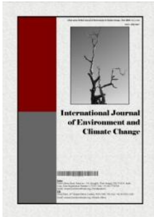

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Prospects and Constraints of Transplanted Maize, Wheat, Sorghum and Pearl Millet: A Review

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Cereal crops such as maize, wheat, sorghum and pearl millet are important for human consumption due to their nutritional benefits. These cereals play pivotal roles to meet world's food demand. However, maintenance of food security particularly in the circumstance of changing climate, constantly urges for modification of agro-techniques and one such modification is the incorporation of transplanting technique in these cereals as an alternative under a non-practicable situation of direct sowing. Transplanting is a method of transferring seedlings grown in nursery or others to the field. It has been already found to shorten the crop duration and improve germination, plant stand, seed and seedling quality parameters, growth, yield and economic profitability of these cereals. Besides, research findings are also available stating that transplanting helps these cereals to cope up with vagaries of weather and to exhibit greater radiation and water use efficiencies and suppression of weeds. Outcomes of transplanting are however dependent on various factors like methods of nursery raising, the variety used, mode of planting, age of seedlings etc. In spite of these prospects, transplanting technique is not so popular in these cereals due to poor dissemination, discouraging research findings, pest and disease problems, lack of suitable package of practices etc. Therefore, focuses are to be given in conducting more and more research trials to confirm its location and situation wise efficacy and also in developing and disseminating a suitable package of practices of transplanting accordingly.

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1. INTRODUCTION

Cereals (taxonomically, members of Gramineae/ Poaceae family) have remained as most important staple foods in almost every nation of the globe since prehistoric times. Starting from the period of hunting and gathering of wild types to this present era of cultivated ones, cereals have been dominating throughout in human diet [1]. They are rich source of complex carbohydrates, protein, fat, fibre, minerals, vitamins, enzymes etc [2]. Worldwide cereals are given priority due to their role in meeting caloric demands. Beside the human consumption, cereals also have their uses in industry, livestock sector, religious purpose etc. According to FAO [3], cereals top the chart among all the cultivated crops with global production of around 2721 million tonnes. Maize, wheat, sorghum and pearl millet are some important cereal crops grown intensively across the world over the years. Maize or corn (*Zea mays* L.), one of the chief cultivated cereals of the globe, scores third in terms of production after wheat and rice. Maize contains abundant amount of carbohydrates (70%), protein (10%), oil (4%), fat (5-7%), crude fibre (2.3%), ash (1.4%), vitamins (vitamin A, E, riboflavin, nicotinic acid), iron, phosphorus etc [4]. Its multipurpose uses as livestock feed, food for humans in various forms, industrial raw materials for production of alcohols, starch, syrup, sweeteners, ethanol or biofuels, textile products, cosmetics, paper, gum etc as well as high efficiencies to utilise radiant energy and CO_2 for ensuring ample production even under changing climate scenario have made maize to achieve several tags like 'miracle crop', 'queen of cereals', 'the crop of the future'. Wheat (*Triticum* sp.) is another major cereal crop of the globe. It is nutritionally rich in carbohydrates (60-80%), protein (10-15%), fat (2%), minerals (1.8%), crude fibre (2.2%), vitamins (Vitamin B complex, E) etc [5,6]. It is used mainly as food (direct or indirect consumption) in various forms (bread, pasta, spaghetti, macaroni, cake, noodles, porridge, baby food, biscuit, cookie, pastry etc), livestock feed, seed, starch and fuel. Since ancient days, wheat has been serving the hungry world and is therefore truly considered as most important staple food of the world [7]. Although, unlike maize and wheat, sorghum and pearl millet are categorized as minor cereals, they both hold great significance specially the arid/semiarid tropical areas or drought prone countries of the world. Sorghum (*Sorghum* sp.) is one of significant staple foods of rural people of African, South Asian, Central American countries and 5th most glorious cereal of the globe after wheat, rice, maize and barley [8]. It contains sizeable quantity of starch (69.5%), amylose sugar (26.9%), soluble sugar (1.2%), protein (11.4%), fat (3.3%), crude fibre (1.9%), ash (1.9%), vitamins (B complex), copper, magnesium, calcium, iron, phosphorus, zinc, potassium etc [9,10]. Although it is typically grown in dry land areas, sorghum is gradually gaining importance throughout the world for its high yield potential and diverse uses [11]. It is cultivated for grain (specially, to serve as food during lean period) as well as forage (to provide livestock feed). Besides, sorghum has important role as raw material in industrial sector (for preparations of fuel, starch, sugar, syrup, beverages etc). Pearl millet (*Pennisetum glaucum*) is another exigent dry land crop of the world. In drought prone countries like Africa, pearl millet is cultivated as resilient crop and used as major staple food and livestock feed. It is a good source of starch (66.7%), amylose sugar (25.9%), soluble sugar (2.1%), protein (10.6%), fat (5.1%), crude fibre (1.3%), ash (1.9%), vitamins (Vitamin A, B), calcium, iron, zinc, phosphorus, potassium, magnesium, manganese etc [9,12].

In the present unavoidable scenarios of changing climate, pest and disease infestations, deterioration of soil health and shrinkage of agricultural land coupled with urbanization and population increase, ensuring food security urges for more productivity of crops particularly through modification of agro-techniques. One such modification which is gaining momentum in recent times for increasing the productivity of maize, wheat, sorghum and pearl millet is shifting traditional crop establishment methods to transplanting particularly in adverse agro-climatic situation when traditional methods are not feasible. Ideal crop stand establishment is a vital prerequisite to cope up with climate change that further ensures vigorous growth and high productivity of crop [13]. In this context, transplanting is assumed as a major alternative of traditional direct sowing methods as it aims to ensure better crop stand and thereby crop growth and productivity.

2. TRANSPLANTING

Transplanting is a process by which a plant can be shifted from one place to another. In this technique, seeds are sown in nursery or pot/tray under controlled conditions with careful monitoring and later, with the onsets of favourable time and field condition, the seedlings are taken for planting in the main field. Transplanting technique is by far most popular in rice. Even, several vegetables like chilli, brinjal, tomato, mustard etc and flowers like lilies, chrysanthemum, petunias etc are often successfully grown with this technique. However, various literature evidences suggest that transplanting has been attempted in cereals like maize, wheat, sorghum, pearl millet also and positive outcomes from most of the attempts are very much inspiring.

2.1 Transplanted Maize: Prospects

Maize transplanting is relatively new but promising agronomic crop establishment option which is being adopted by various countries around the world today. With this technique, it is possible to achieve a successful production of maize as third crop in a year which is otherwise often not possible in context of changing climate and land use constraints. Further, late harvest of previous crops and short duration of crop specific season sometimes demand in cultivation of photo-insensitive maize with earliest possible maturity to uplift cropping intensity of farmers' fields. Under late planting situation, transplanting of maize is a promising option which overcomes yield reduction and helps the farmers to get a good produce which direct seeded maize fails to provide [14]. During mid-80s North Korea has first started to transplant maize in its 80% crop land area [15]. Later, farmers of Red river delta of Vietnam have successfully adopted this technology (in 1.2 million ha area) and harvested maize within 80 days [16,17,18,19,20,21]. Transplanting of maize has provided encouraging results in many regions of the world like North India [22,23], South Africa [24], Mexico [25], South China [26,27], Germany and Netherlands [28]. Already, North Korea has increased transplanted maize cultivation from 350000 ha to 700000 ha [17]. Vietnam, within the period between 1983 and 1990, has increased transplanted maize area from 50000 ha to 250000 ha [17]. FAO has predicted that transplanting of maize can also be beneficial to Bangladesh, Indonesia, Haiti etc [17,29]. The positive impacts of transplanting on maize cultivation are described below.

2.1.1 Better stand establishment

Transplanting of maize assures high crop stand establishment as chances of seedling mortality is comparatively less than direct seeded maize due to choosing healthy seedlings for transplanting [30,31,32]. Further, transplanting requires less seed rate to produce optimum plant population than direct sowing. Early establishment of maize seedlings through transplanting can be a factor for ensuring good plant density in main field [33]. Fanadzo et al. [24] stated that transplanted maize in South African conditions ensured better plant stand (96% of target) as compared to direct seeded maize (78% of target). It has been noticed that birds, squirrels, rats etc pose serious damage to germinated maize seedlings [34]. Besides, poor weather (wind, rainfall, temperature etc) and land situations also harm newly emerged seedlings very much, which is in most of the cases unrecoverable and results in seedling mortality. Raising maize seedlings in nursery under controlled conditions and sufficient monitoring followed by their transplanting under favourable field conditions, can be a suitable strategy to combat with seedlings damage related problems [24].

2.1.2 Superior seed quality parameters

It has been reported by researches from different corner of the world that nursery raising of maize has exhibited superiority of seed quality parameters. For instances, high germination percentage from sowing sweet corn seeds in plastic plug trays and consequently good field performance were observed by [35,36,37]. Fayaz et al. [32] experienced enhancements of germination percentage, leaf number, root and shoot lengths, seedlings fresh and dry weights and vigour index of sweet corn under controlled temperature in transplanted poly pot. Rattin et al. [30] and Di Benedetto et al. [38] also reported greater germination or emergence of maize by transplanting as compared to direct sowing in main field.

2.1.3 Shorter crop duration

By shifting to transplanting from direct sowing, it is possible to achieve maize production at least one to three weeks earlier [39,40] depending on variety and atmospheric temperature due to early flowering or shift from vegetative to reproductive phase [31]. In USA and France, transplanting has reduced the maturity of maize by 1-3 weeks and 10-12 days, respectively [41]. Kumar et al. [42] stated that as compared to direct sowing (100-110 days for *kharif* maize and 170-190 days for *rabi* maize), maturity of transplanted maize has been earlier (60-90 days for *kharif* maize and 110-130 days for *rabi* maize). Earlier, Basu and Sharma [43] also confirmed about shortening the crop duration of transplanted *rabi* maize and reported early crop maturity by 8-10 days. Miguel-Chávez and Larqué-Saavedra [25] from Mexico obtained matured maize crop within 134 days as compared to direct sowing in wet soil (151 days) and in dry soil (180 days). Ricketson and Thorpe [44] and Ledent et al. [45] observed earlier maturity of transplanted sweet corn by 7-12 days and 10-15 days, respectively over direct sowing. Miller [39] and Wyatt and Mullins [40] on the other hand observed 1-3 weeks earlier maturity of transplanted sweet corn over direct sowing. It is needless to mention here that although findings were variety and weather specific, transplanted maize matured early in every case.

2.1.4 Better withstand or skip of vagaries of weather

Long [26] opined that transplanting of maize seedlings successfully skipped end season drought in South China. Tinh [16] form Vietnam also observed similar type of result and reported that 7-10 days before harvesting of summer rice from Red River Delta, maize seeds were sown along the bunds and canals under adequate temperature, sunlight, humidity and seedlings were transplanted to main field on residual soil moisture after summer rice harvesting and before cultivation of spring rice, for early flowering and maturity of winter maize with conscious avoidance of late season drought. Miguel-Chávez and Larqué-Saavedra [25] from Mexico noticed that 15-20 days old transplanted maize seedlings flowered earlier (in 67 days) as compared to direct sowing in wet soil (88 days) and in dry soil (109 days) and thereby, successfully skipped drought during flowering. Further, they also observed avoidance of cool temperature during grain filling stage as it progressed earlier in response to flowering.

2.1.5 Greater weed suppression and water use efficiency

Transplanted maize observes less infestation of weeds as compared to direct sown maize and thereby minimises use of manual or chemical weed management practices. When transplanting is done in main field, maize plants are already developed by few days or weeks as compared to weeds which need times to emerge after land preparation of main field. As a result, transplanted maize seedlings have the ability to suppress weed population in the field by greater coverage of resources. Miguel-Chávez and Larqué-Saavedra [25] from Mexico used only one weeding in the entire growth period of transplanted maize. Further, they reported that transplanted maize ensured greater water use efficiency as compared to direct seeded maize due to better utilisation of water by transplanting of already developed maize seedlings with the onset of rainfall which was not possible with direct sowing, as direct sowing required few days to germinate and within this initial period, bulk of the water got evaporated.

2.1.6 Improved crop growth and yield

Improvement of crop growth and yield is the ultimate goal of any farmer. So far, several research works ([14,25,35,46,47,48,49] etc), have been identified regarding improvement of maize growth and yield by transplanting technique. In this context, it is worthy to mention that successful crop performance through transplanting relies on various factors such as raising of seedlings by different methods, age of seedlings to be transplanted, planting date, variety used, nutrient and water managements etc. Some of the research findings regarding improvement of maize growth and yield by transplanting according to various factors mentioned above have been listed in Table 1.

2.1.7 Economic viability

From economics point of view, reports are also available regarding the viability of transplanting of maize. Improvement of yield by this technique puts significant reflection on profitability of maize cultivation. Sobarad [50] found greater profitability from transplanted maize as compared to direct sowing. Various factors such as methods of nursery raisings, variety, age of seedlings etc determine the extent of economic viability under transplanting condition. Kumar et al. [42] obtained best benefit: cost from the seedlings raised in sand culture or raised beds. Besides, Kumar et al. [42] also observed that higher economic return and profit when 5 weeks old seedlings were transplanted over transplanting of 4, 6 and 7 weeks old seedlings.

Patel et al. [51] observed higher net return and profitability by using the variety HQPM 1 over GM 3 and transplanting 3 weeks old seedlings over others. Patel et al. [51] also found lowest profitability from transplanting of 5 weeks old seedlings and economic loss from transplanting of 6 weeks old seedlings. Hajong [52] obtained higher net return and benefit: cost by raising the maize seedlings in poly bag than raising the seedlings in raised bed, flat bed and poly cup. Hajong [52] further reported greater economic profit from transplanting of 7 days old seedlings than transplanting of 14 and 21 days old seedlings and direct sowing. Earlier, Ibrahim and Gopalasamy [48] recommended young seedlings for transplanting as they obtained best net return from transplanting of 5 days old seedlings, than transplanting of 10 days old seedlings and direct sowing.

2.2 Transplanted Wheat: Prospects

Worldwide, wheat is mostly grown through direct sowing. Instances of wheat established through transplanting are very rare. However, in recent years, transplanting of cereals other than rice is receiving considerable attention. Scientists are trying to incorporate this innovation in wheat cultivation also. Wheat if sown late, results in extreme yield loss due to terminal withdrawal of winter and onset of summer. In India, rice –wheat culture is most prevalent one. Late harvest of rice due to delayed maturity and renovation of land in most of the cases require times and thus prevent sowing of wheat at right time. As wheat is mostly a season specific crop, delayed sowing causes abrupt shift of vegetative and reproductive phases resulting in poor expression of crop growth and yield. With adoption of this new transplanting technology in wheat, problems of delayed sowing and terminal heat effect can be solved to some extent as transplanting reduces the crop duration by several days. Raising of wheat seedlings in nursery when rice is in the main field, provide farmers additional time between harvesting of rice and preparing their land for next crop wheat. This approach thus helps the farmers to establish wheat seedlings in the main filed absolutely at right time as farmers do not have to spend days waiting for emergence of seedlings which otherwise is most common with direct sowing. Not only in India, but also in various regions of the globe, where delayed harvesting of previous crop is a major setback, transplanting of wheat seedlings has very good prospect. Unlike rice, although wheat transplanting is not so popular, researches have been started many years ago. For instances, improvements of wheat yield by transplanting have been reported by Yoshioka and Fujii [53] and Chi et al. [54]. At the initial stages of this technology, gap filling was the only reason for its adoption because of its superiority over seed sowing on fertile soil to generate branches of active root and to uplift growth and yield of wheat [54]. In recent years, establishment of wheat through transplanting is being tried by some researchers in order evaluate its comparative performance with direct sowing. Xu et al. [55] reported that some areas of China where labour problem had been less established, adopted wheat transplanting successfully (In early 70s, almost 1700 ha or 30% area of Beijing adopted cultivation of transplanted wheat). In a study, transplanting of wheat had been found to exhibit greater plant height, top stem diameter, total leaf area, number of kernels per spike, kernel weight, spike length, rachis internode length and increment of yield over early and late sowings [55]. Further, Xu et al. [55] tried to evaluate the comparative performance of different timings of transplanting and direct sowing and observed that both early and late transplanting of seedlings expressed superior growth and yield of wheat, over early and late sowing. Further, among different timings of transplanting, wheat seedlings transplanted early exhibited greater spike per m^2, kernel weight, leaf area and yield over late transplanting which on other hand, achieved greater kernels per spike, spike weight, spike length, spikelet per spike, spikelet internode length, green area etc and lesser stripe rust and powdery mildew disease indexes over early transplants [55]. In Haryana, India, Rai et al. [56] used hydroponically raised wheat seedlings of different ages for transplanting and observed that transplanting was superior in terms of crop performance over direct sowing and specifically, transplanting of 7 days old seedlings attained greater plant height, tiller numbers, panicle length, number of grains per panicle, biomass and yield over transplanting of 10 and 12 days old seedlings. In another experiment, Hossain and Altab Maniruzzaman [57] in Bangladesh reported that late transplanting of wheat recorded 16% higher grain yield due to production a greater number of grains per spike and grain weight over direct sowing. Transplanting of wheat thus has very good prospect for successful production as transplanting delays senescence, produces high root biomass, more tillers and possesses high resistances to lodging and diseases [54].

Table 1. Research findings regarding the effect of transplanting according to various factors on performance of maize

Factor(s)	Crop performance(s)	Finding(s)	Reference(s)
Methods of nursery raising	Crop stand establishment	Sand bed and raised bed raisings of maize seedlings were healthier due to good aeration, tilth and other management factors and therefore got established better by showing low mortality and higher recovery of transplanting shock than plastic and flatbed raisings. The finding was confirmed by Basu et al. [92].	[42]
	Seedling quality	Sowing of large size sweet corn seeds (>0.6 cm) on large trays (58 cm^3) filled with coconut fiber and vermiculite (2:1) produced higher germination % and root length than sowing of small size sweet corn seeds (<0.6 cm) on small trays (18 cm^3) filled with coconut fiber and sand (2:1). Sowing of large size sweet corn seeds (>0.6 cm) on small trays (18 cm^3) filled with coconut fiber and sand (2:1) produced greater root fresh weight, while sowing of small size sweet corn seeds (<0.6 cm) on large trays (58 cm^3) filled with coconut fiber and sand (2:1) exhibited higher length and fresh weight of shoot.	[93]
		Sowing of sweet corn seeds in 49-cell tray showed better germination % than sowing on 19-cell tray.	[94]
	Growth attributes	Nursery raisings in sand bed and raised bed produced healthier seedlings which on transplanting attained greater plant height, longer leaves, dry matter accumulation at 30, 60 and 90 days after transplanting (DAT), root volume and leaf area index at 90 DAT of *rabi* maize as compared to flat bed and plastic bed raisings.	[42]
		Seedling establishment in poly pot exhibited more plant height, dry matter accumulation, leaf area index, numbers of functional leaves than nursery raised seedlings and direct sown maize seed in main field.	[32]
		Nursery raising of maize seedlings in poly bag exhibited better plant height and dry matter accumulation over raisings of seedlings in raised bed, flat bed and poly cups.	[52]
	Flowering and maturity	As compared to direct sowing, maize transplanting achieved early flowering (50% tasseling and silking), grain filling with best performance by raising of seedling in cup nursery and thereby 7-8 days earlier maturity with earliest by seedling raising in poly bag nursery.	[95]
		Raisings of seedlings in in sand bed and raised bed attained 50 % flowering 8-10 days later than plastic bed raised seedlings but achieved 10-12 days early maturity.	[42]
		Transplanting of seedlings raised in 50-cell plastic strip matured 7-9 days earlier than bare ground raising. The result was in conformity with the findings of Miller [39] and Wyatt and Akridge [97].	[96]
Planting date	Growth attributes	In comparison between three planting dates (25th June, 10th July and 25th July), planting on 25th June ensured best plant height and dry matter accumulation under transplanted condition.	[50]
		Among three transplanting dates used (21st December, 5th January and 20th January), planting on	[98]

Factor(s)	Crop performance(s)	Finding(s)	Reference(s)
		21st December produced tallest plant with relatively higher leaf area index and dry matter accumulation over others.	
		Among various planting dates used (20, 30 November, 10, 20, 30 December), planting on 10th December and 20th November recorded tallest and shortest maize plants respectively.	[99]
Planting density	Growth attributes	Transplanting of sweet corn at a density of 4 seedlings per m^2 exhibited higher plant height, dry mater accumulation, relative leaf area expansion rate, relative growth rate, net assimilation rate than high densities (8 and 12 seedlings per m^2).	[30]
Age of seedlings	Crop stand establishment	Transplanting of older maize seedlings (7 weeks) exhibited more mortality and lower stand establishment than younger seedlings (5 weeks).	[42]
		Young (three weeks old) seedlings exhibited better crop stand as compared to older seedlings (lowest in 6 weeks old seedlings).	[31]
		Transplanting of 40 days old maize seedlings resulted in less mortality and better stand establishment than 60-80 days old seedlings.	[23]
	Growth attributes	Transplanting of 7 weeks old seedlings recorded greater plant height, longer leaf and dry matter accumulation up to 90 DAT after which senescence took place and from 90 DAT onwards 5 weeks old seedling transplanted maize exhibited greater plant height, leaf area index, dry matter accumulation and root biomass. These findings were in line with the works of Andreas and Ransom [100], Dhillon et al. [101], Kumar et al. [102] and Town Phung [103].	[42]
		Transplanting of 6 weeks old *rabi* maize seedlings accumulated maximum dry matter over two weeks old seedling transplanting, but achieved lowest root length and root biomass at 30 DAT due to less recovery from transplanting shock as compared to three weeks old seedling transplanting. Similar observations have been reported by Adesina et al. [104] and Agbaje [105]. Moreover, 6 weeks old transplants were more vulnerable to lodging than others.	[51]
		Transplanting of 6 weeks old *rabi* maize seedlings attained maximum plant height at 20 and 40 DAT as they were already grown by few folds in nursery but at maturity, recorded lowest plant height and maximum height was achieved by transplanting of three weeks old seedlings. Similarly Three weeks old seedling transplanting produced highest number of leaves at maturity. Dale and Drennan [33] also observed decline in leaf number at 45 days old seedling transplanting compared to younger ones.	[31]
		Transplanting of maize seedlings at two leaf stage recorded rapid growth (such as plant height) than transplanting of seedlings with three or four leaf stages. It was in agreement with the findings of Ma and Li [106] who also suggested transplanting of seedlings with 2-3 leaf stages for best growth. Zhang [107] earlier reported better survival of younger seedlings than older ones from transplanting shock.	[108]

Factor(s)	Crop performance(s)	Finding(s)	Reference(s)
		Transplanting of 7 days old maize seedlings accumulated greater amount of dry matter at harvest over direct sowing and transplanting of 14 and 21 days old seedlings.	[52]
		Transplanting of seedlings at 55 days after sowing (DAS) ensured higher plant height, leaf area index and dry matter accumulation than those at 40 DAS.	[98]
	Crop duration	Transplanting of 20-30 days old seedlings got established 15-20 days prior to older spring maize seedlings and thereby achieved early maturity.	[109]
	Flowering and maturity	As compared to younger seedlings, transplanting of 7 weeks old maize seedlings attained 50% flowering and maturity a lot earlier.	[42]
		Transplanting of older seedlings (21 days) ensured faster maturity than younger ones (14 days old) and direct sowing.	[99]
		Transplanting of 4-5 weeks old seedlings matured 8-10 days earlier than direct sown maize.	[92]
Method of transplanting	Growth attributes	As compared to flat bed or raised bed planting, transplanting of seedlings on ridges produced highest plant height, leaf area index and dry matter accumulation of maize.	[98]
Nitrogen rate	Days to 50% flowering and milking	Application of various doses of nitrogen in transplanted maize ensured quick onsets of 50% flowering and milking stages as compared to direct sowing with earliest onsets occurred under application of 180 kg N/ha and above.	[24]
Variety	Crop stand establishment	Variety HQPM 1 exhibited better crop stand than GM 3 under transplanting condition.	[31]
	Growth attributes	Variety HQPM 1 produced higher plant height and more number of leaves than GM 3 under transplanting condition.	[31]
		Variety HQPM 1 exhibited higher dry matter accumulation, root length and root biomass and less lodging percentage that variety GM 3 under transplanting condition.	[51]
Methods of nursery raising	Yield attributes and yield	Transplanting of sand bed and raised bed seedlings exhibited higher number of grains per cob, 100 grain weight and better grain yield of maize as compared to flat bed and plastic bed raised seedlings. Dhillon et al. [101] reported similar type of observations.	[42]
		Seedling establishment in poly pot produced greater cob length, girth, weight, number of grains per cob and number of cobs per plant, green cob yield, green fodder yield and harvest index than nursery raised seedlings and direct sown maize seed in main field.	[32]
		Nursery raising by several methods for transplanting achieved greater cob length (cup nursery), number of cobs per m^2 (poly bag and cup nurseries), number of grains per cob (dry bed and compost nurseries), 1000 grain weight (dapog nursery), grain yield (poly bag and cup nurseries)and harvest index (mud cake nursery) than direct sowing.	[95]
		Nursery raising of maize seedlings in poly bag recorded higher grain and stover yields over raisings of seedlings in raised bed, flat bed and poly cups.	[52]

Factor(s)	Crop performance(s)	Finding(s)	Reference(s)
Planting date	Yield attributes and yield	In comparison between three planting dates (25th June, 10th July and 25th July), planting on 25th June recorded highest grain yield, stover yield and harvest index under transplanted condition.	[50]
		Among three transplanting dates used (21st December, 5th January and 20th January), planting on 21st December produced highest grain yield, stover yield and harvest index.	[98]
		Among various planting dates used (20, 30 November, 10, 20, 30 December), planting on 20th November produced maximum cob length and diameter, number of cobs per plant, number of grains per cob row and grain yield, while planting on 30th December recorded lowest cob length and diameter, grain and stover yields. Highest stover yield was recorded by planting on 30th November.	[99]
Planting density	Yield attributes and yield	Transplanting of sweet corn at high density (12 seedlings per m^2) recorded although the low individual ear yield but produced higher yield per ha by increasing harvest index and radiation use efficiency than the density of 4 seedlings per m^2. The result was in conformity with the findings of Sarlangue et al. [110].	[30]
Age of seedlings	Yield attributes and yield	Transplanting of 5 weeks old maize seedlings recorded maximum grains per cob, 100 grain weight, grain and stover yields and grain: stover over other ages of seedlings while 7 weeks old seedling transplanting remained as poorest performer due to its forced maturity. Similar findings have been put forward by Dhillon et al. [101], Dale and Drennan [33] and Basu et al. [92].	[42]
		Transplanting of young (three weeks old) seedlings produced maximum cob length, girth, number of grains per cob, grain and straw yields over older ones (lowest in 6 weeks old seedlings) due to improved source-sink relationship.	[31]
		Transplanting of maize seedlings at two leaf stage produced greater yield than transplanting of seedlings with three or four leaf stages. It was in conformity with the findings of Ruan [111] who also obtained best result from transplanting of seedlings with two leaf and one bud.	[108]
		Transplanting of three and six weeks old seedlings produced respectively highest and lowest grain and straw yields, harvest index and protein content.	[51]
		Transplanting of 7 days old maize seedlings recorded highest grain yield, stover yield and harvest index over direct sowing and transplanting of 14 and 21 days old seedlings.	[52]
		Transplanting of 21 days old seedlings produced highest 1000 grain weight but lowest grain yield (highest from 14 days old seedlings) and stover yield. Harvest index was however highest in transplanting of 21 days old seedlings.	[99]
		Transplanting of seedlings at 55 DAS ensured better grain yield, stover yield and harvest index than those at 40 DAS.	[98]
		Transplanting od 14 and 21 days old maize seedlings recorded statistically similar yields.	[112]

Factor(s)	Crop performance(s)	Finding(s)	Reference(s)
Method of transplanting	Yield attributes and yield	As compared to flat bed or raised bed planting, transplanting of seedlings on ridges produced highest grain yield, stover yield and harvest index of maize.	[98]
Nitrogen rate	Yield attributes and yield	Transplanted maize required relatively low nitrogen to produce higher cob length and better green cob yield than direct sown maize. However, at higher doses of nitrogen, the difference was not prominent between direct sowing and transplanting.	[24]
Variety	Yield attributes and yield	Variety HQPM 1 produced maximum cob length, girth, number of grains per cob, grain and straw yields than GM 3 under transplanting condition. The result was in conformity with the findings of Anil and Sezer [113] in transplanted sweet corn.	[31]
		Variety HQPM 1 produced higher grain and straw yields and harvest index than GM 3 under transplanting condition.	[51]
		Variety Pacific-11 produced greater yield attributes and yield than variety BARI maize-6 under transplanting condition.	[99]

2.3 Transplanted Sorghum: Prospects

Farmers of dry land areas suffer most due to erratic rainfall and its poor distribution. Cultivation of sorghum being the dry land crop needs special care under the context of climate change. Transplanting of sorghum is a promising technique to ensure food security in arid and semi-arid areas under weather bound risk and unpredictability. With this technique, it is possible to prolong the growing season and to obtain a good produce under poor rainfall condition where direct sowing fails to establish [58,59,60]. Besides, direct sowing of sorghum by common broadcasting often causes damages to germinated seedlings by wind, sun scorching, birds, squirrel and rodent attack while such damages can be avoided with transplanting of nursery raised healthy seedlings [61]. Under dry land situation where irrigation fails to be incorporated, transplanting of sorghum shows better establishment than common broadcasting of seeds [62]. Even in irrigated situation, transplanting of sorghum is a viable alternative of direct sowing. In condition of delayed onset of rainfall, farmers are forced to wait for several days to get favourable condition (i.e. start of rainy season) for sowing sorghum seeds in the field. This often delays the crop period and reduces cropping intensity of the field. Conversely, transplanted sorghum does care about onset of rainy season as healthy seedlings are raised in nursery under controlled condition and as a result, the crop can be harvested prior to direct sowing, ensuring the cultivation of next crop [63]. Traditionally, transplanting of sorghum meant only the gap filling from thinning operation and farmers of dry land areas got subsistence through it. For instance, Chivasa et al. [64] mentioned that gap filling by transplanting of thinned sorghum seedlings saved 97% of Zimbabwean farmers. Transplanting of sorghum seedlings for gap filling has also been noticed in few areas of Africa and Asia [65]. However, such way of transplanting often delays the maturity of gap filled plants, provides plants to face terminal drought, pest and disease infestations and invites problems regarding harvesting and starting next crop cultivation. According to Wien [66], true transplanting should involve nursery raising of seedlings. Olabanji et al. [58] reported raising of sorghum seedlings on edges of lake and transplanting under residual moisture at the age of 30-40 days in NE Nigeria. Countries like Zimbabwe, Ghana have already adopted the techniques of nursery raising before rainy season and transplanting of 3-5 weeks old sorghum seedlings with onset of rain. BOSTID [67] and Mapfumo et al. [68] also reported about sorghum cultivation traditionally through transplanting in West Africa. In Cameroon, raising of sorghum seedlings in nursery during rainy season and their transplanting after rains recedes have been stated by Chantereau and Nicou [69]. It is common that late harvest of previous crop due to vagaries of rainfall causes failure of next crop due to poor establishment through direct sowing, terminal moisture stresses and several other problems. Under such late planting situation, transplanted sorghum performs better than direct sowing [70]. Bitzer [71] reported that in Kentucky, USA, late maturing sweet sorghum ensured 3 weeks early maturity and escaped terminal frost through raising of seedlings in tobacco float system followed by transplanting in the main field. In sorghum cultivation weed infestation specially, striga is a major problem which can be solved through transplanting technique [61]. Clottey et al. [60] reported significant reduction of striga population in transplanted sorghum through seedlings with well-developed roots in nursery which unlike direct sowing, did not release exudates to stimulate striga germination. Besides, studies by Clottey et al. [60] and Young and Mottram [61] have reported that transplanted sorghum exhibits less infestation of insect pests such as sorghum shoot fly, spittle bug etc than direct sowing. In another study conducted by Jada et al. [72], root knot nematode (*Meloidogyne javanica*) infestation in nursery has been found to be checked after transplanting in the main field due to less multiplication and migration under residual soil moisture condition. Advantages of transplanting sorghum in conservation of seeds and water have also been reported by Mapfumo et al. [73] and Young and Mottram [61], respectively. Use of minimal water or residual moisture for raising sorghum seedlings in nursery has been reported by Assefa et al. [59]. Further, works are available to state that transplanting ensures better crop performance than direct sowing. Olabanji et al. [58] reported that transplanted sorghum produced a greater number of grains per panicle than direct sowing. Diress and Mitiku [74] and Young and Mottram [61] observed improved yield through transplanting of sorghum. Better stand establishment, greater number of tillers, effective tillers, early flowering, high yield through transplanting over direct sowing of sorghum have been reported by Assefa et al. [59]. Workineh [75] reported that sorghum transplanting on basin along with application of 64:46 kg N: P_2O_5 per ha outperformed other planting options and remained at par with direct sowing under same dose of N: P_2O_5 per ha in terms of grain yield and rain water use efficiency. Performance of transplanted sorghum is very much variety and location specific. In a study conducted by Krishnamurthy et al. [76], among five sorghum varieties taken, CSH-1 and Swarna performed best in terms of dry matter accumulation, leaf area, dry weight per ear, grain weight per ear, 1000 grain weight and grain yield by surviving transplanting shock the most. Age of seedlings, planting date, seedling density, leaf numbers etc are some other important factors to be considered for successful sorghum cultivation through transplanting. Depending on location, agro-climatic situations, age of seedlings for transplanting (which is a major factor for successful sorghum cultivation as mentioned by Krishnamurthy et al. [76]) is decided. Chantereau and Nicou [69] stated 30-40 days old seedlings are most suitable for sorghum transplanting while Oswald et al. [65] obtained best yield from transplanting of 7-10 days old seedlings. Tenkouano et al. [70], in another research, reported smaller number of sorghum grains per head from transplanting of very young seedlings as compared to medium aged ones. Villela and Junior [77] and Mapfumo et al. [73] reported decrease of number of grains per panicle with increased age of sorghum seedlings. Agbaje and Olofintoye [78] in their study found relatively short plant height when 8 weeks old sorghum seedlings were transplanted due to transplanting shock. Assefa et al. [59] noticed that transplanting of 20-50 days old sorghum seedlings exhibited 10-25 days and 50-65 days early flowering and maturity respectively than direct sowing with earliest flowering by escaping terminal drought and best yield observed through transplanting of 30-45 days old seedlings raised in nursery at 7 cm plant to plant spacing. Similarly, Young and Mottram [61] reported from their study that 20, 30 and 40 days old seedlings flowered much earlier than 50 days old sorghum seedlings. Increased age of seedlings producing tallest plant and leaf number in nursery and tiller number (but less effective tiller number), earliest flowering (specially, under raising of seedlings at wide plant to plant spacing) in the main field have been noticed by Assefa et al. [59]. Mapfumo et al. [73] also reported about early flowering from transplanting of older sorghum seedlings. Assefa et al. [59] further noticed that young seedlings (around 30 and 40 days old) grown at wide nursery plant to plant spacing (7 cm) exhibited better survival by mitigating the transplanting shock than older seedlings (around 50 days old) with narrow nursery plant to plant spacing (3 cm). Assefa et al. [59] also reported that nursery raising of seedlings at narrow (3 cm) and wide (7 cm) plant to plant spacings made tallest seedlings and highest number of leaves respectively. As compared to direct sowing and youngest (30 days) and oldest (50 days) seedlings, medium aged sorghum seedlings (40 days) ensured maximum grain yield while both youngest and medium aged seedlings achieved higher biomass yield over direct sowing and oldest seedlings [59]. Mapfumo et al. [73] in their study observed effects of leaf number and seedling age on performance of transplanted sorghum and reported that leaf clipping up to 39 days old seedlings increased tiller number with decrease of same at 49 days old seedlings and vice versa in case of non-clipping of leaves during transplanting time. However, Mapfumo et al. [73] also observed that mid aged seedlings (39 days old) under non clipping of leaves during transplanting produced maximum number of grains per panicle but best yield was achieved through leaf clipping at transplanting of younger seedlings. In another study, Mapfumo et al. [68] wanted to find out the impacts of water and density of sowing on performance of sorghum in nursery as well as in main field and reported that at 28 days after sowing, increased density of sorghum seedlings (1000 plants per m^2) in nursery recorded lowest and highest leaf areas under 25% and 75% soil moisture depletions respectively. However, in main field condition, 75% depletion of nursery soil moisture expressed lowest yield as compared to 25% and 50% nursery soil moisture depletions. The combinations of low seedling density (500 plants per m^2) and 75% soil moisture depletion in nursery, medium seedling density (750 plants per m^2) and 50% soil moisture depletion in nursery, high seedling density (1000 plants per m^2) and 25% soil moisture depletion in nursery achieved maximum 1000 grain weights of sorghum [68].

2.4 Transplanted Pearl Millet: Prospects

Cultivation of pearl millet particularly in dry land areas has faced some major constraints in recent years due to erratic and non-uniform rainfall. Poor establishment and severe water stress faced by this crop have resulted in considerable reduction of yield. Transplanting of pearl millet thus has become a relevant option as nursery raised seedlings show good establishment in main field [62] as well as reduce the exposure to water stress by shortening crop duration [79].

Wien [66] stated that minimisation of over-crowding of plant population and conservation of water by maximising water use efficiency can be possible with transplanting technique. Under delayed onset of rainfall or its early break, transplanting of pearl millet seedlings is a viable alternative to direct sowing as seedlings can still be grown for another few days in nursery. Even, in nursery, seedling growing requires minimal water application and transplanting can be even done in soil with residual moisture condition [61]. Mapfumo et al. [68] confirmed that depletion of nursery soil moisture although curtailed down the seedlings growth a bit, there was no significant impact on stand establishment, durations of 50% flowering and maturity and grain yield observed in the main field. Further, nursery raising of seedlings ensures greater and vigorous plant density in the main field through transplanting from less seed rate as good maintenance of seeds in nursery along with methods such as seed priming improve germination percentage of pearl millet seeds. Traditionally, millet growers have used transplanting technique for filling gap from thinned seedlings [80]. In India, under irrigated condition of Tamil Nadu, Karnataka, Gujarat and Andhra Pradesh, transplanting of pearl millet (*Bajra*) is a common practice where 15-20 days old seedlings raised from raised bed nurseries are being transplanted in moist soil and the crop matures 18-21 earlier than direct seeded crop [80]. Early maturity of transplanted *Bajra* reduces hunger days for the people of arid and semi-arid areas such as Zimbabwe, Ghana etc where even women are expressing their interests in transplantation technique [61]. Moreover, pearl millet transplanting has been reported to successfully reduce downy mildew infestation [80] and millet stem borer attack [81] in the crop period. Further, works of several researchers around the world suggest that transplanted pearl millet expresses better growth and out yields direct seeded/broadcasted pearl millet. Upadhyay et al. [82] and Singh et al. [83] noticed enhancement of pearl millet yield and recoupment of yield reduction under late sown condition. Earlier, Mann and Singh [84], Mercer-Quarshie [85], Labe et al. [86] and Robinson [87] also observed increment of pearl millet yield through transplanting. Young and Mottram [61] reported that transplanted pearl millet comparatively achieved early flowering, maturity and enhancement of grain and stover yields over direct sown pearl millet. Lopez-Dominguez et al. [88] similarly found increment of stover yield of fodder pearl millet grown through shifting from direct sowing to transplanting. Crop performances of pearl millet through transplanting take several factors such as age of seedlings, planting date, seedling density, leaf numbers, variety etc under consideration. In 2006, Murungu et al. [89] reported that age of the seedlings exerted variable impacts on pearl millet produce with however, comparatively better yield observed from transplanting of 30 days old seedlings over direct sowing under late sown condition, which confirmed the findings of Young and Mottram [61] that 20-30 days and 30-40 days old pearl millet seedlings were suitable for transplanting under early and late sown scenarios, respectively. Jan et al. [79] observed that transplanted pearl millet was superior over direct seeded pearl millet in terms of plant height, number of leaves per plant, number of grains per panicle, 1000 grain weight and grain yield. Earlier, Pal [90] and Mapfumo [62] also confirmed the increments of 1000 grain weight and grain yield of pearl millet grown through transplanting method. Further, Jan et al. [79] observed that early date of pearl millet transplanting achieved best plant height, number of leaves per plant, panicle length, panicle weight, number of grains per panicle, 1000 grain weight and grain yield as early transplanting utilised more photoperiod for light interception, production and translocation of photosynthates to various sinks than late transplanting. Chouhan et al. [91] noticed that early transplanting gave better yield of summer pearl millet than late transplanting. In a different study, Mapfumo et al. [73] observed that transplanting of older pearl millet seedlings established poorly and attained early flowering and resulted in lesser yield as compared to younger ones. Mapfumo et al. [73] observed further that seedling leaves clipped during transplanting helped to recover transplanting shock and made crop to best withstand water stress as transpiration was checked through leaf clipping, which resulted in better establishment and yield of pearl millet over transplanting of non-clipped seedlings.

2.5 Constraints of Transplanting

Transplanting, apart from holding good prospects in maize, wheat, sorghum and pearl millet, also poses several constraints of adoption as well as demerits. As transplanting technique of these crops is very much unorthodox, stereotypic mentality of farmers in sticking to the traditional crop establishment practice rather than updating themselves with technological interventions is prominent. Further, poor extension services, lack of adequate demonstration and awareness, lack of facilitation of positive assurance and credits in case of risk etc aggravate the situation of unpopularity of transplanting in maize, wheat, sorghum and pearl millet. Labour crisis in present agricultural scenario is another important reason for farmers' reluctance on adoption of transplanting as it is a labour-intensive approach (more steps involved than direct sowing). Sometimes, transplanting urges for some initial capital investment for fencing, preparation and monitoring of nurseries which small and marginal farmers fail to afford. Damage of seeds and seedlings by termites, ants, birds and animals in unprotected nursery, lack of availability of water and other input sources near the nursery etc are some important constraints associated with transplanting. Further, as compared to direct sowing which is better acceptable due to its less demand of concentration of mind, more attention and care regarding seedling management practices, protection etc are needed to be paid in case of transplanting. Often, long distance of nursery from the main field is another constraint as transplanting needs quick response from uprooting of seedlings from nursery to establishment in main field. Besides, transplanting is not always and everywhere feasible due the eccentric behaviour of weather. For instance, if onset of rain gets delayed, there is a chance of overgrowth of seedlings in nursery. Further, there is lack of suitable package of practices regarding the preparation and maintenance of nurseries, time of transplanting, density of transplanting, nutrient, water and pest management schedules, inter-cultural operations etc. Another fact is that the outcomes of transplanting are not always encouraging. Many researchers have reported no growth and yield improvements and in fact, reduction of growth and yield by adopting transplanting over direct sowing. For instances, Zhao et al. [108], Wellbaum et al. [114], Wyatt and Akridge [97], Waters et al. [41], Ricketson [115], Wyatt and Mullins [40], Pendleton and Egli [116] reported reduced plant heights and low yields from transplanted sweet corns as compared to direct sowings due to the effect of transplanting shocks. Monteiro et al. [63] reported comparatively less biomass in transplanted sorghum than direct sowing. Carranza De La and Vicuna [117] and Dahatonde [118] observed reductions of yield of maize and sorghum respectively, under transplanting condition. Di Benedetto and Rattin [47] reported poor performance of transplanted maize due to transplanting shock and low potential of root replacement. Andonova et al. [119] found that direct sown sweet corn exhibited better leaf area index, radiation use efficiency, dry weight, relative leaf area expansion rate, relative growth rate and net assimilation rate than transplanted sweet corn. Moreover, transplanting is often associated with the problem of insect pest and disease infestations. For instances, Aboubakary et al. [120], Mathieu et al. [121], Ajayi et al. [122] reported infestation of lepidopteran stem borer in transplanted sorghum. Djimadoumngar [123], Ratnadass [124], Ezzeldin et al. [125], Djodda et al. [126], Jacques et al. [127] found two types of lepidopteran stem borer (*Sesamia cretica* and *Sesamia poephaga*) in transplanted sorghum. Djodda et al. [126] stated that infestation of lepidopteran stem borer varies according to variety, date and method used in transplanting of sorghum. Jada et al. [72] reported that infestation of seedlings by root knot nematode in nursery reduced vegetative growth, produced thin stem and caused chlorosis and yellowing of leaves. Bitzer [71] observed damping off disease in nursery and pre mature heading in main field when early maturing sorghum was used for transplanting.

3. CONCLUSION

Despite of its several constraints, transplanting holds very good prospects in cereals like maize, wheat, sorghum and pearl millet. Under vagaries of weather and engagement of land by previous crop, when direct sowing is not possible, transplanting of these cereals can be promising alternative for the farmers to mitigate crop failure and improve cropping intensity and performance. However, this unfamiliar technology needs to be disseminated properly through strong extension services. Besides, ideal package of practices of this technology should be developed for various agro-climatic conditions. Further, it is important to highlight here that this modification of agro-techniques i.e. shifting from direct sowing to transplanting of cereals other than rice is now at rudimentary stage. Hence, there is a pertinent need of the hour for various multi-locational and situational research works to confirm location and situation wise efficacy of this unorthodox technology before adopting it for commercial crop cultivation.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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