6. Upland rice in Brazil

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Rainfed or upland rice is grown in Brazil at latitudes lower than 20º South, with the largest production areas concentrated in the states of Mato Grosso, Tocantins, Rondônia, Goiás, Maranhão, and Pará. According to Conab (2019), the upland rice area in the 2018/2019 growing season in these states was 346.6 thousand ha, representing 20% of the rice area in Brazil, with an average yield of 2.35 Mg ha^{-1}, counting only 7.8 % of Brazilian rice production. Upland rice played a very important role in the expansion of the agricultural frontier in central Brazil from the 1980s to 1990s and peaked at 5 million hectares cultivated in Brazil in 1987 (Martínez et al., 2014).

Upland rice is no longer the main component of agricultural production in Central Brazil due to the difficulty to commercialize it as a result of the competition with irrigated rice from southern Brazil, large yield fluctuations, low-profit margins, and grain quality. In the last decade, a decrease in a cultivated area of around 70% has been observed (Heinemann et al., 2015, 2019), a tendency which seems likely to continue if the occurrence of water deficiency worsens as a result of climate change (Ramirez-Villegas et al. 2018).

In addition to these factors, it is to highlight that Embrapa’s activities of upland rice breeding program, since the 1980s, have

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focused on direct selection for the grain production and adaptation to highly favorable regions (free from water stress). In this process of genetic selection, there is a risk of developing specialized genotypes for favorable areas, which do not have sufficient plasticity and, therefore, do not respond well under conditions of stress (Heinemann et al., 2015).

Upland rice fields in Brazil are located in the region called Cerrado, where Oxisols predominate with low water storage capacity. During the rainy season (October-April), when rice is grown, rainfall distribution is irregular, with droughts of two to three weeks being common. Rice’s high evapotranspiration demand combined with the characteristic of the soils, causes these droughts, which, in turn, provoke considerable rice yield decreases, resulting in fluctuations in production.

The relative impact of water deficiency on upland rice culture has been growing in recent decades in central Brazil (Figure 88). In the 1980s, Douradão cultivar predominated, with a relative impact of water deficiency between 0 and 15%. With the adoption of new cultivars, there was an increase in yield, but the relative impact of water deficiency in the study region increased (Heinemann et al., 2019).

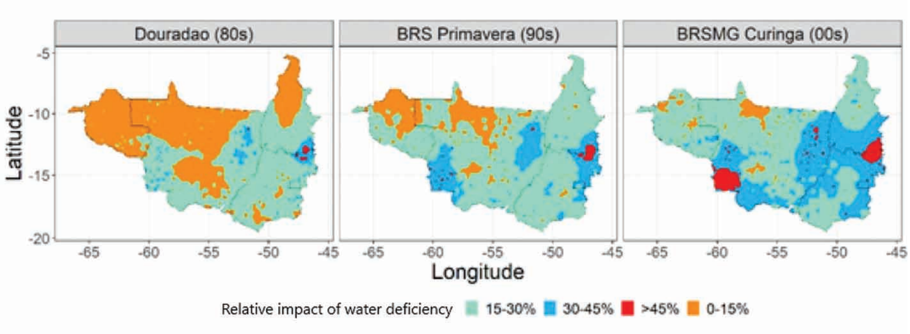


Figure 88. Relative impact of water deficiency on upland rice in central Brazil (Goiás, Mato Grosso, Rondônia and Tocantins states) in the periods from 1980 to 1989 (80s), cultivar Douradão, 1990 to 1999 (90s), cultivar BRS Primavera from 2000 to 2013 (00s), cultivar BRSMG Curinga. Source: Adapted from Heinemann et al. (2019).

6.1. Characterization of the production area

The central region of Brazil, which is the main producer of upland rice, was stratified into three environmental groups called highly favorable (HF), favorable (F), and less favorable (LF) (Figure 89) according to the application of a simulation yield model, growth and development of rice culture (Heinemann et al., 2015).

Highly Favorable Region (HF):

This region is characterized by an annual rainfall (1,581 mm) higher than the average (1,505 mm). Annual global solar radiation, annual air temperature range, average maximum, and minimum annual temperature showing average values ??of 6,894 MJ m^{-2}, 0.98 °C, 23.78 °C, and 18.06 °C, respectively. The average yield of this region is higher than the national upland rice average. In this environment, soil with a more clayey texture predominates, and the sowing dates are concentrated at the beginning of the sowing window (1st to 10th November) and flowering occurs around 71 days after the emergence (Cultivar BRS Primavera). This region represents only 19% of the area comprising the states of Goiás, Mato Grosso, Rondônia, and Tocantins.

Favorable Region (F):

In this region annual rainfall is 1,500 mm with annual global solar radiation, annual air temperature range, average maximum and minimum annual temperature of 6,944 MJ m^{-2}, 0.99 °C, 24.23 °C, and 18.23 °C, respectively. For this environment, the average flowering is 70 days after the emergence (Cultivar BRS Primavera). The predominant soil textures in this region are sandy-loam (28%) and clay-loam (24%). This region represents 44% of the production area of the states of Goiás, Mato Grosso, Rondônia, and Tocantins.

Unfavorable Region (UR):

In this environment, the total annual rainfall is lower than the general average (1,465 mm), while the values of global annual solar radiation, the annual amplitude of the maximum and minimum annual mean temperature are higher than the general averages. The main characteristic of this region is the predominance of soils with a sandy texture and sandy-loam (33 and 41%, respectively), with sowing dates concentrated at the end of the sowing window (30th December to 10th January). This region represents 37% of the area comprising the states of Goiás, Mato Grosso, Rondônia, and Tocantins.

Figure 89. Geographic distribution of highly favorable (AF), favorable (F) and unfavorable (PF) regions for upland rice in Brazil. Source: Adapted from Heinemann et al. (2015).

6.2. Yield potential

The geographical distribution of the yield potential of upland rice is illustrated in Figure 90. To calculate the yield potential, 79 field trials were used, from 2011 to 2017, allocated in 34 municipalities of the production region, called upland cultivation value (CV) of Embrapa's rice breeding program. The yield potential for each group of tests in the same municipality was considered the one in which 5% of the highest yield values were found.

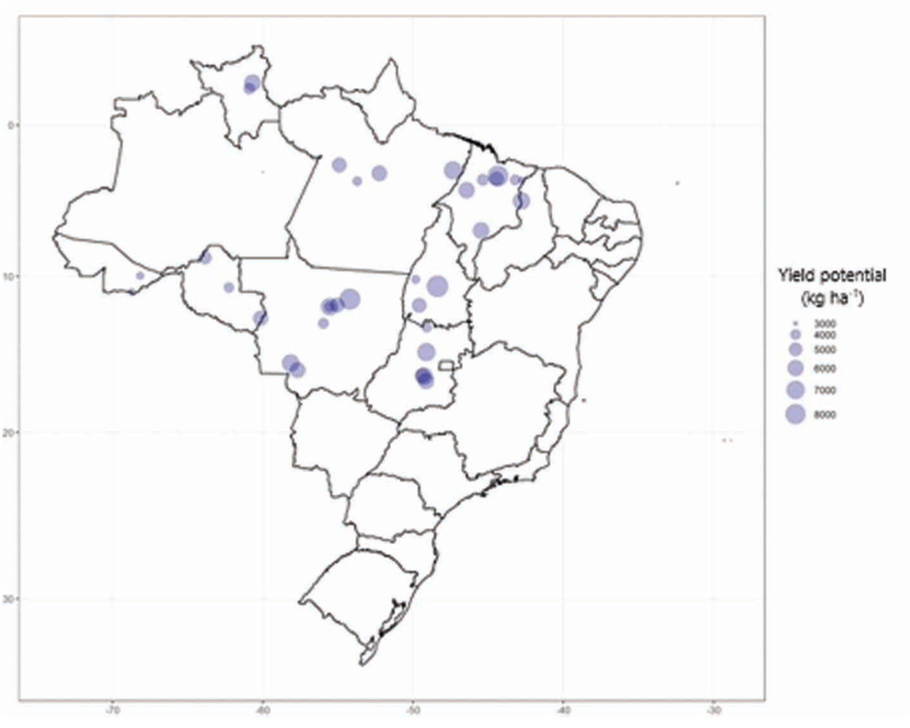


Figure 90. Geographic distribution of yield potential yield in the upland rice producing region in Brazil. IBGE, 2014. Source: Embrapa Rice and Beans.

6.3. Agrometeorological conditions of yield

Upland rice can achieve high yields when its climatic requirements are met. However, when this does not occur, there may be a reduction in yield, which will be proportional to the duration and intensity of meteorological adversities during the development cycle.

In this regard, for the upland rice crop to have good growth and development, the interaction climate-plant needs to be adequately quantified and monitored. For this purpose, the climatic elements over the years must be known, such as solar radiation, air temperature, rain, photoperiod, among others, which have a great influence on rice production.

6.3.1. Air temperature

Air temperature is one of the most important climatic elements for the growth, development, and yield of rice, as each stage of development requires a minimum, optimal, and maximum critical temperature. The upland rice requires, for the germination process, air temperatures within the range of 18 to 40 °C, 25 to 31°C for flowering, and around 30 °C for maturation (Chapter 2).

Air temperatures above 35 °C, under water stress conditions, can cause spikelet sterility. The reproductive phase starts right after the differentiation of the floral primordium. It is at this moment that the plant is most sensitive to high air temperatures. Daytime air temperatures above 33 °C can interrupt this process. Similarly, nighttime air temperatures above 29 °C increase susceptibility to spikelet sterility, which causes reductions in grain yield. The second most sensitive phase is pre-flowering, or, more specifically, about 10 days before the panicle emission. Similar to low temperatures, there are great differences among cultivars in terms of tolerance to high air temperatures (Yoshida & Parao, 1976).

In preferential sowing dates, in the Brazilian Cerrado region, there is normally no significant negative influence of low air temperatures, since in most locations the average minimum temperature in January and February, a period that generally coincides with the reproductive stage of the crop, is above 17° C. However, in higher altitude locations, it is possible to evidence some influence of this climatic element.

The influence of low air temperatures can be considered severe for sowings performed off-season. Temperatures of 15 to 19°C during the reproductive phase can impair the development of microspores, causing the sterility of pollen grains, resulting in high sterility of spikelets (Ghadirnezhad; Fallah, 2014).

The end of the reproductive phase and the beginning of the grain-filling phase should not coincide with May, June, July, and August, when the minimum air temperature is below that required by the crop in most of the Brazilian cerrado (Fageria, 1984), even when supplementary irrigation is possible (Lobato & Silva, 1995). When there are low air temperatures, as in between February and September in the Brazilian Cerrado, there is an elongation of the cycle, a decrease in plant size, leaf area index, and yield in upland rice.

6.3.2. Solar radiation

The solar radiation (SR) that reaches the Earth’s surface is the source of energy for photosynthesis and evapotranspiration of plants. SR is formed by two components: direct radiation (fraction of the global radiation that did not interact with the atmosphere) and diffuse radiation (fraction of the global radiation that interacted with the constituents of the atmosphere and was yet again irradiated in all directions). The proportion of diffuse radiation in relation to the global radiation is maximum at the moments close to sunrise and sunset and on completely cloudy days when all global radiation is diffuse. In the photosynthesis process, plants use only a fraction of the incident radiation at a wavelength between 0.4 and 0.7 µ, called photosynthetically active radiation (PAR). PAR is approximately 50% of the incident global radiation (Montheith, 1972).

The low availability of global solar radiation significantly decreases the leaves' photosynthetic rate, resulting in decreased dry matter accumulation (Sun et al., 2016). Its greatest impact is mainly in the grain filling phase, implying a reduction in yield due to the decrease in the number of grains m^{-2} and the mass of grains (Dingkuhn et al., 2015). Higher rice yields in subtropical environments can be explained by the larger accumulation of global solar radiation during the plants' development cycle (Santos et al., 2017).

Radiation Use Efficiency (RUE, g MJ^{-1}) is defined as the ratio between the aerial biomass accumulated by the plant and the amount of intercepted radiation, or the efficiency of converting radiation into dry matter. RUE is an essential parameter in crop growth simulation models for the accumulation of biomass, grain yield, and the prediction of yield potential.

6.3.3. Photoperiod

The photoperiod is defined, in hours per day, as the length of time between the first rays of the sun at sunrise and the last rays of the sun at sunset. In other words, it is the length of a day plus the duration of the twilight (morning and afternoon). The plant's response to the photoperiod is called photoperiodism. Since upland rice is a short-day plant (10 hours of daylight), it shortens its cycle and anticipates flowering. Yoshida & Parao (1976) characterized the main aspects related to the sensitivity of rice plants to the photoperiod.

The points that deserve to be highlighted are a) In cultivars that respond to the photoperiod, the vegetative development phase of rice can be divided into the basic vegetative phase or the juvenile phase (BVP) and the photoperiod sensitive phase (PSP). The PSP of photoperiod low sensitive cultivars is shorter than 30 days, whereas the cultivar considered sensitive to the photoperiod is longer than 31 days; b) The optimal photoperiod is considered the length of the day in which the duration of the emergence until flowering is minimal. The optimal photoperiod, for most cultivars, is between 9 and 10 hours; c) The critical photoperiod is the one in which the plant will take the maximum time (days) to reach the flowering phase or, depending on the cultivar, it will not reach flowering at all.

The reaction of rice plants to the photoperiod can be classified a: Insensitive - when PSP is short (less than 1 day) and BVP varies from short to long; Little Sensitive - when there is a significant increase in the length of the plant cycle (photoperiod longer than 12 hours); the duration of PSP can exceed 30 days, but the flowering will occur in any long photoperiod; Very Sensitive - when there is a significant increase in the length of the cycle with an increase in the photoperiod; there is no flowering beyond the critical photoperiod; BVP is usually short (no more than 40 days) (Steinmetz et al., 2006).

In general, it can be said that, for the main rice production regions in the world, the photoperiod is not a limiting factor, following the recommended sowing dates. This is because during the adaptation and/or breeding process of new cultivars, those that show cycle lengths compatible with the photoperiod of the region are selected.

6.3.4. Rain

The characteristics of the water regime expressed by the amount and distribution of rainfall during the cycle of upland rice are the main limiting factors to reach high yields. In the Brazilian Cerrado, droughts (short periods with a shortage of rainfall) are common during the rainy season. In general, these dry periods are characterized by high evaporative air demand, high levels of solar radiation, and high air temperatures. Also, Cerrado is characterized by the predominance of soils with high-speed water infiltration, low water storage capacity, and low natural fertility (Espinoza et al., 1982).

6.4. Climate zoning risk

Due to irregular rainfall distribution, the climatic risk, which is characterized by the amount of water in the soil available for crops, is severe as a result of the frequent decrease in the amount of water. Often, this rainfall irregularity results in periods without rain that last from 5 to 35 days, which reduces grain yield (Heinemann, 2010). However, it is believed that the negative effect caused by the decrease in water can be minimized when the rainfall characteristics of each region and the behavior of the crops in their different phenological phases are known. Put differently, the suggestion is to sow in those periods when the probability of a decrease in the rain is smaller, especially during the flowering and the grain filling phase.

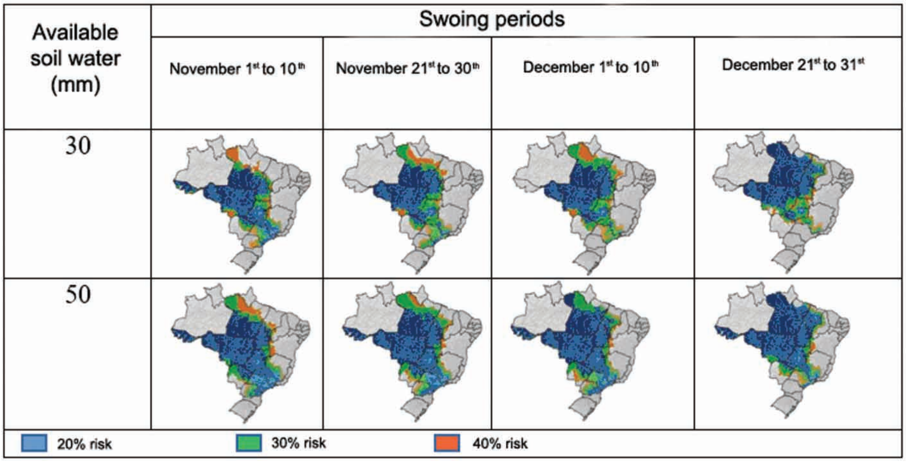
Still in this line of research, Stone et al. (1980) observed that, under conditions of water stress, upland rice showed reductions in the number of grains per panicle, in the mass of grains, in the total dry matter production, in the height of the plant and in the harvest index, as well as an increase the percentage of sterile spikelets.

Depending on the plant's development stage, the negative effects resulting from water stress can vary. If water stress occurs during the vegetative phase, a reduction in plant height, number of tillers, and leaf area may occur. However, the plant can recover if its water needs are met in time to allow recovery before flowering. But, if stress occurs during the reproductive phase, there is no point in supplying the plant's water needs in the following phases, considering that the effects will be severe, to the point of considerably affecting yield.

To reduce the negative effects resulting from the water deficit, it is necessary to sow in periods in which the flowering and grain filling phases coincide with greater rainfall periods. And this is possible with a zoning of climatic risk through a water balance study.

To estimate the climatic risks to which upland rice crops are exposed, the SARRA model was used to calculate the water balance (Regional Analysis System for Agroclimatic Risks), taking into account rain, potential evapotranspiration, the crop coefficient (Kc), the soil available water capacity and the upland rice development stages. The areas and periods most appropriate for upland rice cultivation in Brazil, as a percentage of risk, are shown in Table 22.

Table 22. Spatialization of climatic risk for upland rice in Brazil. Source: Steinmetz e Silva (2017).



6.5. Irrigation

The use of supplementary sprinkler irrigation minimizes the risk of water deficiency, which results in significant increases in upland rice yield. Considering that yield in this system can reach levels similar to those obtained with flood irrigation, with equivalent quality, the cultivation of rice under sprinkling becomes an interesting alternative.

The greatest advantage of sprinkler irrigation in upland rice crop is its contribution to production stability, by reducing water stress. Besides, irrigation provides higher yields and better grain quality. Rodrigues & Arf (2002), in Selvíria, MS, in the 1999/00 growing season, verified a 30% increase in rice yield with the use of supplementary sprinkler irrigation. For the same location, the increase reached 91%, in 2000/01 (Soratto et al., 2002). Arf et al. (2002) found, in a year with droughts, in which supplementary irrigation promoted increases in yield that ranged from 113 to 177%.

The frequent periods of water stress which the upland rice plant undergoes during the growing season cause lower grain quality when compared to flooded rice. The percentage of sterile spikelets and plastered grains increases considerably when water deficiency occurs during the phases of panicle emission and grain filling (Sant'Ana, 1989). With the use of sprinkler irrigation, the rice plant is not subjected to water stress, as a result, the grain filling process is not discontinued.

Consequently, the number of grains per panicle and the mass of grains (Soratto et al., 2002) are larger and the number of sterile spikelets is smaller (Rodrigues & Arf, 2002). Inadequate grain formation and the presence of plastered grains lead to a higher percentage of broken grains. Arf et al. (2002) found that sprinkler irrigation increased the milling yield and whole grains, mainly in a year with droughts. In addition to the increase in yield and grain quality, it is possible to use irrigation equipment for other crops (beans and wheat, for example), in the Fall-Winter harvest, thus enabling broader use of the equipment and providing greater profitability to the farmer.

An important aspect to consider regarding sprinkler irrigation is the interval between irrigations. Stone et al. (1986), in a study conducted in Goiânia (GO), concluded that combining yield and profit, irrigation of rice by sprinkling should be carried out in a way that the soil water potential, measured at 0.15 m in depth, do not reach values below than -0.025 MPa.

It is difficult to accurately quantify the total volume of water needed when supplementary irrigation is used, as it depends on the amount and distribution of rainfall. The total water requirement for the upland rice cycle usually ranges from 600 to 700 mm. However, considering early cultivars and the use of no-tillage, this value can be reduced to around 450 mm. Counting only on supplementary irrigation, the irrigation depths reach values below 200 mm per cycle, in the Southeast, Midwest, and North regions of Brazil.

The water requirement of rice irrigated by sprinkling can be estimated from evapometric tanks, based on the relation between the water evaporation measured in the USWB Class A tank (ECA) and the crop evapotranspiration (CET), using the coefficient of the tank (Kp) and the crop coefficient (Kc), so that CET = ECA.Kp.Kc.

Doorenbos & Kassam (1979) presented Kp values for the climate and the environment surrounding the tank. The Kc values for different stages of rice cultivation (Table 23) are higher for rice sown in soil conventionally prepared (PC) than for cultivated under no-tillage (NT). Stone & Silveira (2004) found that evapotranspiration under NT was 15% lower than that in DP/NT (Table 24), which reduces the need for supplementary irrigation.

Table 23. Crop coefficients for upland rice sown at 0.20 m spacing between rows. Source: Adapted from Stone & Silva (1999).

Development Phase	Length (days)	Crop coefficient (Kc)	
		PC[1*]	PD[2*]
Emergence – Beginning of tillering	20	0.58	0.18
Beginning of tillering – Panicle differentiation	45	0.72	0.67
Panicle differentiation – Pasty grain	55	1.34	1.28
Pasty grain – Panicle maturation	15	0.67	0.53

Table 24. Estimation of evapotranspiration and the need for supplementary irrigation in upland rice, in the conventional soil preparation system and in no-tillage. Source: Adapted from Stone & Silveira (2004).

Municípality	Evapotranspiration (mm/growing season)		Supplementary Irrigation (mm/growing season)	
	PC[1]	PD[2]	PC[1]	PD[2]
Guaíra – SP	629	530	106	70
Unaí – MG	565	482	194	167
Vicentinópolis – GO	578	495	71	46
Primavera do Leste – MT	487	417	73	45

[1] Conventional soil preparation; [2] No-tillage

In an experiment carried out at Embrapa Rice and Beans, using the ORYZA2000 v.3 simulation model (Bouman et al., 2001) and data from 30 years of 52 weather stations, the need for water supplementation for upland rice was estimated in the states of Goiás, Mato Grosso, Rondônia, and Tocantins. The average water needs for eight sowing dates were analyzed, from 1st November to 10th January, as well as physical-water characteristics of the soils that represent 70% of the region, with the available water capacity varying from 3 to 8% for the first 16 cm deep and phenotypic characteristics of the upland rice cultivar BRS Primavera.

The state of Rondônia showed the lowest demand for water supplementation and the state of Goiás the highest (Table 25), due to the characteristics of the rainfall regime in these states. Rondônia is influenced by systems that operate in the Amazon, for example, tropical mesoscale convective complexes, and Goiás is influenced by extratropical systems, such as cold fronts and instability lines. In general, the highest demands for water supplementation were verified at the beginning and at the end of the sowing period considered.

Table 25. Need for water supplementation for upland rice cultivation for the states of GO, MT, RO and TO at different sowing dates. Source: Adapted from Stone et al. (2015).

State	Sowing date							
	01/11	10/11	20/11	30/11	10/12	20/12	30/12	10/01
	Irrigation depth (mm growing season^{-1})							
GO	143	142	144	148	151	155	164	175
MT	142	137	132	131	135	138	141	146
RO	130	124	120	120	122	125	126	133
TO	146	140	134	130	132	133	136	140

Another way to calculate the amount of water to be applied to the soil already sown with rice is by using a tensiometer and the soil water retention curve. Tensiometers are devices that measure the matrix potential of soil water. The retention curve relates the water content or content of the soil to the force with which the water is retained. It is a physical-hydric property of the soil, determined in the laboratory.

The tensiometers must be installed in the soil at two depths, 0.15 m and 0.30 m, in at least three representative points of the field, when it is the case of central pivot irrigation. These points must correspond to 4/10, 7/10, and 9/10 of the pivot radius, in a straight line from the base. The 0.15m tensiometer is called “decisive” because it indicates the time of irrigation, while the 0.30 m tensiometer is called “controlling” because it indicates whether irrigation is being done well, without excess or lack of water. The irrigation should be performed when the average of the readings of the decision tensiometers is around -0.025 MPa (Stone et al., 1986).

The procedure to determine the amount of water to be applied follows: with the moisture retention curve, it is verified how much -0.025 MPa corresponds to the water content in the soil, shown in m^3 of water m^{-3} of soil. Then, the difference between the moisture content at -0.006 MPa (field capacity) and -0.025 MPa is calculated. This difference, multiplied by the depth of 0.30 m, will indicate the Irrigated water amount. This is due to the fact that the soil layer 0-0.30 m deep encompasses almost all of the roots of rice irrigated by sprinkling and that the reading of the decision tensiometer represents the average matrix potential of water in the soil at this layer.