GERMINATION IN LOWER OSMOTIC POTENTIAL AS AN INDEX OF DROUGHT RESISTANCE IN CROP PLANTS - A REVIEW

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INTRODUCTION

In arid and semi-arid zones having meagre irrigation facilities, water shortage is the most important cause of the failure of seed germination and plant growth. This water deficit may be due to an actual lack of adequate moisture in the soil (matrix potential) or due to presence of excessive quantities of solutes in the soil water (osmotic potential) or both. The selection of varieties and species of plants that have the capacity to germinate in drought, to endure drought and still produce optimum is, therefore, of prime importance in arid zone farming.

Germination of seeds in various osmotic potentials produced with a suitable solute is a simple, easy and reproducible test which gives a relative measure of any differences among varieties for their character of drought resistance. This is done with the assumption that a seed which can germinate by absorbing water against a lower osmotic potential, its resulting plant may also absorb moisture under similar conditions of moisture stress. A lot of work has been done on this aspect but the views of the scientists are much controversial. Some accept that the ability of germination in lower osmotic potentials is inherent character of varieties and species and is generally correlated with drought resistance and adaptability in dry tracts (Yamasaki 1929b and Vasudevan and Balasubramaniam, 1965) while the second view does not support this hypothesis (Amoedt and Johnston 1936, Birdsall and Neatby, 1944 and Mcginnies, 1960). This article deals with these and some other aspects of germination and subsequent plant growth in lower osmotic potentials.

The terms water potential, osmotic potential and matrix potential have been used in accordance with the recommendations of Slatyer and Taylor (1960) and Manohar et al (1966) to express the different levels of energy status of water i.e. moisture stress (101.3 joules kg=1 atm).

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For germination of seeds, a certain level of hydration of seed must be attained before the physiological processes are triggered on (Hunter and Erickson, 1952). It has been reported that dry seeds may have as low as -10,000 joules/kg water potential (Manohar, 1966a), therefore, the soil moisture content need not be very high for their germination (Peters, 1920). However, most rapid germination occurs when soil moisture is at or slightly below field capacity. According to Doneen and McGillivary (1943) and Manohar and Heydecker (1964a) the seeds of certain species may germinate even when the soil moisture level is at permanent wilting or slightly lower. It is, therefore, logical to deduce that a seed which has a capacity to germinate with lower degree of hydration may stand better chances of germination in scanty rainfall areas. Soriano (1962) has pointed out in this connection that xeric germination depends not only on the minimum imbibition required, but also on the imbibition pressure and the time factor.

Blaim (1960) stated that very little attention has, so far, been paid to water uptake problem. Seed water uptake has been distinguished into two stages by Atkins (1909). The first stage i.e. imbibition was thought to be connected with the swelling of colloids and the second i.e. germination due to osmosis. Blaim (1960) doubted this conjecture and proposed that uptake of water by embryo should be considered as a physiological process and it is distinct from that of endosperm which is exclusively connected with imbibition of soil colloids. Although different mechanisms of water uptake may exist in endosperm and embryo, yet it appears that embryo growth is dependent, to a great extent, on the endosperm food and growth factors (Sircar and Lahiri 1956). Sircar and Ghosh (1962) observed that endosperm protein is hydrolysed and other aminoacids appear and are translocated to the embryo at germination. Presumably the endosperm must attain certain degree of hydration to trigger on the hydrolysis processes which are essential for the availability of food factor for the growing embryo. Similarly, Manohar (1966b) reported that embryo cells must attain a definite degree of moisture level to initiate vital processes to growth. This degree of hydration will, of course, vary in different types of seeds. Soriano (1962) stressed that a high power of imbibition is considered to be characteristic of xeric germination.

GERMINATION IN RELATION TO LOW OSMOTIC POTENTIAL

The adverse effect of lower osmotic potential on absorption of water by seeds has been observed by several workers. Uhvits (1946) germinated alfalfa seeds on substrates supplied with the solutions of sodium chloride and mannitol at osmotic potentials ranging from about -100 to -1500 joules/kg. She found that
higher the concentration of sodium chloride or mannitol, the lower were the rates and percentages of germination of alfalfa seeds. Similar decrease in germination of alfalfa seeds under different osmotic solutions of mannitol was reported by Dotzenko and Dean (1959). While studying the effects of simulated drought on germination and seedling growth of four sorghum varieties, Evans and Stickler (1961) showed decreased germination with decrease in matrix potential. Rodger et al (1957) reported a method for evaluating winter hardiness in alfalfa based on differences in rate and total germination in sucrose and sodium chloride solutions of definite osmotic potentials. He found that lower osmotic potential decreased the speed and total germination. McGinnies (1960) while working on germination of different grass seeds under various osmotic potentials observed delayed germination in lower osmotic potential, the rate as well as total germination was reduced in all cases. Manohar and Mathur (1965) studied the problem in detail by germinating *Pennisetum typhoides* seeds under different osmotic potentials and showed that the rate of germination as well as total germination were significantly reduced in lower osmotic potentials. It was reported that the lowering of the potential of the germination medium results in a decrease in the potential gradient between the seed and its germination medium (Manohar and Heydecker, 1964b) resulting in slowing down of the rate of the movement of water to the seed. Further, while studying the moisture uptake by different parts of the pea seeds, germinating in two osmotic potentials, Manohar (1967) reported that the rate of moisture absorption was reduced maximum in embryo (without cotyledons) as compared to in cotyledons and seed coats.

Ayers (1952) germinated onion and sugarbeet seeds under different moisture stress and salinity conditions and observed that effect of salinity in diminishing emergence percentage is more severe than at the low levels of soil moisture, even though in the former case the soil was still above the permanent wilting percentage. Mehta and Desai (1958) reported 100 per cent germination of *Bajra* at 1 per cent salt concentration of soil solution at field capacity while only 54 per cent germination was recorded at 2 per cent salt concentration. Lawton (1949), from a series of field studies, had suggested that the crop plants of weak, medium and strong salt tolerance will not grow when the soil solution at field capacity exceeds 2, 2.3 and 2.7 per cent salt concentrations, respectively. Younis et al (1963) while germinating alfalfa varieties in solutions of different osmotic potentials observed a decrease in germination with increase in moisture stress. Similar findings of poor germination in lower osmotic potential have also been reported by Ayers and Hayward (1948), Dewey (1962 a, b), Tedmor and Hillel (1963), Manohar and Heydecker (1964b), Manohar (1966c), Manohar and Mathur (1966, 1967) and Kaul and Manohar (1966).
Germinability under lower osmotic potential solutions is a heritable character

Yamasaki (1929 a) germinated the seeds of hydrophytic and xerophytic rice varieties, soaked in 3 per cent potassium chlorate for two days, in distilled water and found that although the seeds of hydrophytic varieties germinated well but some got killed due to toxic effect of absorbed salt. On the other hand the xerophytic varieties germinated well and survived without much injury. Helmerick and Pfeifer (1954) found that germination and early growth of yogo winter wheat were significantly superior to that of cheyene winter wheat when germinated under controlled limited moisture conditions. They concluded that the differential germination and growth response between the two varieties were inherent rather than environmental. Germinating different alfalfa varieties under different osmotic potentials produced by manitol, Dotzenko and Dean (1959) observed highly significant interactions of variety $\times$ osmotic treatments, indicating that the ability to germinate under high osmotic stress might be heritable and varied with the different varieties tested. Dotzenko and Haus (1960) further confirmed that indeed the ability of alfalfa seeds to germinate in lower osmotic potential was heritable. Vasudevan and Balsubramanium (1965) while germinating six sorghum varieties in various osmotic solutions observed that germinability of rainfed sorghum strains was distinctly superior to those of irrigated strains.

The imbibitional power of some seeds is enormous (Manohar 1966 a). Shull (1961) found that the seeds of *Xanthium pennsylaniam* imbibed 12 per cent as much water from a saturated sodium chloride solution having an osmotic potential of about $-38,000$ joules/kg as from pure water. Intake of water from a solution with an osmotic potential of about $-1900$ joules/kg was 75 per cent of imbibed water. Very few seeds germinated when the soil moisture content was below the wilting coefficient of the soil. Winter wheat grown on Nebraska has been found to germinate in the soil that was below $-1500$ joules/kg (Knock et al, 1957). The data obtained by Doneen and McGillivary (1943) are more conclusive on this ground. He reported that the emergence of young seedling may occur at permanent wilting percentage or even slightly lower. Thus germination of cabbage seeds was excellent even when the soil moisture content was slightly below the wilting percentage, whereas the germination of celery seed was inhibited when it was slightly below field capacity. Studying water absorption by seeds of different varieties of cotton and corn during the early stages of germination, Stiles (1948) showed that the embryo and the seed of drought resistant No. 293 cotton absorbed about half as much water during the first 96 hours of germination as those of Roger Acala cotton. The low proportion of water in the seed and embryo of former with rapid initial extended absorption of water and high proportion of water in the endosperm were the factors making this variety to germinate under dryland conditions. On the other hand Roger Acala cotton seeds
required almost twice as much water as the former and is, therefore, drought susceptible. Similar trend was observed with different varieties of corn. Hunter and Erickson (1952) working on germination in relation to soil moisture stress concluded that in order to germinate, each species has to attain a specific moisture content. This was found to be approximately 30.5 per cent for corn, 26.5 per cent for rice, 50 per cent for soya bean and 31 per cent for sugarbeet seeds. At 25°C soil should have moisture stress of not less than -1250 joules/kg, -650 joules/kg and -350 joules/kg for germination of corn kernels, soya bean and sugarbeet seeds, respectively.

Germinating seeds of three grasses native to arid and semi-arid regions, Lahiri and Kharbanda (1964) observed significant differences in their moisture requirement for germination and that close parallelism existed between their pattern of water uptake and germinability under low levels of moisture. Seeds of *Cenchrus setigerus* were found to attain the equilibrium stage of water within two hours and the amount of water absorbed was also significantly less than the other two grasses while the seeds of *Lasiurus sindicus* reached the same stage in six hours and also with big amount of moisture absorption. Abichandani and Bhatt (1965) studying the salt tolerance of germinating *Bajra* and *Jowar* varieties concluded that *Bajra* was more salt tolerant than *Jowar*. Some highly salt tolerant varieties of *Bajra* were found to stand fairly a salinity level of 3 per cent in soil solution while the upper limit of salt tolerance of *Jowar* was only 1.8 per cent salt. Varietal differences with regard to germinability in lower osmotic potentials have also been reported by Hayward (1954), Ota and Yasue (1957, 1958), Wahhab (1961), Bernstein (1962) and Manohar (1966 b).

**Germinability under osmotic stress and performance of plants under drought:** Yamasaki (1929 a) germinating the seeds of hydrophytic and xerophytic varieties of rice after soaking in 3 per cent solution of potassium chlorate, found that xerophytic rice was more resistant than hydrophytic rice and that in the former, the ability to grow inspite of salt absorption, by the seeds parallels to drought resistance. He concluded that by means of such germination tests it may be possible to determine, to some extent, the degree of drought resistance in crops. Buchingen (1936) further confirmed the correlation between ability to germinate in lower osmotic potentials produced from sugar field performance. Powell and Pfeifer (1956) used D-mannitol solution to produce drought conditions and concluded that two generations of cheyne winter wheat had highly correlated growth rate when the seeds were germinated under drought conditions. Vasudevan and Balsubramaniam (1965) germinating different grain of sorghum varieties in osmotic solutions of various salts observed that the ability of the seeds to
germinate in lower osmotic potentials paralleled to drought resistance and that the rainfed strains of sorghum were distinctly superior than those of irrigated areas.

Germination alfalfa seeds in lower osmotic potentials as a measure to test winter hardiness, Heinrichs (1959) concluded that the method is not reliable for differentiating alfalfa varieties for their winter hardness character. A species that can germinate well under severe drought conditions may not necessarily withstand drought at maturity and *vice versa* (McGinnies, 1960). Dewey (1962 b), while breeding crested wheat for salt tolerance by growing seedlings in artificially salinized basins, concluded that selection in salinity germination test was ineffective as a means of increasing salt tolerance at subsequent growth stages. Amoedt and Johnston (1936), Birdsall and Neatby (1944), Ashton (1948) and Younis *et al* (1963) too did not record correlation between germinability in lower osmotic potentials and drought resistance of plants.

*Effect of “osmotic” systems on germination*

Uhvits (1946) germinated alfalfa seeds under different iso-osmotic potentials produced with sodium chloride and mannitol and recorded greater reduction of germination in sodium chloride than in mannitol solutions of iso-osmotic potential. She found that germination was almost completely inhibited in ~1515 joules/Kg solution of sodium chloride while 57% germination was recorded in iso-osmotic mannitol solution. She mentioned that the relative adverse effect of sodium chloride at a given osmotic potential appeared to be related to the excess intake of chloride by germinating seeds. Wiggins and Gardner (1959) studied the effectiveness of different levels of droughts produced by various chemicals by recording germination and seedling growth in radish and sorghum. They found that above ~500 joules/Kg solutions of sucrose, glucose and mannitol had only a slight adverse effect on germination of radish and sorghum seeds while about ~500 joules/Kg osmotic potential solution of polyvinyl pyrrolidone and sodium chloride solution almost completely inhibited germination and radicle growth in both the crops. Heinrichs (1959) further supported the earlier findings by obtaining better germination in iso-osmotic solutions of sucrose than in sodium chloride solutions. Ayers and Hayward (1948) stated that salinity may affect the germination in two ways: (1) by decreasing the ease with which the seeds may imbibe water and (2) by facilitating the entry of ions in sufficient amounts to be toxic. Collis-George and Sands (1962) reported that the movement of solutes from soil solution through the cell membrane was a simple diffusion process “because there is not a truly semipermeable membrane which can permanently exclude the solute external to the cell and, therefore, any detrimental biological consequence is that of an internal toxicity rather than an osmotic drought”.
Manohar and Heydecker (1964 b) and Manohar (1966 c) have further investigated the effects of different osmotic systems and have reported that seed coats may not behave as differentially permeable to lower molecular weight chemicals like sodium chloride, sucrose and glycerol or even mannitol which have generally been used to produce osmotic drought in the past. Since solutes enter in seed, their effect can not be ascribed as osmotic effect but a specific chemical effect. They further reported that carboxwaxes of 4000 or higher molecular weight can be successfully used to produce real osmotic droughts for the seed coats which seems to behave as differentially permeable to these solutes.

SUMMARY

Studies on “Germination in lower osmotic potential as an index of drought resistance in crop plants” is presented. These studies show that not much systematic work has been done in the past to confirm any of the prevailing hypotheses. Various workers, working with various crop species, using different levels of osmotic potentials, produced from various chemicals, and under varying environmental conditions have reported conflicting results. It is, therefore, difficult to conclude a definite relationship between the germinability of seeds in lower osmotic potentials and its relation to drought resistance in the resultant crop plants.

A clear thought, however, seems to emerge regarding the suitability of various chemicals as osmotic agents. It is apparent from the review that most of the chemicals which have been used in the past eg. sodium chloride, polyvinylpyrrolidone, sucrose, glycerol and mannitol may enter inside the germinating seeds and thus their effects are much more complex than producing drought. Recent work has, however, shown that the true osmotic stress may be produced by using polyethylene glycol (Carbowax) solutions.

REFERENCES


McGinnies, W. J., 1960. Effect of moisture stress and temperature on germination


