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Wheat /faba bean intercropping system in perspective

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Abstract

In the United Kingdom (UK) and other areas with similar growing conditions wheat (*Triticum aestivum* L.) /faba bean (bean; *Vicia faba* L.) intercropping system has been shown to be promising. However, wheat/ bean intercropping system appear to be less adopted despite empirical evidences that indicate this intercrop combination is productive. Whilst evidences from research on different aspects of the production of wheat/bean intercropping system indicate positive benefits, an assemblage of these various increase in our understanding of this intercrop combination is lacking. With emphasises on materials from the UK, this paper reviews the cultural practices, determinants of yield (s) and seed yields of wheat/bean intercropping system in relation to the constraints and prospects for the adoption of this cropping system.

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Introduction

Intercropping, defined simply as the growing of two or more crops together simultaneously in the same piece of land has been shown to be beneficial in terms of yield stability, increase in total yield, pest and disease management, weed management, erosion control, and soil fertility amongst others (Willey, 1979a; Innis, 1997; Hauggard-Nielson *et al.,* 2006). Several factors are usually considered in choosing crop combinations to intercrop. Some of these factors include crop architecture, growth habit, life span and management practices of the crops, climatic conditions, length of growing seasons, local preference, and growers demand just to mention a few (Ofori and Stern, 1987; Fukai and Trenbath, 1993; Connolly *et al.,* 2001). In any case, the selection of component crop that minimize intercrop competition and maximize complementary effects between the component crops in resource use is the ideal (Willey, 1979b; Hauggard-Nielson *et al.,* 2006).

The most common intercropping system practiced worldwide is based on the cereal/legume combinations (Willey, 1979b). For instance, reports show benefits of wheat (*Triticum aestivum* L.)/faba bean (*Vicia faba* L.) (henceforth referred as bean in this paper) intercropping in terms of land use efficiency in the United Kingdom (UK) (Haymes and Lee, 1999; Ghanbari-Bonjar and Lee, 2002). Whilst wheat/bean intercropping system does not appear to be restricted to the UK environment alone, here greater attention was given to the literatures from the UK. In any case, the main reason for the widespread practice of cereal/legume intercropping system is that it reduces the need for nitrogen (N) fertilizer (Ofori and Stern, 1987). I will return to this point in a subsequent part of this paper. However, it should be pointed out that to improve the performance of cereal/legume intercropping is not restricted to N fixation only. It is possible to manipulate agronomic practices to improve either spatial and/or temporal complementarity in radiation interception and/or the efficiency of its use amongst the component crops in an intercrop (Vandermeer, 1989; Yahuza, 2011a). Indeed, this might also apply to water and non-nitrogen nutrients (Azam-Ali and Squire, 2002).

Broadly, there are two types of wheat varieties: winter wheat and spring wheat. The former is a long duration type because it needs a period of vernalization, a phenomenon that the latter type, which is short duration, does not have (Gooding and Davies, 1997). Similarly, there are two types of bean varieties: the longer duration winter types and the shorter duration spring types (Bulson, 1991; Bulson *et al.,* 1997). In this paper, references may be made to winter-sown and spring-sown varieties of the two crops in certain cases. Similarly, since wheat/bean intercropping experiments have been carried out under both organic (Bulson, 1991; Bulson *et al.,* 1997) and conventional (Haymes and Lee, 1999) management system, here the two systems are discussed in certain cases. It would interest the reader that previously, wheat/bean intercropping system was commonly practiced, but the system was abandoned due to differences in maturity dates of the two crops, which makes harvesting using machines impractical (Bulson, 1991; Bulson *et al.,* 1997). Fortunately, the constraint of differences in maturity dates was overcome by breeding efforts (Bulson, 1991).

Largely, intercropping benefits are usually greater when the growth duration between the component crops differs widely (suggesting temporal effects) than when the crops durations are similar (suggesting spatial effects) (Fukai and Trenbath, 1993; Yahuza, 2011b). In most of the wheat/bean intercropping experiments carried out in the recent past, both wheat and bean were sown and harvested simultaneously (Bulson *et al.,* 1997; Haymes and Lee, 1999), indicating that spatial effects may be responsible for the positive benefits reported. One explanation for this may be to minimize cost by simultaneous sowing and/or harvesting of both crops (Bulson, 1991). The mechanization advantage not withstanding, it may be possible to reduce the yield losses of wheat by delaying sowing date of bean to benefit from temporal complementarity in resource use.

A few wheat/bean intercropping experiments have been carried out on different aspects of the production of this intercrop combination (Bulson, 1991; Bulson *et al.,* 1997). However, despite evidences to indicate that this intercrop combination is productive, there has been less adoption by the target growers. One explanation could be due to the facts that these various increase in our understanding of the production of wheat/bean intercropping system has not been gathered in a single work. Here, based on empirical evidences from the literatures an attempt was made to review cultural practices, yields and other factors associated with the production of wheat/bean intercropping system in relation to constraints and prospects for the adoption of this intercrop system.

Cultural practices

For the sole crop, basically, irrespective of the crop species involved the major cultural practices are land preparation, sowing, fertilizer application, weed management, pest and disease management and final harvesting (Gooding and Davies, 1997). The complexity of intercropping as it relates to the agronomic practices is that the two or more component crops may have differences in the type and/or timing of each of these cultural practices (Azam-Ali and Squire, 2002). Consequently, the success of any given intercropping system depends largely on whether or not the component crops can be simultaneously managed agronomically (Vandermeer, 1989). Interestingly, the winter wheat varieties have similar duration as the winter bean varieties whilst the spring wheat varieties have similar durations as the spring bean varieties. This clearly indicate that it may be possible manage the two crops simultaneously as was previously demonstrated (Haymes and Lee, 1999).

Site selection, pre-sowing operations and sowing

Appropriate site selection is necessary for the cultivation of any crop whether under experimentation or farmer managed conditions (Vandermeer, 1989). Several factors are often considered in choosing site to grow any given crop species, of which preceding crops that was established is one of the most critical (Huxham *et al.,* 2005). For wheat/bean intercropping systems there appear to be less uniformity in the crops species that were established before the crop was established. For instance, in the investigations of Haymes and Lee (1999), their wheat/bean intercropping Experiments 1, 2 and 3 were preceded by Italian ryegrass (*Lolium multiflorum*)/red clover (*Trifolium pratense*) pasture, winter wheat and winter oats (*Avena sativa*), respectively. However, they did acknowledge that the differences were due to commercial rotation that was in operation at their institution. On the other hand, Ghanbari-Bonjar and Lee (2002), in another experiment at the same site as above, established forage wheat/bean intercropping experiment after a crop of forage maize (*Zea mays*). Bulson *et al.* (1997) under organic farming system grew wheat/bean intercropping experiment after a wheat crop was established in the preceding cropping year. Similarly, under organic management in the investigations of Gooding *et al.* (2007) which were carried out across Europe, wheat/bean intercropping experiments were preceded by cereals. These various investigations suggest that cereal is the preferred crop to sow before wheat/bean intercropping experiment is established. However, in situations of very low soil fertility conditions, establishing wheat/bean intercropping system after a legume crop may be advisable. It should be pointed out that preceding wheat/bean intercropping system after a pulse legume crop may subject bean in the wheat/bean intercropping system to greater susceptibility to pest and disease problems, and should be avoided unless the soil fertility is too low.

For good establishment, growth and yield appropriate land preparation is necessary for any given crop species whether as a sole crop or as an intercrop (Innis, 1997). In most cases the basic operations involved are ploughing, harrowing and ridging. For experimental purposes, further manual works aimed at reducing variability might be carried out before the seeds are sown. The nature and timing of each of these cultural practices is dependant on the crop species involved as well as climatic and weather conditions of the given locality where the crop is to be sown (Vandermeer, 1989). For wheat/bean intercropping system, the literatures indicate that it is possible to carry out similar land preparation for the two crops (Bulson *et al.,* 1997). As it relates to the timing of the land preparation, for the winter types of the two crops, these operations can be carried out between July to August (Haymes and Lee, 1999). For the spring types, further land preparation can be accomplished around early February to March (Haymes and Lee, 1999).

Similarly, around end of February to early march soils samples may be taken from 0-90 cm depth using soil coroner in order to analyze variables such as soil pH, available N, phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) and in some cases sulphur (S) (Haymes and Lee, 1999; Ghanbari-Bonjar and Lee, 2002). Often soils are collected at various points in the field; thereafter they are bulked before the analyses are carried out. For instance, in the investigation of Haymes and Lee (1999), the values for the soil analyses indicate 35-51, 122-163 and 16-48 mg/l for P, K and Mg respectively. They concluded that the soil was of medium to high soil fertility. It should be pointed out that whilst at this time (i.e. February) the winter-sown crop must have been established, the spring crop has not.

After, the land preparation are completed the next operation is sowing. This can be carried out manually or using specialized equipment such as a driller (Haymes and Lee, 1999; Ghanbari-Bonjar and Lee, 2002). Here manual drilling is not discussed further. However, before the seeds are sown, seeds rates as well as seeds to be sown per plot needs to be determined. This is because cost for seed represents an important variable cost to the grower (Nix, 2009). Thus, the need to determine appropriate seed rate to sow is important in order to reduce production cost. Determining seed rate combinations is even more difficult under intercropping because of the need to reduce inter-specific competition for growth resources (Helenius and Jokinen, 1994; Park *et al.,* 2002; Neumann *et al.,* 2009). Often seed rate per plot would depend on the area needed to be sown as well as the seed quality (Khah *et al.,* 1989; Azam-Ali and Squire, 2002). If the seeds were sourced from reliable seed companies data on the germination percentage as well as the thousand seed weight might have been included, and the seed rate as well as seed required to sow per plot can be easily calculated. However, if these data are not provided, a preliminary germination test in the laboratory and/or in the field in addition to determine the thousand seed weight may be desired. In the UK, the recommended seed rate for winter wheat is around 200-250 seeds/m^2 (Gooding *et al.,* 2002) whist that for spring wheat is 480-550 seeds/m^2 (Khah *et al.,* 1989; Ghanbari-Bonjar and Lee, 2002). Similarly, the recommended seed rate for bean is about 30-40 seeds/m^2 irrespective of whether winter or spring varieties are involved. Ghanbari-Bonjar and Lee (2002), who grew wheat/bean intercropping for forage sow up to 48 seeds/m^2 of bean. However, under intercropping seed rate required for each of the component crop are lower (Ghanbari-Bonjar and Lee (2002). For instance, Bulson *et al.* (1997) reported that maximum total intercrop yields was obtained at density combinations which was 75% recommended density of sole crops for each of wheat and bean components. This clearly indicates that under intercropping conditions, seed rate required for each of the two component crops are lower.

Provided the required seed to be sown per plot are well measured, it is possible to sow the seeds for the two crops simultaneously (Bulson, 1991; Bulson *et al.,* 1997; Tosti and Guiducci, 2010). For instance, Ghanbari-Bonjar and Lee (2002) sow beans at a depth of 7 cm with a Pneumasem vacuum drill and later the wheat was drilled to 3 cm depth with a Hege plot drill. Similarly, Haymes and Lee (2002) drilled beans to 10 cm depth and then later wheat at 3 cm depth. It should be pointed out that for these two investigations even though separate equipment was used to drill seeds for each of the two crops, the two crops were drilled on the same or very close dates. Indeed, there are specialized drills that can drill seeds for each of the two crops to a specified depth in one operation simultaneously. Here the use of such specialist drills is recommended for the prospective farmer and researcher. As regards sowing time, for winter-crops sowing can be carried from late September to early November (Bulson *et al.,* 1997; Haymes and Lee, 1999; Ghanbari-Bonjar and Lee, 2002). On the other hand, for spring-sown crop sowing can be accomplished from early March to mid April (Haymes and Lee, 1999; Ghanbari-Bonjar and Lee, 2002). Moreover, in order to reduce competition between plants in a crop and/or intercrop appropriate spacing is necessary. For the sole crops of each of wheat and bean, Ghanbari-Bonjar and Lee (2002), used 17 cm and 34 cm inter-row spacing respectively. On the other hand, for the intercrop these investigators used 17 cm inter-row spacing. Similarly, Haymes and Lee (1999) used 34 cm and 17 cm inter-row spacing for the sole crops and intercrops respectively. Following, the results of these investigations, it can be concluded that for wheat/bean intercropping experiments inter-row spacing of about 17 cm may be appropriate.

Nitrogen management and nitrogen fertilizer application

Nitrogen is the most important macronutrient applied to most crops (Hauggard-Nielson *et al.*, 2009). Nix (2009) stated that the recommended N rate for application to wheat in the UK is 210 kg/ha. This follows that the higher N applied to wheat crop under sole cropping conditions might explain the maximum wheat seed yields obtained in several investigations (Foulkes *et al.,* 2007; Kindred *et al.*, 2008). However, the productivity of intercropping in terms of yield advantages is greater under low N levels if a legume is involved (Fukai and Trenbath, 1993; Morgado and Willey, 2003). For instance, for the spring-sown wheat/bean intercropping system up to 150 kg N/ha of ammonium nitrate (Nitram) fertilizer was applied by Ghanbari-Bonjar and Lee (2002) but the optimal forage yield was obtained at 75 kg N/ha. The prevalence of the legume-based intercropping systems may be because some studies have shown that the non-legume components derive N from the legume components (Banik *et al.,* 2006). However, the extent to which this is true is still a subject of intense debate (Ofori and Stern, 1987; Francis, 1989; Willey, 1990). Others concluded that there is no direct transfer of N from legume to the non-legume crop in intercrop systems, but that N is made available for subsequent crop (Stern, 1993; Yunusa and Rashid, 2007; Urbatzkaa *et al.,* 2009). It is not the objective of this paper to consider this in detail, since N fixation is not the focal point.

It is, however, worth noting that provided the level of available soil N is not too great, the legume component of the intercrop can use soil N without affecting its N fixing ability (Ghanbari-Bonjar and Lee, 2002 ; Hauggard-Nielson *et al*., 2008; 2009). This invariably means that with respect to N in principle cereal/legume intercrop combination is meant to be a low-input system. For instance, Hiebsch and McCollum (1987) after evaluating 472 legume-non legume intercrop experimental datasets stated that the intercrop advantage was greater when the non-legume component is grown without adequate N. They emphasised that the advantage reduces and usually disappears completely as the N applied to the non-legume component approaches adequacy. Martin and Snaydon (1982), Ofori and Stern (1987) and Ghaley *et al.* (2005) also reached similar conclusions. This may because too much N in soil simply reduces N fixation (Stern, 1993; Hauggard-Nielson *et al*., 2009). Nevertheless, the low N applied to the intercrops compared to a well-managed wheat sole crop has a benefit of a substantial input cost reduction to the prospective grower of wheat/bean intercropping system. Moreover, indications from wheat/bean intercropping experiments suggest that bean is less competitive for N than does the wheat in agreement with the wider literature (Ghanbari-Bonjar and Lee, 2002; Gooding *et al.,* 2007). It can be recommended that applied N fertilizer to wheat/bean intercropping system should not exceed 100 kg/ha following the conclusions of Ghanbari-Bonjar and Lee (2002). Although this can be applied after establishment, split application may be necessary in order to allow the canopy to remain green for a longer period. For instance, Ghanbari-Bonjar and Lee (2002) applied half of the N fertilizer a day after sowing (in March) and the balance 35 days after sowing as a split dose to the spring-sown forage wheat/bean intercropping experiment they investigated. Similarly, these authors applied half of the N fertilizer 120 days after sowing and the balance 180 days after sowing to the winter-sown forage wheat/bean intercropping experiment.

Sulphur management and sulphur fertilizer application

The increasing importance of sulphur fertilization in crop production is well-documented (Withers *et al.*, 1997; Zhao *et al.*, 1999; Garrido-Lestache *et al.*, 2005). Indeed, a number of investigations have shown the interrelationships between crops response to applied S and N previously (Eriksen *et al.,* 2001; Thomas *et al.*, 2003; Hauggard-Nielsen *et al.,* 2009). Zhao *et al.* (1999) reported that due to strong interrelationship between N and S, crop response to S fertilization often depends on the amount of N applied. They emphasised that deficiency of S may be induced by a high amount of applied N. They also reiterated that responses to S application are usually greater when abundant amount of N are applied. Although sulphur is less important than phosphorus and potassium, it appears to have received greater attention in wheat/bean intercropping research compared to the other nutrients. The literature indicates that bean is responsive to S fertilizer application (Scherer and Lange, 1996; Gooding *et al.,* 2007). It has been demonstrated that sulphur application decreased wheat seed yields whilst bean seed yield was increased in wheat/bean intercropping system (Gooding *et al.,* 2007). This indicates that beans were more competitive for S than N since bean has no capacity to fix S by itself.

Given the fact that with respect to N fertilization, wheat/bean intercropping system is generally low input, it appears addition of sulphur may always lead to a reduction in wheat yield because for S fertilization to have a positive effects, sufficient N must be applied. Perhaps this might explain the contrast found between the negative response of wheat intercrop to sulphur fertilization (Gooding *et al.*, 2007), compared to a positive response of wheat sole crop to sulphur application demonstrated by other investigators (Salvagiotti and Miralles, 2008; Salvagiotti *et al.*, 2009). Thus, the implication to the prospective grower of wheat/bean intercropping system is that application of sulphur may decrease seed yields but improve the quality attributes, which normally determines the premium prices for wheat. In other words, although sulphur application may reduce yields, the quality attributes that normally determines the market prices for wheat may be improved as these quality attributes are often associated with quality of protein content of the seed (Gooding and Davies, 1997). The literature indicate that the S requirement of wheat is about 15-20 kg/ha (Zhao *et al.*, 1999). For wheat/bean intercropping, unlike, N since both wheat and bean are responsive to sulphur fertilization it may be necessary to apply greater amount to wheat/bean intercrop compared to the amount for wheat sole crop. Here, 18-20 kg/ha of S is recommended for application to wheat/bean intercrop. In addition, since N responses mostly depend on S availability (Thomas *et al.*, 2003), it would be sensible to apply S fertilizer simultaneously with N fertilizers following the conclusions of others (Salvagiotti and Miralles, 2008; Salvagiotti *et al.*, 2009).

Major weed species and weed management

Weeds are unwanted plants that compete with the crops for growth resources, thereby reducing the crop biomass and may affect the crop seed yield substantially (Mennan and Zandstra, 2005). For instance, Mason *et al.* (2007) reported that weeds reduced wheat yield by as much as 63%. Several strategies have been used to reduce the competitiveness of weeds against crops, including the use of herbicides or by non-chemical agronomic manipulations such as the use of competitive cultivars (Abbes *et al.,* 2007), sowing date, seed sowing rate (Mason *et al.,* 2007) and intercropping (Haymes and Lee, 1999; Ghanbari-Bonjar and Lee, 2002; Banik *et al.,* 2006). Although under commercial practice, chemical control (herbicide application) is the most predominant weed management method, non-chemical methods of weed management have less detrimental effects on the environment (Bulson *et al.,* 1997; Banik *et al.,* 2006). The success of non-chemical weed management system depends largely on the competitive abilities of the crops against weeds. This largely depends on the major weed species infesting the crop in the field. Sometimes, despite the fact that weeds can be controlled with appropriate herbicides, there may be a need to combine chemical weed control with some non-chemical agronomic methods in order to save the cost of production (Blackshaw *et al.,* 2005). Indeed, the need for integrated weed management strategies to reduce the use of herbicides has been highlighted (Chikowo *et al.,* 2009). However, such strategies have rarely been investigated for wheat/bean intercropping systems, even though in some studies (e.g. Haymes and Lee, 1999; Ghanbari-Bonjar and Lee, 2002) no herbicide was applied at all.

In the UK, According to Bulson *et al.* (1997), the most abundant weed species in wheat/bean intercropping experiment was fumitory (*Fumaria officinalis*). They also found out that other species with lesser abundance were creeping buttercup (Ranunculus repens), docks (*Rumex spp.)*, creeping thistle (*Cirsium arvense*), corn poppy (*Papaver rhoeas*), redshank (*Polygonum maculosa*), cleavers (*Galium aparine*), annual meadow-grass (*Poa annua*), rough stalk meadow-grass (*Poa trivialis*) and common couch (*Elymus repens*). Ghanbari-Bonjar and Lee (2002) also reported that the major weeds found in wheat/bean intercropping experiments were fumitory, cleavers, creeping buttercup (*Ranunculus repens*), annual meadow-grass, docks and common couch. Similarly, Haymes and Lee (1999), found out that fumitory, corn poppy, scentless mayweed (*Matricaria perforata*), knot weed (*Polygonum aviculare*), fat hen (*Chenopodium album*) and shepherd's purse (*Capsella bursa-pastoris*) were important weed species in wheat/bean intercropping system. From these investigations, it can be concluded that fumitory is the most important weed species in wheat/bean intercropping system under UK growing conditions. Thus, the control of this weed species must be given due attention if wheat/bean intercrop are expected to give maximum yields.

It has been demonstrated that wheat/bean intercrop reduces weed biomass and hence increases yield under conventional management (Haymes and Lee, 1999) and under organic management (Bulson, 1991; Bulson *et al.,* 1997). For instance, Ghanbari-Bonjar and Lee (2002) demonstrated that averaged over different N rates, weed biomass were 229.1 kg/ha, 176.3 kg/ha and 101.1 kg/ha for sole crops bean, sole crop wheat and wheat/bean intercrop respectively. Similarly, Bulson *et al.* (1997) found out that sole crop wheat was more competitive with weeds than sole crop beans but the intercrop was either similar or more competitive with the weeds than sole crop wheat when wheat was sown at 75% of recommended density. Haymes and Lee (1999) showed that winter wheat/bean intercrops have less suppressive ability on weeds than the spring wheat/bean. They attributed this to the dominance of the bean in the winter experiment. They suggested using taller wheat cultivars to overcome this problem. However, if tall wheat cultivars are sown the harvest index may be low (Fischer, 2007). Therefore, a better option might be to use shorter bean cultivars instead.

Pest and disease management

Pest and diseases outbreak have potential to substantially limit growth and yield of crops if not well managed (Francis, 1989). As sole crops, both wheat (Gooding and Davies, 1997) and bean (Anon, 2010; Stoddard *et al.,* 2010) are susceptible to a wide range of pest and diseases. Intercropping helped to control pests and diseases problems (Trenbath, 1993). For instance, Natarajan *et al.* (1985) demonstrated that intercropping with sorghum produced a large reduction in the incidence of *Fusarium udum* (wilt) in pigeon pea (*Cajanus cajan*) by up to 55%. Vandermeer (1989) concluded that the ability of the intercrops to reduce pest attacks as one factor that might be involved in what he described as the facilitative production principle. It is worthy to state that reduction in pest attack might be obtained in the following way as reported by Vandermeer (1989). i) The host plants are more widely spread in intercrops, such that they are more difficult to locate. ii) One of the component crops might serve as a trap crop to deter the pest from finding the other crop. iii) One of the component crop species might serve as a repellent to the pest.

For bean, one of the most important diseases is chocolate spot (*Botrytis fabae*), perhaps because the crop produces large amount of biomass (Bulson *et al.,* 1997; Anon, 2010; Stoddard *et al.,* 2010). However, intercropping affords greater protection against pest and disease problems including chocolate spot disease (Sahile *et al.,* 2008). This follows that wheat/bean intercrop might have greater tolerance to pest and disease problem than each of the component sole crops might. Unfortunately, there appear to be less attention to study pest and disease problems in wheat/bean intercropping system. It may be because more resistant or tolerant varieties are often used irrespective of the cropping system involved (Bulson *et al.,* 1997; Ghanbari-Bonjar and Lee, 2002). Apparently, pest and disease problems in wheat/bean intercropping system may be more important under organic management system where the use of chemicals is not allowed (Bulson *et al.,* 1997). For instance, in the investigation of Bulson *et al.* (1997) wheat was infected by both Mildew (*Erysiphe graminis*) and brown rust (*Puccinia recondita*) even though the severity of the former was greater. As these authors emphasised mildew infection severity increased as the proportion of beans increased in contrast to the conclusions in the wider literature. They concluded that this might be because of the high N content of the wheat since beans were less competitive for N. Similarly, bean was infected by chocolate spot disease, which was later minimized due to dry spell. However, they pointed out that intercropping had no substantial effects on the severity of the disease. Their investigation was in contrast to that of Sahile *et al.* (2008) who found out that intercropping successfully reduced the severity of chocolate spot disease. Here, it is recommended that where possible appropriate pest and disease materials should be applied in addition to intercropping and/or other non-chemical methods to minimize pest and disease problems in wheat/bean intercropping system.

Biomass yields

Provided water is not in short supply, the amount of biomass yields produced by crops depends on the amount of radiation intercepted which is itself largely determined by the size of the leaf area and its distribution with time (Biscoe and Gallagher, 1978a; Robertson *et al.,* 2001). Thus, biomass is a function of intercepted photosynthetically active radiation (PAR) multiplied by the efficiency with which PAR is used to form the biomass (Radiation use efficiency) (Yahuza, 2011a). I will return to this point later in the paper. In addition, it is important to maintain the green leaf surface for a long time to maximize dry matter production. Biomass yield can be improved as the plant population density is increased. This is possible by increasing the seed-sowing rate of one crop species or planting a second or more crop species. However, when the asymptotic yield is reached, increasing the plant population density is not necessary because no greater total biomass can be obtained for a given crop species at that location (Azam-Ali and Squire, 2002; Yahuza, 2011c). It is possible to obtain greater biomass by wheat/bean intercrop compared to their component sole crops because the two components crops are different in their morphological and perhaps physiological attributes, which may have implication on resource use by the two crops.

It is well established that biomass yield is one of the main determinant of wheat seed yields under sole cropping conditions (Whaley *et al.,* 2000; Gooding *et al.,* 2002). The higher wheat seed yields obtained under winter-sown conditions compared to spring sown conditions, has been related to the ability of the wheat to accumulate greater biomass under the former conditions (Biscoe and Gallagher, 1978). This has been attributed to the fact under the former conditions, the crops stays in the field for a longer period and hence accumulates more biomass than under the latter conditions. Kindred and Gooding (2005) stated that under sole cropping in the UK winter wheat biomass could reach up to 1900g/m^2 when N was applied. Spink *et al.* (2000) also obtained winter wheat biomass yield of up to 1600 g/m^2. For wheat, under intercropping conditions with bean or other crops biomass yields are often substantially reduced largely due to intense competition between the two component crops (Hongo, 1995; Bulson *et al.,* 1997; Haymes and Lee, 1999).

In general, faba bean is known to produce large amount of biomass yields, which might not always be advantageous for the performance of the crop in terms of seed yields (Bulson *et al.,* 1997; De Costa *et al.,* 1997; Haymes and Lee, 1999). Indeed, recently, Khan *et al.* (2010) stated that the high biomass production of bean particularly when sown early could restrict the flow of air in the canopy and thereby favouring the development of diseases. Sahile *et al.* (2008) earlier reached a similar conclusion. Adisarwanto and Knight (1997) obtained biomass of up to 1350 g/m^2 in bean. Others have also found bean seed yields to be variable due to the variation in biomass yields produced. Biomass of bean is known to be greater under winter-sown conditions compared to spring-sown conditions (e.g. Haymes and Lee, 1999). Under intercropping conditions, as was the case with wheat, the biomass yields of bean are typically reduced (Helenius and Jokinen, 1994; Hongo, 1995; Bulson *et al.,* 1997).

Sometimes the objectives of intercropping may be to improve overall total biomass yield relative to either of the sole crops making up the intercropping situations (Vandermeer, 1989). This is based on the assumption that two or more crops would intercept radiation or other growth resources better than when grown alone (e.g. Sivakumar and Virmani, 1984). For instance, Hongo (1995) in a study involving wheat/bean intercropping stated that though biomass yields of both wheat and bean in the intercrop were reduced, intercrop gave higher biomass yields and seed yield than their sole crop counterparts. This clearly indicates that greater productivity may be obtainable by wheat/bean intercrop compared to the component sole crops. Seed yields are determined by biomass yields and the harvest index. However, the latter is less variable compared to the former (Gallagher and Biscoe, 1978b; Fischer, 2007; Foulkes *et al.,* 2007). This suggests that since greater biomass yields are achievable by wheat/bean intercrop, greater seed yields are also achievable.

Biomass partitioning and harvest index

As equally important as the accumulation of dry matter is the distribution of the dry matter among different parts of the crop (Fischer, 2007; Foulkes *et al.,* 2007; Reynolds *et al.,* 2007). When greater assimilate are partitioned to the leaves, it will help to maximize light interception whilst greater partitioning to the roots will assist the plant to utilize soil resources more thoroughly (Fukai and Trenbath, 1993). It should be pointed out that partitioning of assimilates among various plant parts, and particularly allocation to the harvested part, are main determinants of final yield. This indicates that harvest index (HI), which is the ratio of the seed yield to the biomass yield, is one of the main determinants of yields (Yoshida 1972; Gallagher and Biscoe, 1978b). In most cases especially for the arable crops, it is not the total biomass that is important *per se*, but the partitioning of the biomass between the reproductive and the vegetative part of the crop. In general for a given crop and/or variety the HI is stable over a certain range of environment (Azam-Ali and Squire, 2002). Plant breeding has moved the HI up to around 0.5 in most crops. Harvest index is known to be adversely affected by severe drought and diseases during seed filling period (Gallagher and Biscoe, 1978b). However, this can be minimize if assimilates produced and stored in vegetative organs are used to fill seeds (Whaley *et al.,* 2000).

In wheat, there have been evidences that HI is conservative over a range of environment (Teich and Smid, 1993; Sieling *et al.,* 2005). Winter wheat HI of up to 0.53 has been obtained (Kindred and Gooding, 2005). Higher values that may be considered ceiling points have also been reported. For instance, Shearman *et al.* (2005) reported winter wheat HI of up to 0.61. They concluded that future increase in seed yield might depend in increase in the biomass while maintaining the HI. Nevertheless, in contrast to the wider literature, some studies have shown that HI may not always be conservative in wheat. For instance, Song *et al.* (2009) reported wheat sole crop HI ranging from 0.33- 0.45 and 0.37 – 0.47 for irrigated and rainfed treatments respectively. Hiltbrunner *et al.* (2007) reported that winter wheat seed yields were not substantially reduced in a live mulch with white clover (*Trifolium repens*) largely because the HI was stable.

The lower seed yield of faba bean obtained in most studies have been attributed to lower HI of the crop, even though the crop may accumulate high biomass yield (Lopez-Bellido *et al.,* 2005; Khan *et al.,* 2010). However, Loss and Siddique (1997) observed that HI might be difficult to estimate in bean because during senescence, the crop might shed leaves leaving mainly stems and pods at maturity. In general, bean HI is typically low and is usually variable between sites and year (even within the same location) (Bulson *et al.,* 1997; De Costa *et al.,* 1997; Haymes and Lee, 1999). Adisarwanto and Knight (1997) stated that bean HI decrease with increase in density. Bean HI could be as low as 0.30 but higher value of up to 0.40 were also reported.

Largely in an intercrop when competition occurs during the yield production stage, the supply of assimilates to develop the harvested part may be reduced and hence the HI may be low (Fukai and Trenbath, 1993). These authors emphasised that when component crops have similar growth duration particularly in additive intercrops, HI is commonly reduced relative to that in the sole crop because of severe competition between the components crops during later stages of growth. On the other hand, they stated that if the dominant component of an additive intercrop has sufficiently suppressed the dominated component, it experiences similar growth environment in intercrop and sole crop. Hence, the HI is similar to that of the sole crop. Nevertheless, the effects of intercropping on HI are inconsistent. For instance, in the study of Tsubo *et al.* (2001), involving maize and dry beans (*Phaseolus vulgaris*) intercrops the conservative nature of HI was confirmed for both maize and dry beans irrespective of whether sole cropped or intercropped. Other studies showed that intercropping has improved the HI (Harris and Natarajan, 1987; Awal *et al.,* 2006; Morgado and Willey, 2003). Wheat/bean intercropping system has not been reported to negatively affect the HI of each of the component sole crops. Consequently, it can be recommended that improvement of seed yields of wheat/bean intercrop compared to the component sole crops would largely depend on any treatment that would positively improve the biomass yields. Moreover, since wheat/bean intercrop are typically harvested using combine, which may make the determination of HI more difficult and less precise, it is recommended that a sizeable destructive sample should be taken after the crops have both reached physiological maturity prior to combine harvesting in order to determine the HI.

Radiation interception and radiation use efficiency

Solar radiation is a flux of electromagnetic energy, which must be intercepted and utilized instantaneously, as it cannot be stored for later use (Keating and Carberry, 1993; Tsubo *et al.,* 2001). Radiation is important because it has vital role in photosynthesis (Monteith, 1972; Sinoquet *et al.,* 2000; Khan *et al.,* 2010), evaporation (Keating and Carberry, 1993) and transpiration (Kanton and Dennett, 2004). Other details on radiation are detailed in another paper (Yahuza, 2011a). It should be pointed out that in general, the wider literature indicate that in regions where water does note pose critical constraints during the growing period for any given crop species, and the crop is well supplied with growth nutrients mainly N, productivity is mainly governed by the amount of radiation intercepted and the efficiency of its use by the crops (Black and Ong, 2000; Lecoeur and Ney, 2003; Carretero *et al.,* 2010). In other words, physiologically, seed yields is function of intercepted radiation, RUE as well as the HI (Areche *et al*., 2009; Confalone *et al*., 2010; Khan *et al.,* 2010).

Wheat/bean intercropping system appears to be restricted to areas with lower temperatures and plentiful of water (Bulson *et al.,* 1997; Haymes and Lee, 1999), suggesting that radiation may be the main factor, which determines the productivity of this intercrop combination. In other words, conclusions may be drawn that the productivity of this intercrop combinations is largely determined by the amount of intercepted PAR and RUE. Although light interception in wheat/bean intercropping system have been studied in only few investigation (e.g. Hongo, 1995; Haymes and Lee, 1999), it is often argued that intercrops have the capacity to make use of resources, specifically radiation more effectively than the sole crops (Tsubo *et al*., 2001; Rodrigo *et al*., 2001; Zhang *et al.,* 2007). For wheat/bean intercropping system, better use of resource might have been possible because whilst wheat might have used transmitted radiation to produce optimally, bean might have used direct irradiance to produce. This further brings to question the issue of wheat sole cropping displacing wheat/bean intercropping mainly because of the need to mechanize the agronomic practices.

As pointed out earlier, despite the apparent importance of radiation in determining the productivity of this intercrop combination, only a few investigations (e.g. Haymes and Lee, 1999) studied this resource. Even in the investigations of Haymes and Lee (1999) where light interception was carried out almost after every two weeks using tube solarimeters, not all the experiments they investigated were assessed for radiation. Thus, there will be a need to assess radiation interception and RUE in wheat/bean intercropping system in order to understand the physiological basis of the productivity of this intercrop system. Whilst appreciable works on the agronomy of this intercrop system exist in the literature, it does not hold for its physiology. Physiological understanding is necessary in order to improve on the agronomy of this intercrop.

The wider literature suggests that intercrop benefits are greater if crops of different duration or different sowing dates are sown (Vandermeer, 1989; Fukai and Trenbath, 1993). In particular, provided radiation is the most limited resource, temporal complementarity has been argued to be more important than spatial complementarity in resource use. With such long duration crops like wheat and bean, both of whom may be susceptible to cold damage during the winter periods delay in sowing date of any of the component crops to benefit from temporal complementarity in radiation use appear to be a non-starter. For instance, previous investigations indicate that bean seed yield may be reduced, as bean-sowing date is delayed (Loss and Siddique, 1997; Loss *et al*., 1997). Although, different sowing dates have rarely been used in wheat/bean intercropping system in the UK (e.g. Bulson *et al.,* 1997; Haymes and Lee, 1999), it is possible that spatial complementarity will be more important than temporal complementarity in radiation interception. This indicates that the optimum density of the intercrop will be greater than of the individual sole crops, suggesting that a given area of land would be able to support a greater number of plants (Hauggard-Nielson *et al.,* 2006). This clearly suggests that it is possible to improve performance by spatial means in wheat/bean intercropping system as was previously demonstrated by others (Hongo, 1995; Bulson *et al.,* 1997; Haymes and Lee, 1999).

Final harvest for seed yields

In the UK, depending on varieties involved and sowing time, wheat/bean intercrop might be ready for harvesting for seed yields around early August to late September even though in some cases harvesting might continue up to early November (Bulson *et al.,* 1997; Haymes and Lee, 1999). It should be pointed out that often spring-sown crops are harvested comparatively later compared to the winter-sown ones (Haymes and Lee, 1999). Similar to sowing, the cost of managing a given intercropping system might be lower if at final maturity the component crops can be harvested simultaneously. However, in most cases, simultaneous harvesting is feasible only when the component crops were simultaneously sown and/or if they have similar growth duration. For wheat/bean intercropping system, it is well documented that the two component crops can be simultaneously harvested using combine (Bulson *et al.,* 1997; Haymes and Lee, 1999; Gooding *et al.,* 2007). Often the combine harvester is adjusted for the larger bean seeds (Haymes and Lee, 1999). These investigators emphasised that often seed loss is usually negligible. It is not surprising that this intercrop can be simultaneously harvested since the use of different sowing dates in this intercropping system is rare, and the two component crop have similar durations (Bulson, 1991).

The objectives of intercropping may be to increase the total seed yields of the intercrops relative to the various sole crops making up the intercrop (Vandermeer, 1989; Innis, 1997). Indeed, it has been demonstrated that the total intercrop seed yields was greater than yields for each of the sole crops in wheat/bean intercropping system (Hongo, 1995). Similarly, recently, Abera and Feyisa (2008) demonstrated that the total intercrop seed yield was greater than seed yields of sole crops of faba bean and pea in an intercrop involving pea with faba bean. Wang *et al.* (2007) in an intercrop of wheat and chickpea (*Cicer arietinum*) reported that the total intercrop seed yield was greater than yields of both wheat and chickpea sole crops. Li *et al.* (1999) also found out that the total intercrop yields was greater than yields of sole crops of maize and faba bean. These various investigations clearly indicate that it is possible to obtain greater total intercrop yield compared to the yields of the component sole crops.

Wheat if well managed could give maximum yield, which are relatively stable year-to-year (Shearman *et al.,* 2005; Foulkes *et al.,* 2007; Reynolds *et al.,* 2007). By contrast, year-to-year variation in yield even within the same locality and even within the same cultivar is typical of faba bean crop (e.g. Mwanamwenge *et al.,* 1998; Adak *et al.,* 1999). The low and unstable seed yields of bean is due to both abiotic stress such as high temperature (Turpin *et al.,* 2002), water deficit (De Costa *et al.,* 1997; Khan *et al.,* 2010) and pest and disease problems (Sahile *et* *al.,* 2008; Anon, 2010; Stoddard *et al.,* 2010). It should be pointed out that though wheat sole crop if well managed may give maximum yield, this is often associated with substantial input cost for seed, fertilization, and pesticide application just to mention a few. On the other hand, bean seed yield may not be stable, but the input cost for bean may be substantially lower and in addition, the premium price for bean is greater than that for wheat (see Nix, 2009). This suggests that even though bean yields may be substantially reduced, greater premium price paid for bean compared to the wheat may largely offsets some of the yield differential that may exist with the well-managed wheat sole crop. Such variability could even be smaller if wheat and bean are intercropped.

Wheat/bean intercropping system was abandoned mainly because of need for mechanization requirement (Bulson *et al.,* 1997). First, it should be reiterated that mechanization requirement is just one of the factors that determines the acceptability or not of a given cropping system (Vandermeer, 1989). Besides, more recently it was shown that mechanization constraint in wheat/bean intercropping system as it relates to practices such as drilling and harvesting, for example was eliminated (Bulson *et al.,* 1997; Haymes and Lee, 1999; Gooding *et al.,* 2007). Nevertheless, wheat/bean intercropping system advantages are not restricted to the mechanization requirement only. It is the wish of every grower to get greater productivity with lesser input. Although wheat has high yield potential, yields are often substantially reduced when insufficient inputs are used, particularly under sole cropping. For instance, wheat requires substantial amount of N input to produce (Spink *et al.,* 2000; Kindred *et al.,* 2008; Nix, 2009). As discussed earlier, greater N application to wheat under sole cropping often leads to greater yields (Foulkes *et al.,* 2007; Dickin and Wright, 2008; Cossani *et al.,* 2009; Song *et al.* 2009). Invariably, the higher yields obtained is associated with greater input cost. Previous investigations indicate that greater total intercrop yields can be obtained by growing wheat with bean in an intercrop (e.g. Hongo, 1995). This might have been possible because bean is less competitive for N than does the wheat (Gooding *et al.,* 2007). This suggests that greater yields are achievable under wheat/bean intercropping compared to sole cropping of each.

In the UK, wheat sole crop average seed yields are around 800 g/m^2 (DEFRA, 2008; Nix, 2009) and 575 g/m^2 (Nix, 2009) for the winter and spring-sown cultivars respectively. Similarly, under organic management conditions average wheat seed yields are 500 g/m^2 and 400 g/m^2 for the winter and spring cultivars respectively (Lampkin *et al.,* 2008). Under experimental conditions, wheat seed yield of between 700- 900 g/m^2 have been reported under conventionally managed systems in the UK (Whaley *et al.,* 2000; Gooding *et al.,* 2002; Kindred *et al.,* 2008). Other studies reported seed yield of up to 1000 g/m^2 (Spink *et al.,* 2000), and greeter than 1000 g/m^2 (Kindred and Gooding, 2005; Foulkes *et al.,* 2007) mostly at the recommended seed rate of between 200-250 seeds/m^2. Indeed, previous investigations in the UK (Whaley *et al.,* 2000; Gooding *et al.,* 2002) have indicated that seed rate for well-managed winter wheat should not exceed 250 seeds/m^2. Note that under spring-sown conditions seed rate are usually greater because of lesser tillering ability. Similarly, under experimental conditions wheat seed yield of greater than 400 g/m^2 have been reported under organic management conditions in the UK (e.g. Huxham *et al.,* 2005). For the spring-sown wheat, Khah *et al.* (1989) have found seed yields of between 400-500 g/m^2 depending on seed vigour. Ellis *et al.* (1999) later reported lower spring wheat seed yields ranging from 134- 257 g/m^2 at the same location. However, Haymes and Lee (1999) obtained spring wheat seed yields of up to 500 g/m^2.

Irrespective of the season of sowing or cropping system involved, typically wheat seed yield is reduced by intercropping (Hongo, 1995; Haymes and

Lee, 1999; Hiltbrunner *et al.,* 2007). For wheat/bean intercrop, under field experimentation winter wheat intercrop average seed yield of about 110 g/m² have been reported (Haymes and Lee, 1999). Hongo (1995) had earlier reported wheat intercrop seed yield of up to 530 g/m² in wheat/bean intercropping system. Gooding *et al.* (2007) under organic management condition reported mean wheat intercrop seed yield lower than 300 g/m². This clearly, indicates that intercropping reduces wheat seed yields substantially. The implication of this is that seed rate for intercropping wheat with bean is typically lower than the recommended rate for wheat under sole crop conditions (Bulson *et al.,* 1997; Haymes and Lee, 1999).

Faba bean average seed yield is 400 g/m² and 370 g/m² for winter and spring cultivars respectively (Nix, 2009), under conventional management. On the other hand, bean seed yield average 300 g/m² for both the winter and spring cultivars under organic system (Lampkin *et al.,* 2008). Under field experimentations, Hongo (1995) reported winter bean sole crop seed yield of up to 502 g/m². Fasheun and Dennett (1982) had earlier obtained seed yield in the range 360- 430 g/m². Elsewhere winter bean sole crop seed yield of up to 360 g/m² (Haymes and Lee, 1999) and 490 g/m² (Sahile *et al.,* 2008) have been found. As regards to the spring-sown crop, Haymes and Lee (1999) obtained bean seed yield of up to 400 g/m². Similarly, Hussain *et al.* (1988) reported seed yield for the spring bean cultivar of up to 330 g/m². Typically, the seed yield of bean is very low and varies between season and years even within the same location (Barry and Storey, 1977). There have been suggestions that this is due to factors such as high temperature (Turpin *et al.,* 2002), water deficit (De Costa *et al.,* 1997; Anon, 2010) and pest and disease problems (Sahile *et al.,* 2008; Stoddard *et al.,* 2010). In general, the low yield of bean has been attributed to the low HI of the crop, given the fact that the crop is able to achieve a very high biomass at harvest. For instance, Hussain *et al.* (1988) concluded that autumn sowing yielded more than the spring sowing due to greater dry matter production but mainly to a higher HI. This indicates that winter-sown bean is known to produce greater seed yield compared to the spring-sown crop. However, it is not clear in the literature whether seed yield are greater under organic or conventional management systems.

It is well established that faba bean seed yield may be reduced by intercropping (Hongo, 1995; Haymes and Lee, 1999). For instance, Hongo (1995) reported that the bean intercrop seed yields found were roughly about 51% of the yield obtained by their sole crop counterparts. They reported bean intercrop seed yield of up to 338g/m². Elsewhere, Helenius and Jokinen (1994) obtained bean intercrop seed yields of up to 138.3 g/m². As for the wheat, this suggests that recommended seed rate for bean under intercropping is lower than that for the sole crops in agreement with the conclusions of Bulson *et al.* (1997).

Post-harvest practices and quality attributes of products

After simultaneous harvesting, often wheat and bean seeds can be easily separated using appropriate sieves of different grades in the laboratory (Haymes and Lee, 1999). During such separation impurities such as stones, weeds and weed seeds can also be easily removed (Gooding and Davies, 1997; Gooding *et al.,* 2007). Such separations can be easily carried out manually even though specialist light farm machineries are also available. After the separations have taken place, it would be necessary to weigh fresh yield for each plot separately. Later, depending on the researchers' objectives samples may be taken to determine the seed weight, moisture content and other quality parameters.

The literature indicates that wheat quality attributes related to the bread making qualities are often associated with the protein content of the seed, which in turn is related to the N concentration of the seed (Bulson *et al.,* 1997; Gooding and Davies, 1997;

Gooding *et al.,* 2007). Indeed, for instance, the greater preference of conventionally produced wheat compared to the organically produced one is related to the above-mentioned factors. Although intercropping may reduced wheat yields it could be associated with greater concentration of N in the seed for the intercrop wheat compared to the sole crops. For instance, Hauggard-Nielson *et al.* (2006) explained that intercropping cereals with legumes increases N concentration in the cereal seeds because legumes might not compete substantially for soil N even though competition for light may be substantial. Previous investigations suggest that wheat intercrop yield reduction is often compensated by greater N concentration in the seed (Bulson, 1991; Bulson *et al.,* 1997; Gooding *et al.,* 2007). This suggests that intercropping wheat with bean has the potential to improve the marketability of wheat as it relates to quality, which normally determines the premium prices for wheat (Nix, 2009). Moreover, the beneficial effects of sulphur fertilization in wheat/bean intercropping system has been related to improvement of wheat seed quality as regards protein or N concentration (Gooding *et al.*, 2007).

It should be pointed out that the quality attributes of wheat are not determined by N concentration only (Gooding and Davies, 1997). However, other quality attributes such as moisture contents, presence of impurities such as stones, weed seeds etc can be easily taken care in the laboratory (Gooding and Davies, 1997; Haymes and Lee, 1999), but the N concentration of the seed even though related to the moisture content cannot be easily manipulated in the laboratory. Moreover, the fact that intercrops are able to suppress weeds better than the sole crops in wheat/bean intercropping system (Haymes and Lee, 1999), suggests that impurities such as weed seeds may be lower for the intercrop compared to the sole crops. Thus, it would be sensible for growers aiming at improving the quality of their produce to adopt wheat/bean intercropping system in order to be assured of greater marketability of their produce.

Estimates of intercrop performance

Based on land equivalent ratio (LER), wheat/bean intercropping system has been shown to be beneficial (Hongo, 1995; Bulson *et al.,* 1997; Haymes and Lee, 1999). For instance, Haymes and Lee (1999) obtained LER of up to 1.4 in wheat/bean intercropping system under conventional management system. Under organic management system positive LER values were also found Bulson *et al.,* 1997; Gooding *et al.,* 2007). Whilst LER has a meaningful agronomic interpretation, there may be a need to use other indices to estimate the performance of wheat/bean intercropping system since the system has not well being adopted widely. For instance, in another paper the present author reported that crop performance ratio (CPR) was adjudged better suited to describe physical or physiological basis of intercrop performance compared to the component sole crops. Where different growth durations and/or different sowing dates are involved, modified versions of these two indices (LER and CPR) are usually more appropriate as was well detailed in another paper (Yahuza, 2011b). Since the two crops have commercial value, estimates based on monetary evaluations may also be necessary. Except, the investigation of Bulson *et al.* (1997) such type of evaluations have rarely been carried out.

Prospects and constraints for wider adoption

The cropping system adopted by growers in a given area are determined by several factors such as climatic and weather conditions, biological/agronomic factors as well as the socio-cultural and socio-economic factors (Ofori and Stern, 1987; Fukai and Trenbath, 1993; Connolly *et al.*, 2001). The main climatic and weather factors are rainfall, solar radiation, photoperiods and temperature (Vandermeer, 1989; Innis, 1997). Items such as greater seed or total biomass yield production, residual benefit from N fixation, non chemical pest and disease control, as well as non chemical weed management are some of the items that might be termed strictly biological/agronomic factors influencing the choice of a cropping system (Hiebsch and McCollum, 1987; Francis, 1989; Urbatzkaa *et al.,* 2009). Factors such as local preference, yield stability, market prices of agricultural products etc are some of the key socio-economic and/or socio-cultural factors that might influence the adoption of any cropping system (Willey, 1979b; Rao and Singh, 1990; Willey *et al.,* 1997). This clearly indicates the multidimensional nature of inter-related or independent factors that may influence the adoption of any cropping system. Therefore, it is necessary to understand the scepticism and/or aversion of growers to adopt any cropping system, particularly if it appears alien to them.

Over time, mechanization has had its influence on choice of cropping system practiced by growers as well. Whilst, previously wheat/bean intercropping system was widespread in the UK, the need for mechanization displaced the system for sole cropping (Bulson, 1991; Bulson *et al.,* 1997). However, is the choice of cropping system necessarily determined by the mechanization requirement alone? Of the factors that determines the acceptability or otherwise of any given cropping system by the growers, the need for mechanisation is just an item in one side of the equation. In addition, even the purported mechanization requirement could be more effective and efficient only if it guarantees greater income to the grower. Other questions that may be asked include i. Must all the agronomic practices be mechanized? ii. Could some of the agronomic practices be left unmechanized iii. Could mechanization be done simultaneously for more than one type of crops? Similar questions could be asked as it relates to other items such as need for fertilization, need for pesticide application just to mention a few, sometimes argued in favour or against sole cropping (Vandermeer, 1989; Innis, 1997; Azam-Ali and Squire, 2002).

From the standpoint of crop physiology, seed yields may be source and/or sink driven (Fischer, 2007; Reynolds *et al.,* 2007). In other words, the crop must produce sufficient receptors for assimilates produced by the canopy though the process of photosynthesis. For wheat, one way of guaranteeing adequate provision for the storage of assimilates produced is by producing tillers that may survive to bear ears (Whaley *et al.,* 2000). It might be argued that whilst wheat at the lower densities may be mainly source limited, because of lower canopy coverage despite greater tillering capacity, it may not be clear whether wheat yields for plots with higher densities are source or sink limited. It may be possible that at higher densities, the main limitation would be the sink rather than the source. This is because at higher densities total canopy coverage may be obtained, this may be associated with lower sink capacity for the assimilates produced to be partitioned to the reproductive parts (Fischer, 2007). More plants per unit area invariably mean lesser ability to produce tillers that might bear ears and/or reduction in the sizes of the fertile ears (Gooding *et al.,* 2002). In either case, similar yields to plots with lower densities may be possible, and this may be reflected in lesser differences between plots with higher densities and the ones with lower ones. The benefits of wheat/bean intercropping system as regards source-sink relations compared to the sole crops is that the even at lower seed rates, source may pose a limited problems to yield, since total canopy coverage may be obtained earlier. However, due to intense competition within the intercrop particularly at the higher seed rates, it is likely that some sink limitation may be unavoidable.

Every grower will wish to derive greater benefits from lesser inputs. Broadly, there are three factors required for production in any given enterprise namely capital, labour and land (Nix, 2009). Whilst the cost for acquisition of land or sophisticated farm machinery could be spread over a longer period, the cost for seed, fertilization and even labour cannot. Since the profitability of any given cropping system can be determined only after the cost of production are deducted, it is sensible to expect growers to wish to derive maximum output from the minimum input possible. Intercropping, and wheat/bean intercrop system to be specific represents one of the cropping system that have the capacity to reduce input costs tremendously whilst guaranteeing greater maximum outputs. It is clear that the direct and/or indirect input cost whilst guaranteeing maximum output can be translated into greater benefits for the prospective grower of wheat/bean intercropping system.

The vast majority of the literature indicates that conventionally grown crops have greater yield potentials than the organically grown ones (Huxham *et al.,* 2005; Lampkin *et al.,* 2008). Wheat is known to be responsive to N fertilizer (e.g. Sylvester-Bradley *et al.,* 1990), which is prohibited under organic management conditions (FAO, 2001; Stolze and Lampkin, 2009). For the organically managed crops, building soil fertility by means of crop rotations, intercropping and other non-synthetic means are the only available options (Hauggard-Nielson *et al.,* 2008; Hauggard-Nielson *et al.*, 2009). It is well established that the first cereals following a legume crop in a rotation might benefit more from residual N than the subsequent crops (Huxham *et al.,* 2005). Since, legume-based intercropping systems are meant to be low input with respect to applied nitrogen (Hiebsch and McCollum, 1987), provided the organically managed crop is well managed, practically, wheat/bean intercropping systems might have similarities with respect to nitrogen input irrespective of the production system involved. Often it may be unlikely that sufficient available N will be accumulated under organic management, which will match the amount that might be applied to a conventional crop. In addition, applied fertilizer alone does not determine productivity, but also by responses to other agronomic factors such as herbicide, pesticide treatments, fungicide treatment etc (Vandermeer, 1989). Thus, it should be expected that greater wheat/bean intercrop yields might be obtained under conventional management than under organic management system. However, the fact that in most cases crops produced under organic management system command greater prices than the conventional ones meant that greater income might be possible under organic system than the conventional system despite the expected intercrop yield reduction under the former compared to the latter.

In general, yield potential is greater under autumn-sown conditions than under spring-sown conditions (Gooding and Davies, 1997). Moreover, winter-sown wheat is often preferred compared to the spring-sown ones because the former have greater bread-making qualities that often determine the premium prices for wheat compared to the latter. Thus, the prospects of adopting spring-sown wheat/bean intercropping compared to the winter-sown one are not certain. However, the growers aim may largely be dependant on getting maximum benefits from a given enterprise. The literature suggests greater premium prices for spring-sown bean than the winter-sown one (Nix, 2009), thus illustrating that spring-sown wheat/bean intercrop may still have greater prospect of adoption by growers. This is based on the premise that the lower premium prices that might be paid for the spring sown wheat intercrop can be offset by the spring-sown bean greater premium prices.

Conclusions

Based on the survey of literature, for wheat/bean intercropping system, due to similarities in growth duration between the two component crops, it was concluded that the two crops could be agronomically managed simultaneously. The paper also clearly indicates that wheat/bean intercropping system is beneficial, and such benefits can largely be attributed to spatial complementarity between the component crops in the use of growth resources. Given the tremendous benefits of wheat/bean intercrop compared to the component sole crops as was discussed in this paper, growers may wish to adopt wheat/bean intercropping system.

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