of all soil factors, including those of the water films surrounding roots, and of the structure of soil, on the availability of soil oxygen to plant roots (Lemon & Erickson, 1952). It has been proved that the oxygen conditions in the soil play a fundamental role in crop growth. There are, however, few publications concerning the influence of these conditions on the emergence of crops. For the evaluation of the soil aeration status, several indices are applied, of which the most often used and the most important are: oxygen content in soil air, ODR, and the redox potential (Eh) (Glinski & Stepniewski, 1985). ODR is the diffusion rate expressed as a function of both liquid diffusion path length and oxygen concentration in the soil atmosphere. The emergence of crops is preceded by a considerable development of the root system. For this reason the effects of soil oxygen on seedling emergence are better described in terms of ODR than in terms of the oxygen concentration in the soil air. The ODR method, however, has many disadvantages, of which the

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greatest is the lack of a polarographic plateau in water unsaturated soils and the dependence of measurements on the electrical resistance of the soil (McIntyre, 1970). In addition, the application of ODR value has some practical limit. For example, the limiting value of ODR for the emergence of beet was 30 ug $m^{-2}sec^{-1}$ and the critical value was 13 ug $m^{-2}sec^{-1}$. Nevertheless, significant correlations were found between the ODR value and the emergence of seed (Glinski & Labuda, 1979; Glinski *et al.*, 1979; Glinski & Stepniewski, 1981; Glinski *et al.*, 1981; Hanks & Thorp, 1956; Letey *et al.*, 1962; Wengel, 1966). As above mentioned reports, oxygen status is correlated with soil property which directly affects to the soil moisture condition. Glinski *et al.* (1981) have investigated the effect of oxygenation of three soils (sandy, loamy, and loess) at differentiated moisture (10, 50, and 100 hPa) on the emergence of sugar beet.

The determined threshold values of the indices of the ODR are as follows: the optimum value of ODR is 37, the limiting value is 22, and the toxic value is 15 $g \times 10^{-8} cm^{-2} min^{-1}$ respectively.

The investigations of Kaack & Kristensen (1967) of the germination and emergence of wheat indicated, however, a low applicability of ODR in examining the oxygen conditions for emergence, as compared with the oxygen concentration in soil air. Hughes *et al.* (1966), too, did not find any effect of ODR on the germination of two grass seeds.

On the basis of ODR_l and $ODR_{0.5}$ values the crops investigated can be put in the following order with regard to their increased susceptibility to oxygen difficiency at the emergence time: barley oats bean wheat flax maize tomato sugar beet rye (Glinski *et al.*, 1984). Also Glinski *et al.* (1984) introduced the Eh usefulness was less than ODR as an index of soil oxygen availability at seed emergence.

Experiments with the emergence of winter wheat (Glinski *et al.*, 1979) and tomato (Glinski *et al.*, 1978) showed that all three indices of soil oxygenation, i.e. the oxygen concentration in soil air, ODR, and Eh are applicable for characterizing the oxygen conditions for plant emergence almost to the same degree.

During imbibition seeds coated with artificial materials or mucilage substances which sometimes act as a barrier show changed germination. The mucilage which is formed under wet conditions forms prevents the transfer of oxygen to the spinach embryo by gaseous diffusion or aqueous convection currents and restricts it to the process of aqueous diffusion (Heydecker & Orphanos, 1968). Seed coating technique has been developed to increase the stability of seed germination and to increase the growth of seedlings after germination step. The coating, however, acts as a physical barrier to both water and vapour movement into the seeds (Taylor & Kwiatkowski, 2001). Therefore, the negative effect of seed coating on the oxygen and/or moisture uptake by seeds should be speculated when the coating techniques are applied to crop seeds.

The purpose of this investigation was to determine the relationship of ODR (as measured by the platinum microelectrode method) and six film coated snap been germinability in different soil moisture conditions. To test the hypothesis that ODR in the liquid phase are the limiting factor in germination, diffusion rates were varied by changing the moisture film thickness in soil and by changing the oxygen concentration in the soil atmosphere.

MATERIALS AND METHODS

Seed

A single lot of nontreated Labrador snap beans (*Phaseolus vulgare*) seeds purchased from Asgrow Seed Co. (Twin Falls, ID, USA) was used.

Film coating treatment

Five film coating formulations were tested: Incotec-reference (Incotec), SB-2000 (Seedbiotics), Disco (Incotec), Spectrum (GTG), and Celpass (Celpril). The film coating materials were sprayed with an external air atomization nozzle onto seeds in a laboratory-scale-coating drum. The application rate was 3.0% increase of seed weight with film coating polymer. Drying air was provided to facilitate coating efficiency during the coating operation.

Soil and soil preparation

A fine sandy loam obtained on the New York State Agricultural Experiment Station (NYSAES) Farm was used in this experiment. This soil was air dried and the moisture contents determined. To obtain a series (levels) of soil moisture content, the soil moisture content was adjusted to 18, 19, 20, 21, and 22% on a dry weight basis. As the seeds were not germinated at 22% soil moisture due to excessive water for germination, the data from excess soil moisture was excluded .

Seeding

For seeding the coated seed, a plastic tray (31 L×25 D×10.3 cm H) packed with tamped soil (3.5 kg)was prepared. Ten seeds were sown evenly with appropriate spacing followed by the covering with additional soil of 1.5 kg and tamping again.

Soil oxygen diffusion rate measurement

The ODR was measured using platinum micro-electrode method with some modification described by Lemon & Erickson (1952) and McIntyre (1970). The ODR was measured at 1.5 cm depth in the soil as soon as the seeds were sown by Oxygen Diffusion Ratemeter (Jensen Instruments, Model C). The platinum electrode used in the experiment was 0.5 mm in diameter and 4 mm long. The area of the electrode was 0.065 cm^{-2}. The ODR measurements were taken on each day of the experiment with four plantinum electrodes independently connected to the apparatus. The electrodes were placed in the soil at a depth of 1.5 cm through 10 apertures in the cover on the plastic tray. The apertures were opened only for a short time during the measurements. Before every successive measurement the electrodes were washed with distilled water. Calomel electrodes (one reference) and electrodes of copper wire (ten cathodes), 2 mm in diameter and 5 cm long, were permanently fixed in every pot. ODR was measured for 5 minutes, permitting quasistationary conditions to be achieved.

Germination test

The seeds sown into trays were germinated in a constant temperature room at 25°C. The number of emerged seedlings was taken on ninth day after seeding. "Germination" as used in this paper means the percentage of seeds that sprouted and from which the plant emerged above the soil surface.

The length of seedlings (with radicle) was measured and seedling dry weight (without radicle) was determined. Seedling vigor levels for each treatment were calculated by multiplying percent germination by the average seedling length of each treatment. The seedling capability in field was calculated by multiplying seedling vigor by the whole dry matter weight of shoot.

RESULTS AND DISSUSION

ODR in soil with different moisture content

The ODR values of soil were 121.4 $ug/m^{-2}\,sec^{-1}$, 116.9 $ug/m^{-2}\,sec^{-1}$, 75.7 $ug/m^{-2}\,sec^{-1}$, and 55.7 $ug/m^{-2}\,sec^{-1}$ at the soil moisture contents of 18%, 19%, 20%, 21% , respectively (Fig. 1).

Germination percent

Germination percentages of film coated seeds under official seed testing condition was presented in Table 1. There was no large difference in germinability among seeds with different coating materials. The rate of abnormal seedlings and dead seeds, however, showed little difference among coating materials. Because the differences in the percentage of abnormal seedling and dead seeds was not highly critical, it was assumed that the effect of coating treatments on germination could be ignored to examine the oxygen status in soil for seed germination and seedling establishment.

Table 1. Percentages of normal and abnormal seedlings and dead seeds of coating-treated seeds under the official germination test condition.

Treatment	Normal seedling	Abnormal seedling	Dead seed
Control	93±0.48	5±1.00	2±0.42
Incotec-reference	94±0.29	5±0.25	1±0.25
SB 2000	92±0.58	8±0.58	0±0.00
Disco	93±0.48	4±0.41	3±0.48
Spectrum	94±0.29	3±0.25	3±0.25
Celpass	93±0.75	7±0.75	0±0.00

One hundred seeds of each replicate were germinated between moistened paper towel at 25°C for 9 days.

In the experiment, the cover of seedbed trays was open after 6th day of treatment allowing the free exchange of fresh air. There was no further germination for following three days after opening.

The percent of emergence on the 9th days of the experiment, presented in Fig. 1. The result showed that the main factor differentiating the emergence was the oxygen level based on ODR value of the soils. The emergence rate under higher ODR condition in the soil moisture content of 18% in which ODR value was stable showing the range from 120 to 140 ug m^{-2} sec^{-1} did not show significant difference among film coating treatments. The noticeable decrease of ODR value was observed in the lowered soil moisture content below 19% (Fig. 1). When the ODR value was lowered in more wet soil, the emergence of seeds was decreased with different decreasing rate among coating treatment. This result implies that the changes in seed germination was highly dependent on the coating material reflecting different oxygen diffusion property via coating layer. The larger difference was observed in more wet soil in which ODR value was also significantly lowered.

No emergence was observed at the excess soil moisture condition (22%) (data was not presented). Hence this value should be considered as critical soil moisture content. An ODR value of under the soil moisture condition below 20% moisture did not influence the percent emergence significantly. So it can be assumed that the limiting value of soil moisture content for the emergence of snap bean is 20%.

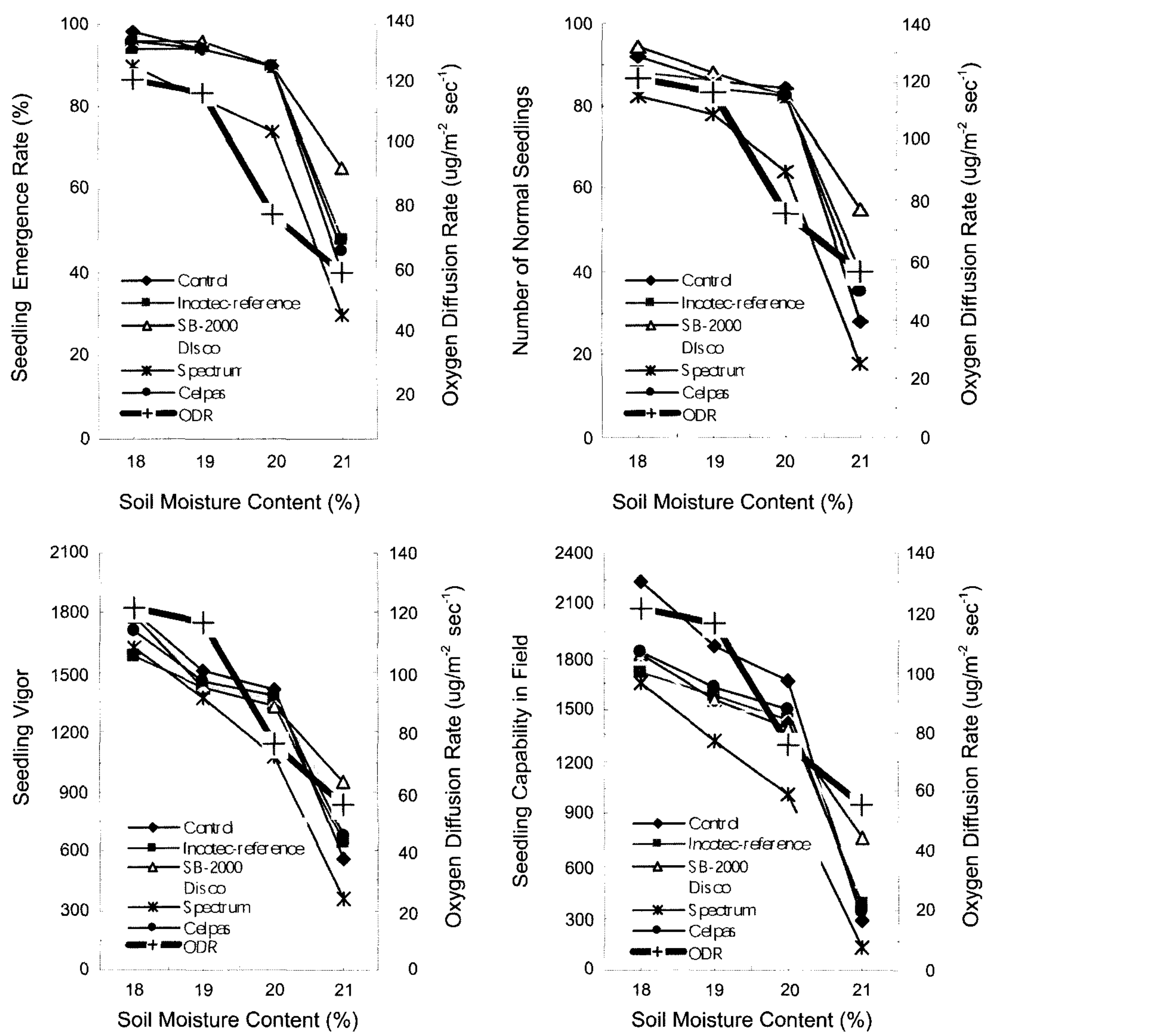

Fig. 1. Relationship between snap bean germinability and oxygen diffusion rate under the different soil moisture content.

The critical value was somewhere between 20 and 22%. The value of 18% soil moisture content may be considered as the optimum for snap bean emergence although the ODR was various at same moisture content depending on soil texture. Germination of seeds coated with Spectrum was dramatically decreased as the soil moisture content increased compared to the other treated materials, but the seeds coated with Incotec-reference, SB-2000, Disco, and Celpass were not difference from the non-treatment. The highest germination was obtained in the seeds treated with SB-2000, then in the order of the Disco>Incotec-reference>Celpass>Spectrum treated seeds, at 21% soil moisture content.

The ODR value, obtained under the experimental conditions, was closely relationed to the soil moisture content. (Fig. 1). The drastic reduction of emergence was occurred from the level of ODR of 33.9 ug m^{-2} sec^{-1}. So, the critical value might be somewhere between 75.7 and 33.9 ug m^{-2} sec^{-1}. Because the reduction in emergence commenced at the ODR value of 75.7 ug m^{-2} sec^{-1} and the optimum values was 121.4 ug m^{-2} sec^{-1}, the evaluation of coating material for oxygen permeability should be test in this range without interference of the effects of shortage and excess of soil moisture on germination. Similar results were reported by Letey *et al.* (1962) for barley. Oxygen diffusion rates of approximately 15×10^{-8} gm cm^{-2} min^{-1} is limiting for barley seed germination whereas the optimum diffusion rate for shoot growth is less than 40×10^{-8}. In wheat, the final emergence of wheat diminishes at ODR value below 70 g×10^{-8} cm^{-2} min^{-1} (Hanks & Thorp 1956). The investigations of Kaack & Kristensen (1967) did not confirm the applicability of ODR as an index of aeration during wheat emergence, but they revealed a high correlation between the emergence and oxygen content. Previous studies mentioned above suggested that the application of ODR value to determine the emergence in field should be speculated with consideration for the property of crop species and soil factors like moisture, temperature, and physical property.

Number of normal seedling

The number of normal seedlings showed the same tendency as the germination rate in the response to the increasing soil moisture content. The number of normal seedlings was sharply decreased in 21% soil moisture content in which emergence was also reduced markedly regardless, regardless of the kind of coating material. The number of normal seedlings from the seeds treated with Spectrum was fewer than those treated with other materials. However, there was no big difference in the number or normal seedlings among coating materials except Spectrum compared to control. Because the seeds coated with Spectrum showed the highly lowered rate as compared to other coating materials in the result of seedling emergence rate, it was reflected that the restricted oxygen permeability via coating layer affects directly to the seed germination and development of normal seedlings under excess soil moisture condition. The greatest number of normal seedlings was shown in the seeds coated with SB 2000, while the number of normal seedling was the lowest in seeds coated with Spectrum under the excess soil moisture content (21%).

Seedling vigor

The seedling vigor was decreased linearly when the soil moisture contents were gradually increased, showing the same tendency as the rate of germination and the number of normal seedlings. Because the seedling vigor was calculated multiplying percent germination by seedling length, this trait reflect in part the qualitative response of plant after germination. The result showed that the influence of oxygen permeability was persistent not only in germination but also in early seedling growth. After radicle emergence, oxygen can be uptake via roots. Therefore, it can be assumed that the reduced seedling growth in early seedling stage can be recovered after further progress of seedling growth. The lowest seedling vigor was resulted in the seeds treated Spectrum which showed the highest inhibiting effect on seed germination.

Seedling capability in field

The dry matter weight of the seedlings from the film coated seeds was decreased compared to non-treated. The reductions resulted in the decrease of seedling capability in field. Although the negative effects of seed coating like poor oxygen permeability and physical resistace of coating crust to plumule and/or radicle protrusion were observed, the suppression might not be directly affect to seedling growth after germination. The result of seedling capability in field, however, showed greater differences among treatments, especially between nontreated control and coating treatments. Therefore, it was concluded that seed coating treatment should be carefully applied when the oxygen content was poor in wet soils.

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